KU LEUVEN

Faculty of Psychology and Educational Sciences
Centre for Instructional Psychology and Technology

SUPPORTING LEARNERS IN CONTROL

INVESTIGATING SELF-REGULATED LEARNING IN BLENDED LEARNING ENVIRONMENTS

Doctoral thesis offered to obtain the degree
of Doctor of Educational Sciences (PhD)

by: **Stijn Van Laer**

supervisor: Prof. **Jan Elen**

2018

FACULTY OF PSYCHOLOGY AND
EDUCATIONAL SCIENCES

CENTRE FOR INSTRUCTIONAL PSYCHOLOGY AND TECHNOLOGY

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Supporting learners in control: Investigating self-regulated learning in blended learning environments

By: Stijn Van Laer
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Blended learning is learning that happens in an instructional context characterized by a deliberate combination of online and classroom-based interventions for instigating and supporting learning. Blended forms of learning have become increasingly popular in education and are realized through a wide range of online and face-to-face instructional interventions. As a result of this variety, blended learning environments differ widely in terms of the technologies and instructional methods used. Existing literature indicates that blended learning environments, as they are currently designed, challenge learners' self-regulated learning. Self-regulated learning is understood here as learners' ability to control and subsequently direct their learning towards improved learning outcomes. The observation that blended learning environments challenge learners' self-regulated learning might be problematic as there is a clear positive correlation between learners' self-regulated learning and their performance. The current lack of insight into what helps different types of learners succeed in blended learning environments hampers the design of blended learning environments that actually support those different learners. More research is therefore needed both to clarify the relationship between blended learning environment design and learners' self-regulated learning and to facilitate effective design.

The current research project provides a basis for investigating support for learners' self-regulated learning in blended learning environments. A conceptual framework is proposed, emphasizing the importance of factors both internal and external to the learner. The framework has been operationalized, validated and empirically investigated in three phases. In the first phase (Section 1), we operationalized the conceptual framework by exploring the methodological challenges inherent to mapping support for self-regulated learning in blended learning environments. Seven attributes proposed by theory to support self-regulated learning were identified (Chapter 1) and translated into an instrument that can be used to describe the degree to which a given blended learning environment supports self-regulated learning (Chapter 2). Additionally, existing approaches to measuring self-regulated learning in such environments (Chapter 3) were combined and developed into a methodology for use in the next phases. The second phase (Section 2) consisted in testing the conceptual framework in an ecologically valid blended learning environment in order to verify its assumptions. Here, we investigated the influence that certain external factors, namely aspects of the environment's design, had on the learners' self-regulatory behaviour (Chapter 4). We then tested the influence of internal factors, namely learner characteristics (Chapter 5). The results of these investigations not only provided insights into the influence of both internal and external factors on learners' self-regulated learning but also served to validate the conceptual framework. The third and final phase (Section 3) was designed to test the conceptual framework more extensively. Here, we carried out empirical investigations to explore the effect of two environmental attributes – reflection cues (Chapter 6) and calibration cues (Chapter 7) – on learners' self-regulated learning. These studies' results confirm that in blended learning environments, not all learners benefit equally from the cues provided and that the use of cues does not automatically result in improved learning outcomes.

The conceptual framework and the insights gathered during the project's empirical investigations contribute to both research and practice. In particular, the project's findings underscore the importance of considering internal and external factors when integrating support for learners' self-regulated learning in blended learning environments. The conceptual framework also opens up potential avenues for future research. With regard to the project's practical relevance, the aim was not to ask whether or not blended learning environments should be used for instruction. Instead, the focus was on overcoming the challenge that blended learning environments pose to learners' self-regulated learning. One key outcome of this project, then, is the conceptual framework itself, which provides a basis for the systematic investigation and design of more supportive blended learning environments. This represents a clear step toward the development of tangible guidelines for the design of environments that supports self-regulated learning and thus facilitates improvements in learning outcomes for all learners.

De controle van lerenden ondersteunen: Zelfgereguleerd leren in blended leeromgevingen

Door: Stijn Van Laer
Promotor: prof. dr. Jan Elen

Blended leren is leren in een instructiecontext die wordt gekenmerkt door een bewuste combinatie van online en klas gebaseerde interventies, met het oog op het aanzetten tot en ondersteunen van leren. Blended vormen van leren zijn erg populair en worden aangeboden via een breed scala aan online en face-to-face instructieactiviteiten. Als gevolg van deze diversiteit verschillen blended leeromgevingen sterk in ontwerp, de gebruikte technologieën en instructiemethoden. Bestaande literatuur geeft echter aan dat blended leeromgevingen, zoals ze momenteel ontworpen worden, het zelfgereguleerd leren van lerenden onder druk zetten. Zelfgestuurd leren is het vermogen van lerenden om hun leerproces te sturen en om zo tot verbeterde leerprestaties te komen. De observatie dat blended leeromgevingen het zelfgereguleerd leren van lerenden onder druk zetten, kan problematisch zijn, aangezien er een duidelijke positieve correlatie bestaat tussen zelfgereguleerd leren en leerprestaties. Het gebrek aan inzicht omtrent welke ondersteuning lerenden met verschillende kenmerken helpt om succesvol te zijn, hindert het ontwerp van blended leeromgevingen die zulke lerende daadwerkelijk wensen te ondersteunen. Meer onderzoek is daarom nodig om zowel de relatie tussen het ontwerp van blended leeromgevingen en het zelfregulerend leren van lerenden te verduidelijken, alsook het effectief ontwerp van zulke leeromgevingen te vergemakkelijken.

Het voorliggende project biedt een basis voor onderzoek naar de ondersteuning voor zelfregulerend leren in blended leeromgevingen. Het stelt een conceptueel kader voor, waarin het belang van zowel factoren intern als extern tot de lerenden wordt benadrukt. In drie fasen werd het conceptueel kader geoperationaliseerd, gevalideerd en empirisch verder onderzocht. In de eerste fase (Sectie 1) hebben we het conceptueel kader geoperationaliseerd door de methodologische uitdagingen te onderzoeken die inherent zijn aan het in kaart brengen van ondersteuning voor zelfregulerend leren in blended leeromgevingen. Zeven door de theorie voorgestelde attributen ter ondersteuning van zelfregulerend leren werden geïdentificeerd (Hoofdstuk 1) en vertaald in een instrument dat kan worden gebruikt om te beschrijven in welke mate een specifieke blended leeromgeving zelfregulerend leren ondersteunt (Hoofdstuk 2). Daarnaast werden bestaande benaderingen voor het meten van zelfregulerend leren in dergelijke leeromgevingen (Hoofdstuk 3) gecombineerd tot een methodologie gebruikt in de volgende twee fasen. De tweede fase (Sectie 2) bestond uit het testen van het conceptueel kader in ecologisch valide blended leeromgevingen om de aannames horende bij het kader te verifiëren. De invloed van bepaalde externe factoren, namelijk de zeven attributen, op het zelfregulerende gedrag van de lerenden (hoofdstuk 4) werd onderzocht. Hier op volgend werd de invloed van interne factoren getest, meer specifiek, kenmerken van de lerenden (Hoofdstuk 5). De resultaten van deze studies gaven niet enkel inzicht in de invloed van zowel interne als externe factoren op het zelfregulerend leren van lerenden, maar dienden ook om het conceptuele kader verder te valideren. De derde en laatste fase (Sectie 3) was bedoeld om het conceptuele kader empirisch toe te passen en zo te testen. Empirisch werd het effect van twee omgevingskenmerken op het zelfgereguleerd leren van lerenden – cues voor reflectie (Hoofdstuk 6) en cues voor kalibratie (Hoofdstuk 7) – nagegaan. De resultaten van deze studies bevestigen dat in blended leeromgevingen niet alle lerenden evenveel baat hebben bij de geboden ondersteuning en dat het gebruik van cues niet automatisch leidt tot leerprestaties.

Het conceptueel kader en de inzichten verzameld tijdens de empirische tests dragen bij aan zowel praktijk als onderzoek. In het bijzonder onderstrepen de bevindingen van het project het belang van het beschouwen van interne en externe factoren bij het ontwerpen en onderzoeken van ondersteuning voor zelfregulerend leren in blended leeromgevingen. Met betrekking tot de praktische relevantie van het project was het niet het oogmerk om na te gaan of blended leeromgevingen al dan niet gebruikt moeten worden. In plaats daarvan lag de focus op het overwinnen van de uitdaging die blended leeromgevingen vormen voor het zelfgeregeld leren van lerenden. Een belangrijk resultaat van dit project is dan ook het conceptueel kader zelf, dat een basis biedt voor het systematisch onderzoeken en ontwerpen van beter ondersteunende blended leeromgevingen. Dit is een duidelijke stap in de richting van de ontwikkeling van tastbare richtlijnen voor het ontwerp van leeromgevingen die zelfregulerend leren ondersteunen en zo lerenden helpen bij het behalen van betere leerprestaties.

Dankwoord

Door: Stijn Van Laer

Het tot stand komen van dit proefschrift heeft het uiterste van me gevergd. Geenszins is het uitwerken er van echter een proces geweest dat ik alleen heb moeten doorlopen. Mocht dit het geval geweest zijn, dan kan ik u verzekeren dat u het voorliggende proefschrift niet te lezen gekregen zou hebben. Om enigszins een blijk van dankbaarheid te tonen, wil ik zonder te pogen volledig te zijn, een aantal mensen specifiek mijn dank betuigen.

De intellectuele zoektocht naar inzichten, al dan niet gerapporteerd in dit proefschrift, heb ik zeer graag samen met mijn promotor prof. dr. Jan Elen mogen afleggen. Zijn niet-aflatende en onvoorwaardelijke steun hebben er voor gezorgd dat ik alle kansen kreeg om me optimaal te ontwikkelen. De talloze erg gewaardeerde revisierondes hebben me aangezet tot het grondig bestuderen van de verschillende concepten en hun optimale operationele uitwerking. Naast de academische vaardigheden die prof. dr. Jan Elen me heeft helpen verwerven, heeft hij me een aantal persoonskenmerken tentoongespreid waar ik erg veel respect voor heb. Hopelijk heb ik me tijdens de afgelopen vier jaar ook een aantal van deze kenmerken eigen kunnen maken. Hiernaast hoop ik dat het lot ons toelaat onze samenwerking in de toekomst verder te kunnen zetten.

Ik was bevoorrecht dit proefschrift binnen een groter project te mogen uitwerken. Ik wil daarom ook graag alle partners van de UGent en de VUB bedanken voor de voorspoedige samenwerking binnen het IWT ALO! Project (SBO 140029). Ruth was gedurende de afgelopen 4 jaar mijn ‘WP2 partner in crime’. Naast het conceptuele was er ook een empirisch luik aan dit proefschrift. Zonder de bereidwilligheid van de partners in de centra voor volwassenenonderwijs (CVO Antwerpen en CVO De Oranjerie), de KU Leuven (Opleidingsonderdeel Instructiepsychologie en -technologie), Bicol University en hun cursisten en studenten was geen van onze hypotheses verworpen of gevalideerd kunnen worden. Ook al ben ik er niet in geslaagd hun werk voldoende te appreciëren tijdens de afgelopen vier jaar, de samenwerking met mevr. Suys en mevr. Vanden Driessche en het vertrouwen dat ze in me hadden was fantastisch. Zonder hen en hun was dit project niet mogelijk geweest.

Ik richt me in dit dankwoord ook graag even tot de academische gemeenschap (AECT, AERA, EARLI, EARLI SIG 6-7, EARLI SIG 16, EARLI SIG 27, ICO, LAK, LLL, …) waartoe ik de afgelopen vier jaar mocht behoren. Zonder de feedback op manuscripten en de input die ik tijdens presentaties, workshops, cursussen, seminaries en dergelijke ontving, was ik nooit zo ver kunnen komen.

Ook de KU Leuven en de collega’s op campus Leuven, Brussel en Kortrijk verdienen hier een vermelding voor hun hulp en steun. Graag wil ik specifiek alle leden van het Centrum voor Instructiepsychologie en –technologie voor het voetlicht brengen. Ik ben alle collega’s erg dankbaar voor de tijd die zij namen om me met raad en daad bij te staan. Zij waren vaak de eerstelijnshulpverleners die me de moed gaven om er steeds tegenaan te blijven gaan. Hiernaast ben ik prof. dr. Lieven Verschaffel erg erkentelijk voor de ruimte die hij, als diensthoofd, me gaf om betrokken te kunnen zijn bij allerhande initiatieven en tijdens de onderzoeksseminaries. Ik bewonder zijn oprechte interesse in het werk van zijn medewerkers. In eenzelfde lijn wil ik ook de Dienst Onderwijsprofessionalisering en -Ondersteuning van de KU Leuven, gepersonifieerd in de vorm van mevr. Cosemans, danken voor hun oprechte interesse in mijn werk. Ook de ondersteunende diensten van de Faculteit Psychologie en Pedagogie verdienen hier een vermelding voor hun ondersteuning bij de praktische uitwerking van dit proefschrift.

In wil ook de tijd nemen om de professoren die deel uitmaakten van de begeleidingscommissie van mijn doctoraatsopleiding, prof. dr. Patrick Onghena en prof. dr. Katie Goeman, alsook de leden van de halftijdse evaluatiecommissie en de uiteindelijke examencommissie, bestaande uit prof. dr. Filip Dochy (chair of the examination committee), prof. dr. Fien Depaepe (Secretary and opponent of the examination committee), prof. dr. Eva Ceulemans (member of the mid-term evaluation committee) prof. dr. Bram De Wever (external opponent of the examination committee), prof. dr. Dragan Gasevic (external opponent of the examination committee), en prof. dr. Marcel Veenman (external member of the mid-term evaluation committee), te bedanken voor hun geïnvesteerde tijd en moeite.

Niet enkel de mensen uit mijn professionele context komt alle lof toe. De leerkrachten van het KVRI in Vorselaar geloofden in mij. De belangstelling die mijn broer en ouders voor mijn werkzaamheden toonden is kenmerkend voor hun betrokkenheid tot mijn persoonlijk welzijn. Hun adviezen en reflecties hebben me steeds geholpen bij het behouden van het nodige perspectief met betrekking tot dit proefschrift en het respect voor de bevoorrechte positie waarin ik me bevond. Ik wil ook mijn directe omgeving bedanken om tijdig de druk van mijn schouders te nemen en mijn aandacht op te eisen wanneer ik te veel in mijn werk op ging. Ik denk hierbij vooraleerst aan de leden van ons wijlen Koninklijke Lierse Sportkring.

Tot slot had ik dit nooit kunnen doen zonder Sam. Ik kan me geen betere partner voorstellen om zulk project mee te doorlopen. Ze heeft me getolereerd tijdens één van de meest uitdagende periodes van mijn nog relatief jonge leven. Ze was er altijd en gaf zich altijd voor honderd procent, van haar heb ik uiteindelijk nog het meest geleerd denk ik.

Bedankt allemaal voor jullie betrokkenheid.

Hartelijke groeten

Stijn Van Laer   Leuven, september 2018

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INTRODUCTION

Technology in education is a phenomenon of all times. As far back as the Stone Age, stories and early forms of instruction were supported by illustrative cave drawings (Saettler, 1968). In recent years, it is electronic educational technologies that have attracted much research attention. The use of electronic technologies in education can be traced back to the early 1930s (Reiser, 1987, 2001, 2017). Audiovisual media such as radio, television and film entered the educational field with the promise of enriching learners' learning experiences. Soon the effects of these media on learning outcomes were being investigated, especially in times of high training need (i.e., Second World War) and in regions where large physical distances needed to be overcome (Australia, Canada and the United States). With the rise of the computer in the late 1970s, interaction was added to the functionalities of educational technology, enabling the replacement or assistance of instructors in the support of learners' learning. As soon as computers entered the mainstream in the mid 1980s, they were used to shift parts of the physical learning environment to online learning environments, changing the role of the computer from a rather directive cognitive system to a medium that allowed learners to provide their own input (Molenda, 2008). This shift resulted in new approaches to instruction, introducing computer-based distance education and flexible learning using CD-ROMs to provide learners with the necessary courseware. From the 1990s onwards, interest in Internet applications expanded the interactivity and personalizability of educational technology even further through Internet-based learning environments such as blended learning and massive open online courses (MOOCs) (Garrison & Kanuka, 2004). The research project presented in this doctoral thesis focuses on the latter wave of educational technologies, and specifically on the use of blended learning environments to elicit learners' learning.

Blended learning

Since the 2000s, blended learning has become a popular concept in various forms of education (Graham, Allen, & Ure, 2005). While blended learning has been described in numerous ways, Graham et al. (2005) identify three main approaches: blended learning as the combination of different instructional methods, blended learning as the combination of different modalities or delivery media, and blended learning as the combination of face-to-face and computer-mediated instruction. Driscoll (2002) also offers similar means of defining blended learning. She argues that four types of blend can be described: combining modes of web-based technology to accomplish an educational goal, combining pedagogical approaches to produce an optimal learning outcome with or without instructional technology, combining any form of instructional technology with face-to-face instructor-led training, and combining instructional technology with actual job tasks (learning and working). A third set of authors (e.g., Allen, Seaman, & Garrett, 2007; Bernard, Borokhovski, Schmid, Tamim, &

Abrami, 2014) describe the blend on the basis of percentages. For example, according to Allen et al. (2007), blended courses are those in which 30% to 79% of the content is delivered online.

Of these definitions, perhaps the most common is the one that emphasizes the blend of online and offline learning. Several authors who adhere to this perspective describe blended learning as a combination or integration of the strengths of offline instruction (e.g., live instruction and classroom interaction) and online instruction (e.g., technologically mediated interactions between students, teachers and learning resources) (e.g., Bliuc, Goodyear, & Ellis, 2007; Garrison & Kanuka, 2004; Osguthorpe & Graham, 2003; Watson, 2008) in such a way that it is not “just adding on to the existing dominant approach or method” (Garrison & Kanuka, 2004, p. 97). In line with this idea, blended learning is defined in this research project as learning that happens in an instructional context characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning (Boelens, Van Laer, De Wever, & Elen, 2015). Given the definitions presented above, however, the relation of blended learning to concepts such as the flipped classroom and hybrid learning is not always clear-cut and the instantiation of the optimal blend often remains vague (Oliver & Trigwell, 2005). Despite these issues, blended learning as a notion is widely used in higher and adult education (Allen et al., 2007); K-12 education (Picciano, Seaman, Shea, & Swan, 2012); and corporate training (Bonk, 2017; Spring & Graham, 2017).

Research on blended learning

Over the years, blended learning has been studied intensively. The majority of studies on blended learning have focused either on comparing blended and face-to-face learning (Halverson, Graham, Spring, Drysdale, & Henrie, 2014) or on the characteristics that learners need to thrive in such environments (Deschacht & Goeman, 2015). With regard to the latter, research has identified that learners with high verbal ability and self-efficacy (Lynch & Dembo, 2004) and learners with high self-regulatory capabilities (Kizilcec, Pérez-Sanagustín, & Maldonado, 2017; Kuo, Walker, Schroder, & Belland, 2014) perform better in blended learning environments compared to learners who lack these capabilities. Besides this empirical work, there is also a substantial body of literature proposing design frameworks for blended learning. These studies generally articulate or compare frameworks (Graham, Henrie, & Gibbons, 2014). Examples of such contributions include the Kerres and De Witt (2003) 3C framework, with its three main components of content, communication and construct, and the Carman (2002) framework, which has five key ingredients: live events, online content, collaboration, assessment and reference materials. Many of the frameworks available conceptualize the relationship between different elements of blended learning.

Although hypothesized conceptual design frameworks and empirical studies of learners' fit with blended learning environments are both of value, there appear to be opportunities to develop the field of blended learning research further (Halverson et al., 2014). The literature exhibits a clear shortage of research on the core attributes of blended learning environments which affect learners' performance. Following this observation, rather than testing learners' ability to perform well in blended learning environments, more work is needed to test the validity and effectiveness of hypothesized conceptual frameworks. By taking a learner-centred approach, focusing on the relationship between designs of blended learning environments and factors within the learner, empirical blended learning research might identify core attributes that influence learners' learning, which can then be tested and better understood (Ololube, Umunadi, & Kpolovie, 2015).

For blended learning research to be effective, research needs to (1) identify the core elements affecting learners' learning, (2) describe factors of the learning environment and factors within the learner that potentially influence blended learning's effectiveness, and (3) analyse the relation between these elements to fully understand the effect of the design (Dziuban, Picciano, Graham, & Moskal, 2015). Without this information, practitioners cannot use the outcomes of blended learning research; neither can other researchers investigate, add to or falsify them (Driscoll, 2002).

Suitability of blended learning for different learners

Research on blended learning environments generally praises its flexibility and suitability for adult learners (Ausburn, 2004). Adult learners have the experience and ability to control their own learning, which make them particular suitable for blended learning (Knowles, Holton, & Swanson, 2014). For example, authors have stressed autonomy, self-direction and affinity for real-life learning as key characteristics of adult learners (Brookfield, 1986; Caffarella & Merriam, 2000; Tough, 1978). All these characteristics align closely with current conceptions of blended learning (Spring & Graham, 2017). How blended learning environments are experienced by learners who do not possess these inherent characteristics remains unclear, however (Connolly, Murphy, & Moore, 2007). This research project therefore explores the experiences of all learners, including those with less 'desirable' characteristics. One example of such a group of learners is 'second-chance' learners, who often have a variety of motives, negative prior experiences with education and a history of dropping out of school early (Ross & Gray, 2005). Although this description might be rather stereotypical, it can be assumed that when such learners enter a blended learning environment, they face different challenges compared to their better-equipped peers. This claim is supported by research that argues that blended learning environments often require a substantial amount of self-regulated learning on the part of learners (e.g., Bonk & Graham, 2012; Collis, Bruijstens, & van Veen, 2003). Learners need to possess multiple self-regulated learning capabilities if they are to learn successfully in such environments (e.g., Lynch & Dembo, 2004; Sharma, Dick, Chin, & Land, 2007). Cennamo, Ross, and Rogers (2002) further illustrate this by showing that blended learning environments are sufficient for adults with extensive self-regulatory abilities, but that they may fail to engage learners who have fewer self-regulated learning capabilities. To overcome this issue, blended learning research needs to focus, firstly, on the interplay between the design of blended learning environments and learners' learning characteristics, and secondly, on support for learners' self-regulated learning within such environments (Kuo et al., 2014). Only in this way can blended learning environments become more effective and inclusive.

Self-regulation, self-regulated learning and self-regulatory behaviour

Blended learning, like any form of learning, is an activity performed by learners rather than something that happens to them as result of instruction (Bandura, 1989). It is a self-regulated process in which learners regulate their behaviour according to the instructional demands (Zimmerman & Schunk, 2001). This is evidenced by a substantial body of literature showing that scores on performance-related variables are strongly positively correlated with scores on self-regulated-learning-related variables (e.g., Daniela, 2015; Lin, Coburn, & Eisenberg, 2016).

Over the past three decades, various self-regulation theories have been proposed (see: Puustinen & Pulkkinen, 2001). A clear shift has taken place, moving away from the conception of self-regulation as a construct that remains stable over time (aptitude) towards an approach that focuses on the dynamic (event) nature of self-regulation. This has resulted in new theories on self-regulation. Some of the best known of these theories are (1) Boekaerts' Model of Adaptable Learning (Boekaerts, 1992, 1995, 1996b, 1997, 1999; Boekaerts & Corno, 2005), (2) Borkowski's Process-Oriented Model of Metacognition (Borkowski, 1996; Borkowski, Carr, Rellinger, & Pressley, 1990; Pressley, Borkwski, & Schneider, 1989), (3) Pintrich's General Framework for Self-Regulation (Pintrich, 2000b; Pintrich, 2002; Pintrich, 2004; Schunk, Pintrich, & Meece, 2008), (4) Zimmerman's cyclical Social Cognitive Model of Self-Regulation (Zimmerman, 1989; Zimmerman, 1995, 2002, 2008, 2013; Zimmerman, Schunk, & DiBenedetto, 2015), and (5) Winne's Four-Stage Model of Self-Regulated Learning (Winne, 1982, 1985, 1995, 2006; Winne, 2010, 2018; Winne & Hadwin, 1998). Each of the self-regulation theories describes the nature of self-regulation as cyclical, influenceable and covert. First, the theories describe a similar *cyclic* process of self-regulatory phases, often consisting of (a) forethought, (b) enacting and (c) evaluation. Secondly, they stress the *influence* of internal factors (i.e., learners' learner characteristics) and external factors (i.e., context) on the development of self-regulation (see: Puustinen & Pulkkinen, 2001). Finally, the *covert* nature of self-regulation lies in the fact that the cognitive and metacognitive processes occurring in each of its phases cannot be directly observed. These processes and phases are only manifested indirectly through overt behaviours (i.e., learners' behaviour) and behavioural consequences (i.e., learners' learning outcomes) (Veenman, 1993; Veenman, 2011, 2012; Veenman, Van Hout-Wolters, & Afflerbach, 2006; Veenman, Wilhelm, & Beishuizen, 2004). For instance, when a learner recalculates the outcome of a mathematical equation, it is assumed that an evaluation or monitoring process must have preceded this overt cognitive activity of recalculation. In summary, the cyclical and influenceable nature of self-regulation, in particular, means that it is dynamic and changes over time. Because of this, continuous measurements and inferences based on learners' learning behaviour and outcomes are needed to capture self-regulation.

In line with the above, the current research project approaches self-regulation as the 'procedural pendant' of metacognition (e.g., Veenman et al., 2006) and defines it in accordance with Winne and Hadwin (1998) as the deliberate use of cognitive and metacognitive skills, in a particular context, to achieve goals set within or external to the learner. The key characteristics of self-regulation are its cyclical, influenceable and covert nature. Whereas self-regulation refers to goals set within or external to the learner, self-regulated learning, in particular, reflects how learners respond to the instructional goals imposed on them externally by instructors or other educational instances. Finally, learners' behavioural reactions to differences in internal and/or external factors are considered to be self-regulatory behaviour.

Conceptualization of self-regulated learning

In this research project the Winne and Hadwin (1998) model was selected as a tool for reflecting upon the support for self-regulated learning in blended learning environments, since it has a number of characteristics that make it very suitable for our purpose. As the name suggests, Winne's Four-Stage Model of Self-Regulated Learning (Winne, 1982, 1985, 1995, 2006; Winne, 2010, 2018; Winne & Hadwin, 1998) describes four stages: (1) task definition, during which learners develop perceptions of the task concerned, (2) goalsetting and planning, (3) enacting the tactics and strategies chosen during goal-setting and planning, and (4) metacognitively adapting studying techniques, keeping future needs in mind. Each of these phases consists of five elements (COPES): (1) conditions, which affect how a task will be engaged with, (2) operations: cognitive processes and tactics learners employ, (3) product: information created by operations, (4) evaluations: feedback about products (internal or external), and (5) standards: criteria against which products are monitored. The theory emphasizes that learners who are prompted to process effectively in stage one (task definition) and stage two (goal setting and planning) are more likely to have accurate expectations of the task. Finally, each stage and its elements are influenced by internal conditions (i.e., learner characteristics) and external conditions (i.e., context). Winne and Hadwin (1998) identify task conditions (e.g., time constraints, available resources, and social context) and cognitive conditions (e.g., interest, goal orientation, and task knowledge) that influence how a certain task will be engaged with.

The Four-Stage Model of Self-Regulated Learning (Winne & Hadwin, 1998) was selected because of the following considerations. First, the model looks beyond the focus on purely instructional stimuli and their effects on learning, contesting the assumption that all learners process the stimuli as intended (Winne, 1982). Instead, the authors see learners as active agents (Winne, 1982, 1985, 2006) or mediating factors in the instructional process (Keller, 2010; Winne, 1982). A second consideration is that the model gives clear indications about which phases of the self-regulated learning process to target and which parts of learners' cognitive processes are malleable enough to impact learners' self-regulated learning (Winne & Hadwin, 1998). On the one hand, the insight that task definition and goal-setting and planning are the main phases to target is highly instructive (Greene & Azevedo, 2007). On the other hand, the COPES heuristic provides us with directions for targeting elements of learners' cognitive systems during interventions (Greene & Azevedo, 2007). Thirdly, because monitoring and control function as the key drivers of regulation within each phase, Winne and Hadwin's model (1998) effectively describes how changes in one phase can lead to changes in other phases over the course of learning (Greene & Azevedo, 2007). This allows the model to detail the recursive nature of self-regulated learning more explicitly (Greene & Azevedo, 2007).

Measuring self-regulated learning

Theories on self-regulated learning have shifted from self-regulated learning as an aptitude to self-regulated learning as an event. In parallel, the conceptualization of measurement approaches to capture it have also evolved. Measurements shifted from single measurements administered before or after the execution of a task to continuous measurements administered throughout the execution of the task (Winne & Perry, 2000). The latter type of measurement is referred to as an on-line measurement whereas the former is referred to as an off-line measurement of self-regulated learning (Pintrich, 2004). Following the shift in conceptualization of the self-regulated learning concept, the use of off-line measurements that were based on learners' own perceptions (e.g., self-reports) came under pressure (e.g., Endedijk, Brekelmans, Sleegers, & Vermunt, 2016). This is mainly because such types of measurements assume that learners are capable of predicting, reflecting or estimating in general terms (before or after a task) how they will act in a certain context, and they subsequently rely on learners' perceptions of their own self-regulated learning rather than on the actual self-regulated learning they exhibit (Veenman, Bavelaar, De Wolf, & Van Haaren, 2014).

The recording of learning-related behavioural data that are suitable for quantitative analysis has become almost effortless and unobtrusive for learners in computer-based learning environments (e.g., Winne, Nesbit, & Popowich, 2017), making this type of data particularly interesting for both practice and research. An example of this usefulness is the mining of theory-based patterns from big data to investigate self-regulated learning strategies in MOOCs (Maldonado-Mahauad, Pérez-Sanagustín, Kizilcec, Morales, & Munoz-Gama, 2018). Other successful examples include the identification of traces of self-regulated learning in activity streams (Cicchinelli et al., 2018) and the assessment of online learning material and its relation to learners' quantitative behaviour patterns and their effects on motivation and learning performance (Yang, Li, & Xing, 2018). Applications are plentiful and diverse, but this has resulted in complex and often hard-to-follow methodological approaches and analyses. Since the introduction of learners' behaviour in the field of self-regulated learning, researchers have been emphasizing the need for methodological frameworks to guide its application (e.g., Bannert, Reimann, & Sonnenberg, 2014). Yet, to date, no such frameworks have been proposed, hindering progress towards transparent methods, comparative studies and applications in ecologically valid contexts (e.g., Beach & Pedersen, 2013; Lupia & Alter, 2014). Finally, to be able to investigate learners' goal-directedness, the relationship between learners' regulatory behaviour and learning outcomes needs to be investigated. When it comes to using learners' self-regulatory behaviour, this means investigating the effect that differences in learners' self-regulatory behaviour have on learners' learning outcomes.

Hypothesized conceptual framework

In accordance with Winne and Hadwin (1998), we defined self-regulated learning as the deliberate use of cognitive and metacognitive skills, in a particular context, to achieve goals set within or external to the learner. As self-regulation is cyclical, influenceable and covert in nature and refers to goals within or external to the learner, self-regulated learning, in particular, reflects how learners respond to the instructional goals imposed on them externally. Behavioural reactions to differences in internal and/or external factors, then, are considered to be self-regulatory behaviour. Based on these theoretical assumptions, we hypothesized a conceptual framework which would direct our investigation of the support for learners' self-regulated learning in blended learning environments (see Figure 1). In what follows, the various elements of the hypothesized framework are discussed and then related to the research project as a whole.

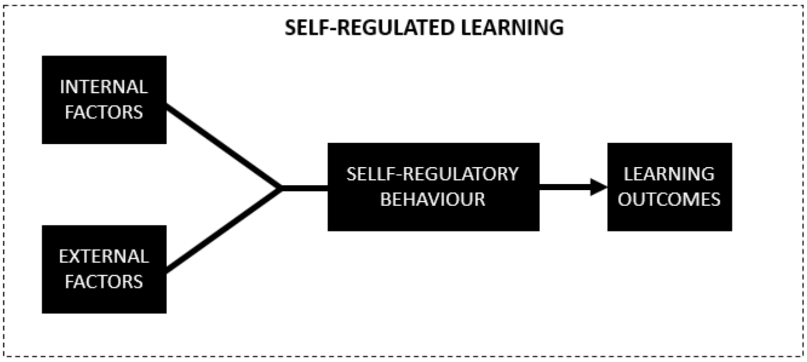

Figure 1. Visual representation of the conceptual framework under investigation.

Factors influencing learners' self-regulated learning

As demonstrated by the current conceptualizations of self-regulated learning, self-regulated learning is believed to be influenced by two categories of factors: internal and external factors. The former relates to cognitive, motivational and metacognitive aspects of learning. The latter relates to factors external to the learner, for example the design of the learning environment.

Factors within the learner

Although self-regulated learning seems to be influenced by external factors (i.e., design of learning environments), which lead to various decisions and learning outcomes (e.g., Panadero, Jonsson, & Strijbos, 2016; Perels, Otto, Landmann, Hertel, & Schmitz, 2007), learners themselves (and their cognitive, metacognitive and motivational characteristics) also influence and affect learning processes (e.g., Bransford, Brown, & Cocking, 2000; Endedijk, Brekelmans, Verloop, Sleegers, & Vermunt, 2014; Zimmerman, 2002). The Winne and Hadwin model (1998) proposes the following set of internal factors (cognitive conditions): (a) beliefs, dispositions and styles, (b) motivational orientation, (c) domain knowledge, (d) knowledge of task, and (e) knowledge of study tactics and strategies. In order to operationalize these factors, we combined them into three categories of internal factors often investigated in the literature on self-regulated learning (e.g., Boekaerts, Pintrich, & Zeidner, 2005; Greene & Azevedo, 2007). The first category relates to cognitive characteristics and includes, for example, domain knowledge. The second category relates to motivational characteristics and includes motivational orientation, beliefs, dispositions and styles. The final category relates to metacognitive characteristics and includes knowledge of task, knowledge of study tactics and strategies. Based on reviews by Butler and Winne (1995), Greene and Azevedo (2007), Winne (1996) and Winne and Butler (1994) we identified learner variables for the different studies presented in this research project . We then selected the variables related to self-regulated learning and to the Winne and Hadwin (1998) model that were most stable (over time). The exact configuration of these three categories of factors differs in the seven studies undertaken during the research project. The sub-sections below discuss each category and the learner variables addressed in each study, along with their operationalization.

Cognitive factors

Cognitive characteristics in research on self-regulated learning typically consist of two elements: (1) intelligence (Spolsky, 1989) and (2) prior domain knowledge (Hirschfeld & Gelman, 1994). In contrast to intelligence as a fixed multifaceted concept, which is difficult to measure (Deary, Strand, Smith, & Fernandes, 2007), prior domain knowledge is reported to be an equally good predictor of future academic performance and learners' self-regulated learning (e.g., Murphy & Alexander, 2002; Winne & Hadwin, 1998). Prior domain knowledge is knowledge that learners already have in the domain and is frequently used when investigating the relationship between learners' cognitive characteristics and self-regulated learning (e.g., Moos & Azevedo, 2008; Moos & Azevedo, 2009; Winters, Greene, & Costich, 2008). Such investigations have indicated that learners who can automatically and seemingly effortlessly retrieve effective knowledge from memory have little need to deliberately self-regulate (Greene & Azevedo, 2007). Learners with lower prior domain knowledge face quite a different task, in which self-regulated learning can substantially enhance achievement (Winne & Butler, 1994). An example of how learners' prior knowledge influences self-regulated learning processes is provided by Moos and Azevedo (2008), who showed that learners with high prior domain knowledge used significantly more planning and monitoring strategies and fewer strategies for meeting the goals of the task than those with low prior knowledge. In contrast, those with low prior knowledge used more cognitive processing strategies related to the content of the course. Similar findings were obtained in the literature on expertise. The more extensive one's prior domain knowledge is, the lesser the need to search for, use and regulate metacognitive tactics or strategies (e.g., Lesgold et al., 1988; Song, Kalet, & Plass, 2016). Based on these observations, the assumption made by the Winne and Hadwin (1998) model is that operations in (i) task identification and (ii) goal-setting and planning are affected by prior domain knowledge. For learners with high prior domain knowledge (in contrast to learners with lower levels), the need to regulate using content strategies is lower because of their embedded previously acquired knowledge.

Motivational factors

Motivational influences on self-regulated learning are well established (e.g., Pintrich, 2004). Overall, Winne and Hadwin's (1998) model relates to motivation by providing a framework for explaining motivation's effect on self-regulated learning, more specifically about how the various constructs under the general motivation concept influence each phase of learning, not just strategy use and performance (Greene & Azevedo, 2007). In this research project, we focus on three motivational concepts: the expectancy-value approach, the goal orientation approach and academic self-concept.

Wigfield and Eccles (2000) proposed the expectancy-value model of motivation based on efficacy, expectancies and task value. This model focuses on learners' expectations of success on upcoming tasks and the values and affect learners' assign to this task. Each of the expectancy-value approach components can be related to Winne and Hadwin's (1998) model. With regard to the value component, the model suggests that determinations of effort are products of the goal-setting and planning phase and thus impact the next phases of self-regulated learning. If the effort necessary exceeds some personal threshold, a learner may ignore other standards and decide to skip a task (Duffy & Azevedo, 2015). As regards expectancy, the model suggests that efficacy expectations influence the standards created in the different phases of self-regulated learning. Higher self-efficacy predicts the types of goals constructed, and decisions regarding whether to persist in, or even attempt, an academic task. Learners who have a poor understanding of their ability to perform necessary goal-related activities may undermine their own learning in multiple phases (Moos, 2014). In relation to affect, negative affect can result in a learner abandoning his or her goals, even if learning is taking place. This suggests that effortful learning and study strategies may be cast aside, even when successful, if they take too long to enact (Nelson, Shell, Husman, Fishman, & Soh, 2015).

Concerning the second motivational concept, goal orientation, Pintrich (2000a) divided learners' motivation into mastery goals and performance goals and their two sub-forms: approach and avoidance. Research on mastery goal orientations has focused mainly on the approach form and has found elaborate use of cognitive and metacognitive strategies (e.g., Duffy & Azevedo, 2015; Kitsantas, Steen, & Huie, 2017; Midgley, 2014). Less research has explored the mastery-avoidance orientation. Elliot and McGregor (2001) and Wolters, Pintrich, and Karabenick (2005) found an association between the mastery-avoidance orientation and test anxiety, which is consistent with the characterization of mastery-avoidant learners as perfectionists. Research on the performance-approach orientation is divided. Some authors argue that it can lead to productive self-regulated learning (e.g., Harackiewicz, Barron, Pintrich, Elliot, & Thrash, 2002; Kitsantas et al., 2017; Mega, Ronconi, & De Beni, 2014), whereas others claim that the effects of this form of motivation are still unknown (e.g., Dompnier, Darnon, & Butera, 2013; Midgley, Kaplan, & Middleton, 2001; Senko, Durik, Patel, Lovejoy, & Valentiner, 2013). Findings on the performance-avoidance orientation are also inconclusive. Some research states that this orientation is associated with negative outcomes, such as the use of fewer cognitive strategies (Pintrich, 2000b). Yet, there is also evidence that these types of learners use more cognitive strategies to test their own abilities and compare themselves to others (e.g., Collazo, Elen, & Clarebout, 2015; Crippen, Biesinger, Muis, & Orgill, 2009). Winne and Hadwin's (1998) model, argues that the two different forms of orientation affect all four phases of self-regulation differently.

The third motivational concept, academic self-concept, is defined as learners' perception of themselves within academia (Elliot & Dweck, 2013). Academic self-concept contains two sub-concepts: learning confidence and learning effort. The learning confidence component relates to whether learners feel that academic subjects are easy for them and whether they believe they are good at them, whilst learning effort relates to whether learners like or dislike going to school and studying different subjects (Liu & Wang, 2005). A strong and positive influence of academic self-concept on the number and types of metacognitive strategies used has been observed (e.g., Mega et al., 2014; Soufi, Damirchi, Sedghi, & Sabayan, 2014). Those with stronger academic self-concepts explore learning environments more vigorously, whereas those who have lower self-concepts tend to retreat and concentrate on simple cognitive strategies (e.g., Kuo et al., 2014). Regarding Winne and Hadwin's (1998) model, academic self-concept can be expected to influence the standards by which learners judge their products. Learners with high learning confidence and effort are more likely to create task definition and goal products that allow for greater effort and persistence in the face of difficulties in the next phase of self-regulated learning, namely the enacting phase (Murphy, Alexander, Greene, & Edwards, 2007).

Metacognitive factors

As self-regulation is seen as the procedural pendant of metacognition, metacognitive factors are inevitably linked to self-regulated learning (e.g., Veenman et al., 2006). Butler and Winne (1995), Greene and Azevedo (2007), Winne (1996) and Winne and Butler (1994) emphasize the importance of learners' judgement of learning and metacognitive awareness of tactics and strategies for self-regulated learning. Winne and Hadwin's (1998) model adds to this that both are the key factors during metacognitive monitoring, which is itself essential for successful self-regulated learning (Schraw & Dennison, 1994).

Learners' judgement of learning (Schraw, 2009) is defined as learners' precision in estimating future performance compared to actual performance (Maki, Shields, Wheeler, & Zacchilli, 2005). Based on this information, learners monitor and direct their learning. If learners are able to estimate their performance accurately, it means they are monitoring effectively and are therefore more likely to take appropriate action and regulate their learning (Butler & Winne, 1995). Learners whose judgement of learning is poor tend to make ineffective, suboptimal learning choices (Segedy, 2014).

To be able to set goals and plan based on their monitoring output, learners need to be metacognitively aware of the tactics and strategies they possess (Winne, 1996). As the Winne and Hadwin (1998) model sees tactics and strategies as rules in the form of IF-THEN and IF-THEN-ELSE, propositions expressed as IF conditions in these rules comprise the conditional knowledge learners use in monitoring tasks and deciding when to take actions, which appear as THENS and ELSES. Individual differences in conditional knowledge represented in IF conditions will influence how learners monitor object-level events and whether they identify occasions for applying tactics and strategies. Correspondingly, differences in learners' knowledge of THENS and ELSES constitute differences in learners' ability to exercise metacognitive control. This view is supported by a large body of literature investigating the relation between learners' metacognitive awareness and their use of metacognitive tactics and strategies. Bannert, Sonnenberg, Mengelkamp, and Pieger (2015) and Bannert et al. (2015), for example, investigated whether metacognitively aware learners exhibited different navigation behaviours compared to learners who were less metacognitively aware. The results showed that learners who configured their own metacognitive prompts and learned with them showed significantly different navigation behaviours in the learning session afterwards, compared to learners in the control condition. Similar results were obtained by Azevedo et al. (2016).

Factors external to the learner

Different stages, dimensions and processes of self-regulated learning may be influenced by particular instructional interventions (e.g., Bannert, 2009; Ifenthaler, 2012; Liu, Dev, Dontcheva, & Hoffman, 2016). As pointed out by Ley and Young (2001), several self-regulated learning interventions have been tailored to specific content, learners or media. Interventions have been suggested for writing (Graham, Harris, & Troia, 1998), reading comprehension (Pressley, El-Dinary, Wharton-McDonald, & Brown, 1998) and mathematics (Schunk, 1998). Others have incorporated support for self-regulated learning into college learning (Hofer, Yu, & Pintrich, 1998) or in computer-mediated instruction (Winne & Stockley, 1998). The literature contains only a limited number of studies that have focused on support for self-regulated learning in blended learning environments (Artino, 2008; Kassab, Al-Shafei, Salem, & Otoom, 2015). Some approaches have been directed toward specific populations such as children (Biemiller, Shany, Inglis, & Meichenbaum, 1998; Corno, 1995), adolescents (Belfiore & Hornyak, 1998), and learning disabled learners (Butler, 1998).

Although there is a substantial amount of research available that describes ways to support learners' self-regulated learning, several issues complicate the practical application of these guidelines. First, while much research does consider self-regulated learning as an inherent part of learning, research that takes this perspective and presents concrete design guidelines is scarce. The guidelines formulated often see self-regulated learning as a specific goal (to design for) instead of as an inherent attribute of learning (Schunk & Zimmerman, 2003). This results in descriptions of interventions that focus on increasing specific elements of self-regulated learning (e.g., task definition, monitoring, etc.). Only a few studies have attempted to combine findings into a set of guidelines or principles resembling a conceptual framework. Among the attempts are Ley and Young (2001), Perry and Drummond (2002), and Perry, Nordby, and VandeKamp (2003). Ley and Young (2001) proposed principles for designing learning environments that support self-regulated learning: (a) to help learners prepare and structure an effective learning environment; (b) to organize instruction and activities to facilitate cognitive and metacognitive processes; (c) to use instructional goals and feedback to present the learner with monitoring opportunities; and (d) to provide learners with continuous evaluation information and opportunities to self-evaluate.

In relation to the conceptualization of self-regulated learning used in the current research project, the principles formulated by Ley and Young (2001) seem to relate most closely to the enacting and modifying phases of self-regulated learning (phases 3 and 4, respectively). However, no indications are provided about how to support learners in identifying the task at hand or in setting appropriate goals and planning to achieve them. Perry and Drummond (2002) and Perry et al. (2003) approached support for self-regulated learning in a broader, more general fashion. They suggested that: (a) learners and instructors should function as a community of learners; (b) learners and instructors should be engaged in complex, cognitively demanding activities; (c) increasingly, learners should take control of learning by making choices, controlling challenge and evaluating their work; (d) evaluation should be nonthreatening, embedded in ongoing activities, emphasize processes as well as products, focus on personal progress and encourage learners to view errors as opportunities to learn; and (e) instructors should provide instrumental support to learners' learning, combining explicit instruction and extensive scaffolding to help learners acquire the knowledge and skills they need to complete complex tasks. The guidelines of Perry and Drummond (2002) and Perry, Nordby, and VandeKamp (2003) focus on interventions that trigger the four phases of self-regulated learning through specific interventions (e.g., community of practice, assessment, etc.).

The literature contains no models for the design of learning environments that support learners' self-regulated learning dating from after 2003. Since 2003, educational psychological research has focused on particular metacognitive strategies and skills, rather than self-regulated learning as a whole. Although Ley and Young (2001), Perry and Drummond (2002) and Perry et al. (2003) established sets of guidelines for supporting self-regulated learning, to the best of our knowledge none of these guidelines have been either (1) translated into a generalizable conceptual framework for the support of self-regulated learning, or (2) operationalized to describe and characterize learning environments (including blended learning environments) in a systematic way. This observation is problematic since without such approaches, systematic investigations or empirical attempts at more effective (re)designs are hampered (Münzer, 2003; van Merriënboer & Kirschner, 2001).

To overcome the lack of identified attributes that support learners' self-regulated learning in blended learning environments, Van Laer and Elen (2018) identified seven attributes that support learners' self-regulated learning (see Chapter 1). The first attribute identified is authenticity, or the real-world relevance of the learning experience to learners' lives. The second is personalization, defined as the tailoring of the learning environment to the inherent preferences and needs of each individual learner. The third, learner control, is the degree to which learners have control over the content and activities within the learning environment. The fourth attribute is scaffolding, defined as changes in the task or learning environment which assist learners in accomplishing tasks that would otherwise be beyond their reach. The fifth is interaction, or the way in which the learning environment stimulates learners' involvement with this environment. The sixth is reflection cues, which are prompts intended to activate learners' purposeful critical analysis of knowledge. Finally, the seventh attribute is calibration cues, which are triggers for learners to test their perceptions against their actual performance and study tactics. The combination of these attributes comprises a support system for learners' self-regulated learning in blended learning environments. The proposed framework for the description of the support for self-regulated learning in blended learning environments is one of the few tools that can be used to characterize blended learning environments. Such a framework provides a reference frame to enable comparisons with studies that might have similar or different external factors.

Learners' self-regulatory behaviour and self-regulated learning

Learners' self-regulatory behaviour is defined as the behavioural traces gathered from a learner during instructional processes (Entwistle & Peterson, 2004). Due to the changing conceptualization of self-regulated learning, methods have evolved to on-line measures investigating learners' behaviour. However, since the introduction of learners' behaviour in the field of self-regulated learning, researchers have emphasized the need for a methodological framework to guide its application (e.g., Bannert et al., 2014). Yet, as mentioned above, no such framework has been proposed to date, hindering progress towards transparent methods, comparative studies and applications in ecologically valid contexts (e.g., Beach & Pedersen, 2013; Lupia & Alter, 2014). In this research project, we use computer log files and current directions in the measurement of self-regulated learning as a basis for investigating a methodological framework for learners' self-regulatory behaviour.

As described earlier, one of the key characteristics of self-regulation is the *cyclical* relationship among its components. Cleary, Callan, and Zimmerman (2012) also coined the similar term 'sequential phases of regulation'. The cyclical or sequential relationship between the components of self-regulated learning is reflected in 'event sequences' – patterns of learner behaviour observed in log file data. Both 'event' and 'sequence' are words that are often used in different fields of research to describe a variety of ordered events comprised in patterns (e.g., Abbott, 1995; Suthers & Verbert, 2013). In relation to self-regulated learning, however, the term 'event sequence' implies specific theoretical assumptions and methodological approaches. For example, a first distinction to be made between trace data types is whether the basic information they contain relates to a state or an event. Simply put, each change of state is an event, and each event implies a change of state (Müller, Studer, Gabadinho, & Ritschard, 2010). In log files, a state could be being on a page, while clicking the calendar tool in the online learning environment would be an event that changes the state to being on a different page. Log files are only able to capture events, as without triangulation we are unable to determine what learners are actually doing between two consecutive events (e.g., making coffee, reading, processing). Another distinction pertains to the logging of the order of events or states. If the order is logged, the data is sequenced; if not, it is conceived as an item set.

Once the event sequence data has been collected, it can be investigated in three main ways: pattern mining, pattern pruning and interactive visualization design (Liu, Dev, et al., 2016). Studies investigating differences in learner behaviour generally use pattern mining, defined as the identification of meaningful event sequences (patterns) (e.g., Azevedo et al., 2016; Bannert et al., 2015; Siadaty, Gašević, & Hatala, 2016b). The mining of patterns focuses on two dimensions: the order of the events and containment. When the order of events is preserved, the pattern is a sequential pattern. Sub-sequences in this respect are parts of a sequence whose elements also appear in the same order elsewhere. In other words, sub-sequences are unique sets of ordered events shared by a threshold number of learners. Containment relates to support for a sub-sequence in the sample and is the number (or percentage) of sub-sequences matching other learners' sub-sequences. A frequent sub-sequence is a sub-sequence that is present at least the threshold number of times among learners. Following the identification of sub-sequences, statistical trials can be performed to ascertain whether significant differences in the occurrence of sub-sequences can be linked to conditions internal or external to the learner. In short, containment is the identification of significant discriminant sub-sequences from the set of frequent sub-sequences based on an independent variable.

In conclusion, to be able to establish a methodological framework for investigating learners' self-regulatory behaviour, the steps in event sequence analysis will first need to be examined in terms of the assumptions made and challenges to be overcome, as well as their relation to current conceptualizations of self-regulated learning. Only by doing this will we be able to develop shared guidelines for analysing learners' self-regulatory behaviour in the future (e.g., Bannert et al., 2015).

Learners' learning outcomes and self-regulated learning

As the cognitive and metacognitive processes occurring in each of the phases of self-regulated learning cannot be observed directly, they must be observed through learners' overt behaviours and behavioural consequences (Veenman, 1993; Veenman, 2011, 2012; Veenman et al., 2006; Veenman et al., 2004). The goals imposed on learners and their instructional operationalization may result in learners' self-regulated learning and thus in a variety of learning outcomes (e.g., Endedijk et al., 2014). All too often, learning outcomes are seen at the same level as learners' performance on domain-knowledge-related aspects (Melton, 1997). However, as evidenced by literature, learning outcomes as learners' reaction to instructional interventions are much broader than changes in learners' domain knowledge (e.g., Adesope, Trevisan, & Sundararajan, 2017; Bardovi-Harlig, Mossman, & Vellenga, 2015). In the current research project, learning outcomes will therefore be defined as changes in learners' cognitive, motivational or metacognitive variables (e.g., Allan, 1996; Popham, Eisner, Sullivan, & Tyler, 1969).

Implications for research

The hypothesized conceptual framework views self-regulated learning as a cyclical process which can be observed through learners' learning behaviour and learning outcomes and is influenced by internal and external factors. Such a view poses concrete challenges in terms of how to operationalize the framework so that it may serve as a basis for investigating support for learners' self-regulated learning in blended learning environments.

A first challenge is the absence of a descriptive framework. No descriptive frameworks (or instruments) are available to describe blended learning environments designs before or after interventions with regard to support for self-regulated learning. In order to be able to investigate the impact of blended learning environment designs on learners' self-regulated learning, we will need an instrumentalized framework for describing support in blended learning environments for learners' self-regulated learning. A second challenge is the investigation of learners' self-regulated learning. Few methods are available for investigating learners' self-regulated learning through learners' learning behaviour and learning outcomes in ecologically valid settings. Therefore, to be able to capture self-regulated learning, a methodological framework for investigating self-regulated learning in ecologically valid settings also needs to be established. A third challenge is to operationalize the conceptual framework hypothesized for uncovering the relationship between the internal and external factors and self-regulatory behaviour. To be able to link learners' self-regulatory behaviour to internal and external factors, the two measurements (behaviour and internal/external factors) need to be applied with the appropriate grainsize, at the same time, and related to each other to achieve their maximal potential. Finally, the overall hypothesized framework needs to be investigated in ecologically valid settings. All instruments for the description of (1) internal and (2) external factors, (3) learners' self-regulatory behaviour, and (4) learning outcomes should be applied simultaneously to indicate the conceptual framework's potential for investigating support for learners' self-regulated learning in blended learning environments, with the ultimate aim of facilitating design guidelines in the future. In what follows, I elaborate on how these challenges are addressed in the research project.

Current research project

The current research project aims to provide a basis for investigating support for learners' self-regulated learning in blended learning environments, with the ultimate aim of facilitating the development of future design guidelines. It is not a monograph but a collection of seven studies that have been published or submitted. As a result, some overlap occurs between the theoretical background and methodology sections of the seven manuscripts and this general introduction. It is also important to note the order in which the manuscripts were produced: while the research steps were followed as described, the manuscripts were not necessarily written in the order in which they appear in this thesis. Figure 2 shows how the individual manuscripts have been arranged into sections and chapters for the purposes of this doctoral thesis.

Outline of the doctoral thesis

Based on the hypothesized conceptual framework, this doctoral thesis presents the research project in three phases (sections). Each of the phases addresses particular research questions (chapters). The first phase (Section 1) of the research project relates to the methodological challenges of operationalizing the conceptual framework. Both the investigation of internal and external factors influencing self-regulated learning and learners' self-regulatory behaviour have methodological challenges. The description of internal factors (i.e., learner variables) has a longstanding research tradition, whereas the description of blended learning environments for supporting self-regulation is relatively new. The same goes for the investigation of learners' self-regulated learning through learners' self-regulatory behaviour and learners' learning outcomes, in contrast to investigations which focus solely on learners' learning outcomes. First, seven attributes put forward in the literature as supporting learners' self-regulated learning in blended learning environments are identified (Chapter 1). Second, these attributes are used to propose an instrumentalized framework for the description of this support (Chapter 2). Next, based on the insights from the analysis of learners' self-regulatory behaviour a methodological framework for its analysis is proposed (Chapter 3). By operationalizing the conceptual framework, in the second phase (Section 2), the assumption that internal and external factors influence learners' self-regulated learning was investigated in two descriptive studies. On the one hand, the link between blended learning environment design (Chapter 4) and learners' self-regulatory behaviour was investigated. On the other hand, the link between learners' learning variables (Chapter 5) and learners' self-regulatory behaviour was studied. Following the validation, in Section 2, of the conceptual framework in terms of the relationships between factors influencing self-regulatory behaviour, two empirical studies were administered in the third and final phase (Section 3) with the aim of empirically investigating two of the attributes identified as inherent parts of the support for self-regulated learning in blended learning environments. The two attributes focussed on are cues for reflection and cues for calibration. These two attributes were chosen because of (1) their underexposure in the investigation of instruction for self-regulated learning (e.g., Ley & Young, 2001; Perry, Phillips, & Dowler, 2004), (2) the lack of literature focussing on learners' reflection and calibration for self-regulated learning in blended learning environments (Wang, Han, & Yang, 2015), and (3) the call from practice for the integration of cues for reflection and cues for calibration for self-regulated learning in blended learning practice (Spanjers, Könings, Leppink, & van Merriënboer, 2014). One study explored the effect of cues for reflection (Chapter 6) on learners' self-regulated learning through changes in learners' self-regulatory behaviour and learners' learning outcomes. The other study examined the effect of cues for calibration (Chapter 7) on learners' self-regulated learning, also operationalized through changes in learners' self-regulatory behaviour and learners' learning outcomes. The discussion and conclusions section of this doctoral thesis provides a general discussion of the results and presents the main findings. These findings are related to each other and to the conceptual framework proposed. Additionally, the conclusion reflects on new questions that arise from these findings and how future research could address these questions.

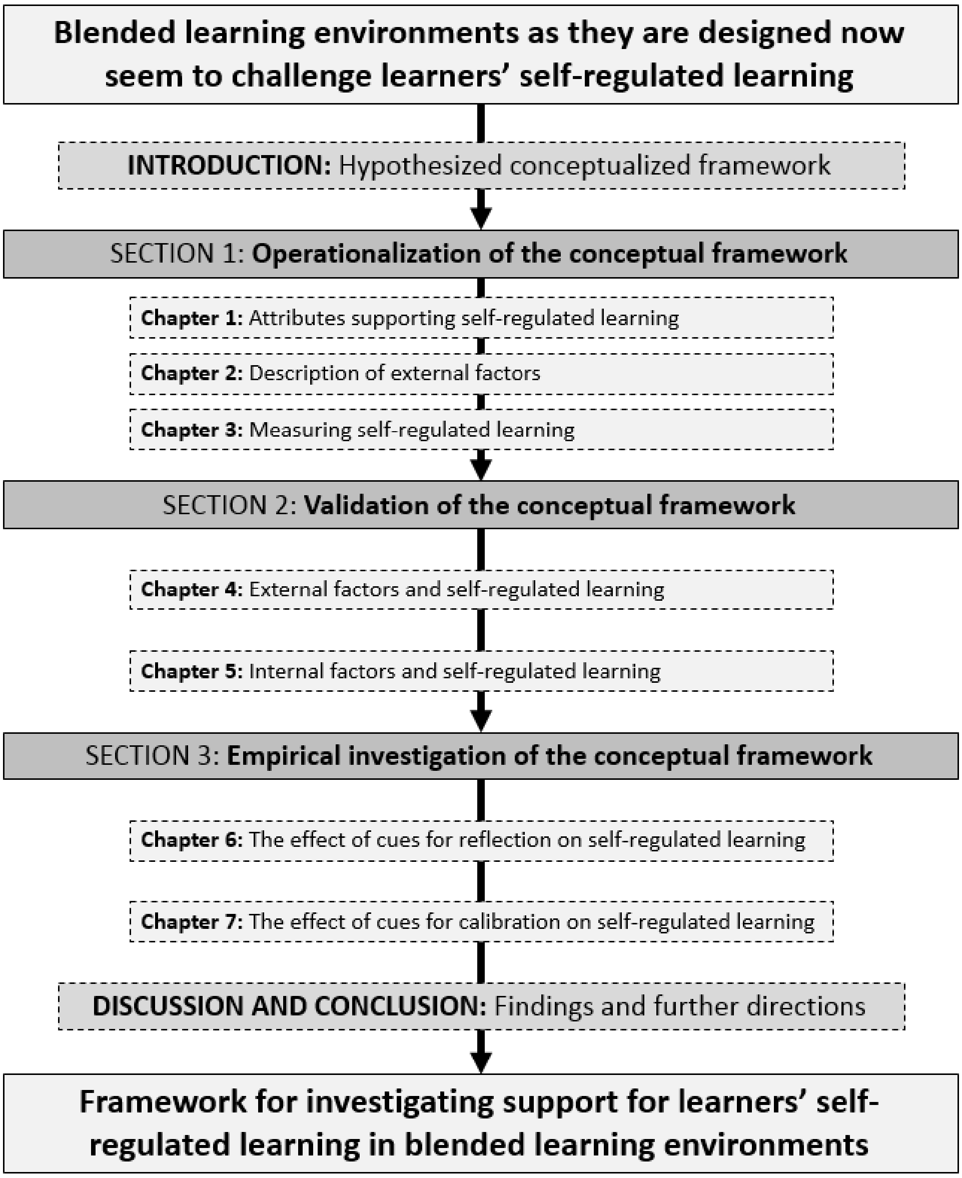

Figure 2. Visualization of the structure of the doctoral thesis.

Context of the research project

The seven studies presented here were carried out in three different and challenging contexts. The first context was second-chance adult education in Flanders, the northern region of Belgium. Here, the courses focused on basic statistical concepts (means, average, frequency, etc.) as part of a broad skill-set which would serve as a basis for later courses. The second context was a Bachelor-level course at a university in the Philippines. The subject of the course was business communication, focusing on the practical skills needed to be able to communicate in a business environment. The third context was a Bachelor-level course taught as part of an academic degree in Psychology and Pedagogical Sciences at a Flemish university. The course covered instructional psychology and technology and introduced educational research to the learners, thus functioning as a basis for further study.

The variety of both learners and subjects in these three contexts allowed us to validate the conceptual framework in different settings and to demonstrate its robustness. With regard to the research approach followed, we explicitly aimed to produce new insights, methods, theories and practices that would affect learning and teaching in ecologically valid settings (Barab & Squire, 2004). This approach helps us to develop new insights (i.e., the conceptual framework) that can be generalized to other contexts. Design-based research, as this approach might be called, is often used to investigate learning in environments that are designed and systematically changed by the researcher. It is a collection of approaches that involve a commitment to investigating learners' activity in naturalistic settings, with the goal of advancing theory while at the same time directly affecting practice (e.g., Barab, 2014; Kelly, Lesh, & Baek, 2014).

If we were to frame the research project in an ontological framework such as Pasteur's quadrant, it would become clear that most of the studies presented in this doctoral thesis involve research that integrates the contributions of rigorous, scientific research with the real-world, application-related concerns of educational practitioners. As such, the findings combine internal and ecological validity, and are practice-based as well as evidence-based (Smith, Schmidt, Edelen-Smith, & Cook, 2013). Chapter 7's investigation of the effect of cues for calibration on learners' self-regulatory behaviour and learning outcomes implies a shift towards the Bohr quadrant. This shift towards a stricter evidence-based practice enabled us to isolate the effect of the intervention and relate it to individual learner characteristics, thus producing a finer-grained picture of the impact of the interventions. Finally, as blended learning refers to learning that happens through the deliberate combination of online and face-to-face instruction, the hypothesized conceptual framework under investigation covers both the online and face-to-face components of blended learning environments. It should be noted, however, that the doctoral thesis itself focuses mainly on the online component of instruction.

SECTION ONE

Operationalization of the conceptual framework

Chapter One

Attributes supporting self-regulated learning

The text of this chapter was published as a review study in *Education and Information Technologies* [Van Laer, S., & Elen, J. (2017). In search of attributes that support self-regulation in blended learning environments. *Education and Information Technologies*, *22*(4), 1395-1454.]

Introduction

During the last two decades, we have seen a steep rise in computer- and web-based technologies, which has led to significant changes in education. Blended forms of learning have become increasingly popular (Garrison & Kanuka, 2004; Garrison & Vaughan, 2008; Graham, 2006; Spanjers et al., 2015). Learning activities within these blended environments are supported by a large variety of online and face-to-face instructional interventions. As a result of this, blended learning environments differ widely in the technologies used, the extent of integration of online and face-to-face instruction and the degree to which online activities are meant to replace face-to-face instruction (Smith & Kurthen, 2007). Despite their popularity, it remains unclear whether these environments are successful, and if they are, which attributes make them successful (Oliver & Trigwell, 2005). An important observation is that blended learning seems to be especially challenging for learners with lower self-regulatory abilities; but the opposite is also true: those who are able to regulate their own learning do well in these environments (Barnard, Lan, To, Paton, & Lai, 2009; Lynch & Dembo, 2004). However, it remains unclear why this is the case and what can be done to help struggling learners. This is problematic since educational research shows that the effectiveness of a learning environment depends on its design (Piccoli, Ahmad, & Ives, 2001), e.g., the nature of the tasks given to learners and the information provided to help them perform the learning activities (Smith & Ragan, 1999; Sweller, Van Merrienboer, & Paas, 1998). In order to design blended learning environments that support self-regulation and thus make learning more effective, we first need to determine the attributes of such environments. This paper therefore makes a first attempt to identify and define these attributes in the existing literature. After providing a brief overview of existing theories of self-regulation, we explain why the model we used as a framework to reflect upon the results of this review was most appropriate. Subsequently, we review the relevant literature, identify the attributes of effective blended learning environments, and define them. This definition is particularly challenging, firstly because an inductive or bottom-up approach was used in this systematic literature review (see: Hart, 2009; Joy, 2007); its aim was to identify attributes rather than validating them. Secondly, numerous studies have already noted (e.g., Petticrew & Roberts, 2008) that conceptual transparency is often lacking in intervention studies within learning and educational sciences. It is likely, then, that while the retrieved studies report on common attributes, they approach them from different perspectives. While this complicates the definition process, such definitions are nonetheless likely to make a key contribution when designing interventions aimed at particular attributes.

Learner variables influencing self-regulation

In this study, learning is seen as an activity performed by learners for themselves in a proactive manner, rather than as something that happens to them as results of instruction (Bandura, 1989; Benson, 2013; Knowles et al., 2014). Learning is therefore seen as a self-regulated process (Zimmerman & Schunk, 2001). This perception of the abilities of learners to regulate their learning originates from the social cognitive perspective (Bandura, 1977). Over the past three decades, various self-regulated learning theories have been grafted onto this perspective. Five main theories can be identified in the leading reviews written to date (e.g., Baumeister & Heatherton, 1996; Boekaerts, 1999; Boekaerts et al., 2005; Puustinen & Pulkkinen, 2001; Zimmerman & Schunk, 2001). These theories describe a cyclic process of self-regulatory phases, often consisting of (a) defining the task, (b) goal-setting and planning, (c) performance and (d) evaluation (e.g., Boekaerts' Model of Adaptable Learning (1992, 1995, 1996a, 1996b, 1997; Boekaerts et al., 2005) and Pintrich's General Framework for Self-regulation (Pintrich, 2000b; Pintrich & De Groot, 1990; Schunk et al., 2008)). In total, the five main theories also identify three categories of variables: (1) cognition (e.g., Zimmerman's cyclical Social Cognitive Model of Self-regulation (Zimmerman, 1986, 1990, 1998, 2000; Zimmerman & Pons, 1986)), (2) metacognition (e.g., Borkowski's Process-oriented Model of Metacognition (Borkowski et al., 1990; Pressley, Levin, & McDaniel, 1987)) and (3) motivation (e.g., Butler & Winne, 1995; Schraw, Crippen, & Hartley, 2006; Schraw & Moshman, 1995; Zimmerman, 2000).

Although no theory of self-regulation can be considered superior to any other, the Winne and Hadwin (1998) model was selected to facilitate the search for attributes of blended learning environment that support self-regulation since it has a number of characteristics that make it very suitable for the purpose of this study. These characteristics are outlined in more detail below. As the name suggests, Winne's Four-stage Model of Self-regulated Learning (Butler & Winne, 1995; Winne, 1995, 1996; Winne & Hadwin, 1998; Winne & Perry, 2000) describes four stages: (1) task definition, during which learners develop perceptions of the task concerned; (2) goal-setting and planning; (3) enacting the tactics and strategies chosen during goal-setting and planning; and (4) metacognitively adapting studying techniques, keeping future needs in mind. Each of these phases consists of five elements: Conditions, Operations, Procedures, Evaluations, and Standards (COPES). The theory emphasizes that learners whose teachers prompt more effective processing in stage one (task definition) and stage two (goal-setting and planning) are more likely to have accurate expectations of the task (Winne & Hadwin, 1998). At the second level, Winne and Hadwin (1998) describe the conditions that influence each of these phases. First, they provide information about the task conditions (e.g., time constraints, available resources and social context). Secondly, they outline the cognitive conditions (e.g., interest, goal orientation and task knowledge) that influence how the task will be engaged with (Winne & Hadwin, 1998). Cognitive conditions are influenced by epistemological beliefs, prior knowledge (all information stored in the long-term memory) and motivation (Winne & Hadwin, 1998).

As mentioned above, the Four-stage Model of Self-regulated Learning has four key characteristics that suit the purposes of this study very well. Firstly, the model looks beyond the focus on instructional stimuli and their effect on learning, assuming instead that all learners process the stimuli as intended (Winne, 1982). The authors see learners as active agents (Winne, 1982, 1985, 2006) or mediating factors in the instructional process, a perspective on instruction which is largely undocumented and needs consideration (Keller, 2010b; Winne, 1982). The model gives clear indications about which phases should be targeted, namely task definition followed by goal-setting and planning (Winne & Hadwin, 1998). A second consideration is that each phase (one to four) incorporates the COPES process, which when combined make up the cognitive system (Greene & Azevedo, 2007). This cognitive system explicitly models how work is done in each phase and allows for a more detailed look at how various aspects of the COPES architecture interact (Greene & Azevedo, 2007). Thirdly, with monitoring and control functioning as the key drivers of regulation within each phase, Winne and Hadwin's model can effectively describe how changes in one phase can lead to changes in other phases over the course of learning (Greene & Azevedo, 2007). This allows the model to explicitly detail the recursive nature of self-regulation (Greene & Azevedo, 2007). A fourth and final reason for this model’s suitability is that it separates task definition and goal-setting and planning into distinct phases, in contrast to the model of Pintrich (2000b) for example; this allows more pertinent questions to be asked about these phases than would otherwise be the case when focusing on instructional interventions (Greene & Azevedo, 2007; Winne & Marx, 1989). In this respect the systematic literature review presented here will focus on asking such questions and identifying the attributes of blended learning environments that are deliberately integrated into or added to the environment in order to support self-regulated learning (Zumbrunn, Tadlock, & Roberts, 2011).

Support in blended learning environments

This study focuses exclusively on blended learning environments. In their editorial for the *Journal of Educational Media*, Whitelock and Jelfs (2003) described three definitions of the concept of blended learning. These definitions were also used as a categorization by Graham (2006) in the handbook of blended learning, and by Ifenthaler (2010) in his book on learning and instruction in the digital age. The first definition (based on Harrison (2003)) views blended learning as the integrated combination of traditional learning with web-based online approaches (Bersin & others, 2003; Orey, 2002a, 2002b; Singh, Reed, & others, 2001; Thomson, 2002). The second one considers it a combination of media and tools employed in an e-learning environment (Reay, 2001; Rooney, 2003; Sands, 2002; Ward & LaBranche, 2003; Young, 2001) and the third one treats it as a combination of a number of didactic approaches, irrespective of the learning technology used (Driscoll, 2002; House, 2002; Rossett, 2002). Driscoll (2002, p. 1) concludes that “the point is that blended learning means different things to different people, which illustrates its widely untapped potential”. Oliver and Trigwell (2005) add that the term remains unclear and ill-defined. Taking these observations into account, the definition used in this study is as follows: “Blended learning is learning that happens in an instructional context which is characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning. Learning happening in purely online or purely classroom-based instructional settings is excluded” (Boelens et al., 2015).

A formal definition of learner support in blended learning environments does not yet seem to have been provided in research literature, although a considerable number of researchers (e.g., Kearsley & Moore, 1996; Keegan, 1996; Robinson, 1995; Tait, 2000; Thorpe, 2002) have made valuable contributions by defining similar concepts. Learner support in blended learning environments often refers to meeting the needs all learners have, choices at course level, preparatory tests, study skills, access to seminars and tutorials, and so on. These are elements in systems of learner support that many practitioners see as essential for the effective provision of blended learning (Kearsley & Moore, 1996; Keegan, 1996). Nonetheless Sewart (1993) notes that a review of key areas of the literature dating back to 1978 does not reveal any comprehensive analysis of learner support services (see also Robinson (1995)). It is therefore particularly challenging to address the issue of learner support in blended learning. Tait (2000) describes the central functions of learner support services in non-strictly face-to-face settings most fundamentally, arguing that it should be cognitive, affective, and systemic (Tait, 2000). In this study, ‘support’ refers to all measures taken to instigate and / or facilitate learning.

A final remark should be made regarding the term ‘learning outcome’. This term is often used in the same sense as learning objectives (Melton, 1997), but in our opinion this understanding is too narrow and too focused on an increase in performance. In this study, learning outcomes are defined as changes (due to support) in cognitive, metacognitive or motivational abilities, which together constitute a learner’s ability to self-regulate (e.g., Allan, 1996; Popham et al., 1969).

Problem statement

There is a growing realization that the precise design of blended learning environments has different impacts on learning for different types of learners. It has been suggested that blended learning makes high demands of learners’ self-regulatory abilities and is therefore a major challenge for those with lower self-regulatory abilities. The opposite is also true: blended learning environments are well suited to learners who work well in environments with e.g., a lot of learner control. We do not yet know why this is the case or what a solution might be for learners who struggle. In particular, little is known about the attributes of blended learning environments that are essential to support learners and how they should guide course design. Winne and Marx (1989) and Keller (2010a) have called for an approach to course design in blended learning that centres more closely around supporting self-regulation. As a consequence, the research question addressed in this systematic literature review is: "What attributes of blended learning environments support learners' self-regulation?" In answering this research question, we identify the attributes of blended learning environments that support self-regulation and define them. On the one hand, this facilitates the design of blended learning environments that meet learners' self-regulatory needs. On the other hand, it also contributes to research in the field of ICT and education by shifting the focus towards learners' self-regulation in technology-mediated environments.

Method

The methodological approach used to answer the research question was based both on research literature on systematic literature reviews (e.g., Hart, 2009; Joy, 2007) and on the methodologies used in highly valued educational reviews with similar methodological aims (e.g., Bernard et al., 2004; Blok, Oostdam, Otter, & Overmaat, 2002; Butler & Winne, 1995; De Jong & Van Joolingen, 1998; Greene & Azevedo, 2007; Tallent-Runnels et al., 2006; Tinto, 1975). The systematic literature review methodology is particularly suited to the aim of this study, because it focuses on the identification, critical evaluation and integration of findings from a considerable number of relevant resources (Baumeister & Leary, 1997). Using this methodology allows us to formulate general statements and overarching conceptualizations (Sternberg, 1991). Although this methodology is most appropriate for the aim of this study, it also has its limitations. Higgins and Green (2008) described the main issues as follows: they argue, firstly, that because such a methodology allows us to target broader research questions, it inevitably restricts the depth of analysis; and secondly, that categorizing findings across the retrieved articles puts pressure on the replicability and transparency of the methodology. As elaborated on below, we propose a peer-reviewed and double-checked bibliographical approach in order to ensure transparency and replicability. As the focus of this study is to identify and define attributes, rather than exploring each attribute in detail, the depth issue is less of a threat. Nonetheless, we propose further research avenues for elaborating on each of the attributes.

By comparing the studies on the systematic literature review methodology, it could be observed that most of the reviews suggest a similar design as presented by Hart (2009). His methodological outline and suggestions will be therefore used to perform the systematic literature review. First, general searches for background information on the study's main concepts were performed. This resulted in an initial map of related topics, a vocabulary of concepts and a provisional list of key authors. The findings of this phase were reported in the introduction of the systematic literature review and functions as a theoretical basis to reflect upon the results of this study. On the other hand, the focus on the topics to be analysed and the identification of information needs regarding the topic was established, resulting in a clear research question. This research question was reported during the problem statement. To answer this research question relevant data was collected and analysed. These procedures will be described below.

Data collection

To establish a collection of publications to be analysed and synthesized, relevant databases for retrieving publications on instruction and information (and communication) technology were identified (n=5): Web of Science, ProQuest, EBSCOhost, Science Direct, and OvidSP. The search terms used to perform the searches derived from a deductive process based on the key concepts of this study as presented in the introduction. The following search string was used: ("blended learning" OR "online learning" OR "hybrid learning" OR "web based learning" OR "distance learning" OR "virtual learning") AND design AND (low OR poor OR inadequate OR negative) AND self-regulat* AND ("prior knowledge" OR "cognitive strategies" OR "learning strategies" OR "motivation") AND (problem* OR solution* OR effects OR issues OR explain*) AND ("adult learner" OR "adult learning" OR postgraduate OR post-graduate OR postsecondary OR post-secondary) NOT (kindergarten OR "primary education" OR "secondary education" OR under-graduate OR undergraduate OR "K-12" OR elementary). A number of additional inclusion and exclusion criteria were specified to select appropriate publications for inclusion in the systematic literature review. To be included in the review, publications had to (a) have been published between January 1985 and February 2015, (b) have no duplicates, (c) include full text, (d) include empirical evidence (research based on, concerned with, or verifiable by observation or experience rather than theory or pure logic (see: Barratt (1971); Mouly (1978)) relating to the impacts and outcomes of blended learning environments; this was to address the perceived lack of empirical evidence concerning blended learning. Finally, publications had to (e) include performance measures that reflected individual courses (micro level) or learning tasks, rather than entire programmes.

Data analysis

Following the suggestion of Hart (2009), the publications were first skimmed for structure, overall topic, style, general reasoning, data and bibliographical references. A second more detailed survey followed of the sections of each publication (introduction, theoretical foundations, methodology, etc.). The third step included the creation of a summary of each publication retrieved. This was to ensure the preservation of the rich data and context of each publication. A minimally condensed version of this summary can be found in Appendix 1. The summary includes: (a) the aim of each publication, (b) the dependent and independent variables, (c) the sample (including the characteristics of the participants), (d) the procedure or method used, (e) the measurement instrument(s) used and (f) the results and conclusions. This analysis was performed and managed in QSR NVIVO 10 and summarized in MS Word and Excel documents. Based on this third step, the analysis for common attributes was performed by comparing the different variables, results, and conclusions with one another. Once the attributes were identified, a twofold (peer-reviewed by the other author), double check (manual versus bibliometric (Cheng et al., 2014) to ensure inter-coder reliability) was performed to ensure that the attributes identified when synthesizing the summaries were found by both researchers individually and explicitly retrieved in the consulted publications. Thus, both researchers synthesized a sample of the summaries and compared their findings. A text search query was also used to check whether the attributes identified by analysing the summaries were also found explicitly in the retrieved publications (see for detailed methodology: Cheng et al. (2014); Graddol, Maybin, and Stierer (1994); Popping (2000); Romero and Ventura (2007); Wegerif and Mercer (1997)). Finally, based on the identification of the common attributes and the publications that refer explicitly to these attributes, a detailed analysis of the publications involved was done to determine what decisions and conclusions could be drawn from these publications. The results of this analysis can be found in the results section.

Results

Using the search string mentioned above, an initial search was performed per database, on title and abstract. In total, 247 publications were retained and imported into Endnote X7. A search for overlap or duplicates was done. The publications retrieved first were retained and the duplicate removed from the database. A total of seventeen publications were deleted and 230 publications retained. The last step was the automatic search, performed in Endnote X7, for the full texts of each abstract. A total of 88 publications were removed from the database due to a lack of full text. The remaining 142 publications were imported into QSR NVivo 10 for further analysis. All 142 publications were scanned for general relevance and empirical evidence. Reviews (n=30) and irrelevant publications (n=17) (see for example: “Community based forest enterprises in Britain: Two organizing typologies” by Ambrose-Oji, Lawrence, and Stewart (2014)) were excluded. This brought the number of publications included to 95. No publications were excluded based on (d) the level of focus (course or curriculum): all the publications retrieved reported on course level.

Descriptive statistics of the publications included

General descriptive statistics say something about the field of blended learning and the inclusion of self-regulation in the discourse. The search included all publications from between January 1985 and February 2015. It is noteworthy that no publications were retrieved from the period 1985 to 2001. Between 2002 and 2009 an annual average of four publications were published relating to the search results of this systematic literature review. Between 2010 and February 2015, an average of eleven publications was published per year. The descriptive results of the systematic literature review also show which journals the majority of retrieved publications originated from. The largest proportion of publications were retrieved from *Computers & Education* (n=19); *Computers in Human Behaviour* produced thirteen publications, followed by *The Internet & Higher Education* (n=10), the *International Journal of Human-Computer Studies* (n=4), *Nurse Education Today* (n=3), *Learning & Instruction* (n=3), *Higher Education* (n=2), *Journal of Computing in Higher Education* (n=2) and the *International Journal of Educational Research* (n=2). These journals accounted for 61% of all the retrieved publications. In total, 61 of the retrieved publications were quantitative; 33 included experimental interventions with pre- and post-tests in controlled conditions; 23 retrieved information using surveys; and 5 reported on quasi-experiments (e.g., no pre- or post-tests). Finally, 13 publications were qualitative in nature and used case studies (n=5), observations (n=1), document analysis (n=2) or interviews (n=5) as their method. In the mixed-method combinations of quasi-experiments and interviews, observations and document analysis were used (n=13). Table 1 shows the number of publications retrieved by type of research and methodology used. The publications retrieved were also analysed by the learning variables taken into account. The majority of the publications (n=57) reported on a mix of learning variables (cognition, metacognition and motivation); 30 publications reported on individual variables. Table 2 shows the number of publications retrieved by learner variable. Both the methodological data and the variables used can be found in the individual summaries presented in Appendix 1.

Table 1

Number of publications retrieved by type of research and methodology used.

Type of research (n=87)	*Quantitative methods*	61		
			Experiment	33
			Quasi-experiment	5
			Survey	23
	Qualitative methods	13		
			Case study	5
			Observation	1
			Document analysis	2
			Interview	5
	Mixed methods	13		

* Eight exclusions were made due to a lack of explicit reference to attributes.

Table 2

Number of publications retrieved by learner variables used.

Learner variables (n=87)	Cognition, metacognition and motivation	15
	Cognition and metacognition	14
	Metacognition and motivation	20
	Cognition and motivation	8
	Cognition	12
	Metacognition	7
	Motivation	11

* Eight exclusions were made due to a lack of explicit reference to attributes.

Attributes of blended learning for self-regulation

As mentioned above, after analysing the publications' descriptive features and learner variables (cognitive, metacognitive, and motivational) a search was performed to identify common attributes of interest in the retrieved publications. Once the attributes were identified, a twofold (peer-reviewed), double check (manual versus bibliometric) was performed to ensure that the attributes identified when synthesizing the summaries were found by both researchers individually and explicitly retrieved in the consulted publications.

The systematic literature review presented here suggests that blended learning environments that foster cognition, metacognition, and motivation and thus support self-regulation have seven main attributes. These attributes are (1) authenticity, (2) personalization, (3) learner control, (4) scaffolding, (5) interaction, (6) reflection cues, and finally (7) calibration cues. Table 3 shows the number of publications retrieved per attribute: 87 reported on at least one attribute (eight were excluded due to a lack of explicit reference to at least one attribute). It is important to note that 59 articles reported on at least two attributes, with a maximum of six attributes per publication. This illustrates the interrelatedness of each attribute with the others. The summaries in Appendix 1 report on the attributes identified in each of the publications. Based on these findings the relevant publications were synthesized in more depth. Each attribute is elaborated on in more detail below.

Table 3

Number of publications retrieved per attribute.

Attributes	Authenticity	29
	Personalization	24
	Learner-control	18
	Scaffolding	24
	Interaction	70
	Reflection	19
	Calibration	15

Authenticity

In total, 29 publications appear to centre around authenticity (e.g., Ai-Lim Lee, Wong, & Fung, 2010; Artino, 2009b; Chen, 2014; Corbalan, Kester, & van Merriënboer, 2008; Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008; Donnelly, 2010; Gulikers, Bastiaens, & Martens, 2005; Smith, Craig, Weir, & McAlpine, 2008; Ting, 2013) and report its influence on cognitive (e.g., Corbalan et al., 2008; Gulikers et al., 2005), metacognitive (e.g., Chen, 2014; Kuo, Hwang, & Lee, 2012) and motivational (e.g., Kovačević, Minović, Milovanović, de Pablos, & Starčević, 2013; Sansone, Fraughton, Zachary, Butner, & Heiner, 2011; Siampou, Komis, & Tselios, 2014) variables that influence the self-regulatory abilities of learners. The retrieved publications contained several definitions of authenticity, ranging from 'real-world relevance' and 'needed in real-life situations' to 'of important interest to the learner for later professional. In sum, authenticity was treated as the real-world relevance, to the learners' professional and personal lives, of the learning experience. It was described as being manifested in both the learning environment and the task at hand.

The majority of publications retrieved referred to the motivational value of authentic learning tasks. In this respect Ai-Lim Lee et al. (2010) used a survey study and Kovačević et al. (2013) an experimental design to conclude that authentic tasks in an educational context are associated with finding meaning and relevance and therefore associated with higher motivation. In their survey study, Sansone et al. (2011) add that when learners have little pre-existing interest or motivation, tasks that practise skills needed in real-life situations were more motivating. An example is provided in the interview study of Smith et al. (2008), who report that learners wanted to be involved in education as long it proved to have a practical application and relevance to their professional background.

On the metacognitive side, a survey study included in the experimental study of Chen (2014) and Kuo et al. (2012) found that authentic digital learning materials significantly influenced learners' perceptions of learning outcome expectations, learning gratification and learning climate in web-based learning environments. Wesiak et al. (2014) conducted an experiment and analysed log-files of learners. They add to the previous findings that real-world relevance in an online medical simulation improved metacognitive skills. Taken together, these findings suggest that authentic tasks influence cognitive (e.g., prior knowledge and performance), metacognitive (e.g., learning outcome expectations) and motivational (e.g., enjoyment, intrinsic motivation) learner variables, which in turn influence the self-regulatory abilities of learners. However, Gulikers et al. (2005) conducted an experiment and emphasized that authentic tasks and authentic contexts are two different things and have different impacts on learning (no evidence was found for the superiority of authentic environments). Corbalan et al. (2008) analysed log-files during an experiment and added to this that for novice learners, the acquisition of complex skills by performing authentic tasks is heavily constrained by the limited processing capacity of their working memory and that such tasks can cause cognitive overload and should therefore be adapted to the individual needs of learners.

Personalization

We identified 24 publications which address personalization (e.g., Hung & Hyun, 2010; Law & Sun, 2012; Leen & Lang, 2013; Liaw, Hatala, & Huang, 2010; Ma, 2012; Reichelt, Kämmerer, Niegemann, & Zander, 2014; Yu, Chen, Yang, Wang, & Yen, 2007). In these publications, personalization is defined as non-homogenous experiences related directly to the tailoring of the learning environment (both the characteristics and objects) to the inherent needs of each individual learner (topics of high interest value). Examples include elements of name recognition or the integration of name-specific references to the learner, self-description or tailoring of the environment to the individual preferences (content, subject, etc.) of the learner and cognitive-situationing or adapting the environment to the performance level of the learner.

Some of the retrieved publications report on interventions carried out to identify the effect of personalization on a mix of learner variables, whereby Reichelt et al. (2014), using a quasi-experimental set-up including document analysis, and Leen and Lang (2013), using a survey study, found that personalized learning materials, a good fit of learning contexts integrating the personal preferences of the learners and communicative features expressed in a personalized style contribute to enhanced motivation and learning, seem to engage learners in learning processes and provide learning success. Accordingly Ai-Lim Lee et al. (2010) investigated the influence of a desktop virtual reality application's constructivist learning characteristics on learning outcomes. During this investigation, they found that options regarding individual preferences relate positively to learning effectiveness and satisfaction.

Other publications reported more generally on the nature of blended learning environments and their suitability with regard to a range of learner variables. Liaw et al. (2010); Ma (2012); Mohammadi (2015); Yu et al. (2007) used survey studies and interviews to evaluate the feasibility of e-learning for continuing education and concluded that diversity, flexibility, adaptability and individualization are catalysts for increasing motivation, user satisfaction, intention to use e-learning and regulating abilities. Law and Sun (2012) did the same with regard to a digital educational game. Here, too, adaptability (to personal preferences) was seen as an influencing factor for the user experience. Although the literature retrieved seems to find a positive influence of personalization on metacognitive and motivational learner variables (e.g., Liaw et al., 2010; Mohammadi, 2015; Yu et al., 2007) personalization itself had no straightforward effect on learning performance (Ai-Lim Lee et al., 2010; Reichelt et al., 2014).

Learner control

In total, 18 publications refer to the amount of control learners have in blended learning environments (e.g., Artino, 2009a, 2009b; Corbalan et al., 2008; Hughes et al., 2013; Hung, Huang, & Yu, 2011; Leen & Lang, 2013; Lin, Fernandez, & Gregor, 2012; Mohammadi, 2015; Reychav & Wu, 2015; Roca, Chiu, & Martínez, 2006; Ting, 2013; Yu et al., 2007). These publications consider learner control to be an inclusive concept that describes the degree of control that learners have over the content and activities within the learning environment. Examples include control over the pace of the course, the content used, learning activities in which the content is presented and content sequencing which allows the learner to determine the order in which the content is provided.

Corbalan et al. (2008) and Hughes et al. (2013) found in their experimental studies, including log-file analysis that shared (learner and instructor) control has positive effects on learner motivation, and that the choice provided positively influenced the amount of effort invested in learning, combined with higher learning outcomes. In his survey study, Artino (2009b) provided evidence for the positive predictive ability of the task learners choose (rehearsal vs in-depth) on elaboration, metacognition, satisfaction and continuing motivation. During their survey study, Lin et al. (2012) found that the higher the level of control and learning afforded by a virtual-reality-based learning environment, the better the learning outcomes as measured by performance achievement, perceived learning effectiveness and satisfaction would be. While learner control seems to influence cognition (Ai-Lim Lee et al., 2010), metacognition (Artino, 2009b) and motivation (Lin et al., 2012) this influence is not unfailingly positive.

Some remarks are made in the publications retrieved. Corbalan et al. (2008) found that learners with lower levels of competence in a domain lack the ability to make productive use of learner control; Artino (2009a) observed, in his survey study on how feelings, and actions are associated with the nature of an online course that a lack of control on the part of the learner results in boredom and frustration. Leen and Lang (2013) found that older adults had a strong need for a sense of belonging and personal growth, and thus a heightened interest in learner control, whereas younger adults' motives for learning were more competition-related. Learners with a high need for control might tend to adopt e-learning quickly, whereas learners with low self-control abilities tend to reject e-learning (Yu et al., 2007). For individuals with lower self-control abilities, it seems essential to establish user-friendly learning environments in the early stages of development (Yu et al., 2007). Hung and Hyun (2010) conclude as a result of their interview study that learners with low prior knowledge require a learning context provided by the instructors to sustain the learning experience.

Scaffolding

The search produced 24 publications related to scaffolding in blended learning environments (e.g., Aleven & Koedinger, 2002; Artino & Jones, 2012; Artino & Stephens, 2009; Chia-Wen, Pei-Di, & Meng-Chuan, 2011; Davis & Yi, 2012; Demetriadis et al., 2008; Govaere, de Kruif, & Valcke, 2012; Kim & Ryu, 2013; Koh & Chai, 2014; Kuo et al., 2012; Niemi, Nevgi, & Virtanen, 2003; Wesiak et al., 2014). These publications define scaffolding as changes in the task or learning environment that assist learners in accomplishing tasks that would otherwise have been beyond their reach. This could involve ongoing diagnosis of the amount of support learners need and the provision of tailored support based on the results of this ongoing diagnosis, both of which result in a decrease in support over time.

Some of the retrieved publications report on interventions done to identify the effect of scaffolding on cognition, metacognition, and motivation. Wesiak et al. (2014), for example, found clear indications that the addition of thinking prompts provided by scaffolding services is beneficial to learners, who reported an increasing amount of effort in terms of time spent. These findings imply a positive effect of the refinements of thinking prompts and/or affective element added. This supports the assumption that scaffolding support fosters metacognition and reflection. Aleven and Koedinger (2002) conducted an experiment and concluded that scaffolding of problem-solving practice, using self-explanation, with a computer-based cognitive scaffolding tutor was an effective tool for the support of the acquisition of metacognitive problem-solving strategies and that guided self-explanation adds value to guided problem-solving practice without self-explanation. Demetriadis et al. (2008) and Govaere et al. (2012) found, using an experimental set-up, that learners in a scaffolded group achieved significantly higher scores, which indicates that explicitly asking scaffolding questions to activate learners has positive effects. Accordingly, Kim and Ryu (2013) showed that, during the assessment of a web-based formative peer assessment system, learners using such a system achieved significantly higher scores for metacognitive awareness. Devised questions, prompts, and peer interaction as scaffolding strategies are shown to facilitate metacognitive skills.

Artino and Stephens (2009), on the other hand, used a survey to investigate the potential developmental difference in self-regulated learning and come up with instructional guidelines to overcome these differences. They suggest that scaffolding for the support of self-regulated learning in online learning environments should ideally be achieved by explicitly providing instructional support, structure, and scaffolds of social interaction. Artino and Jones (2012) articulated the benefits of attending to learners' achievement emotions in structuring online learning environments. This way, learning and performance are improved by facilitating learners' use of adaptive self-regulatory learning strategies. Yu et al. (2007) emphasized, in their investigation of the feasibility of the adaption of e-learning for continuing education, that for learners with lower self-regulatory abilities it is essential to scaffold support around strategies of behaviour modification, to increase learners' confidence and self-regulatory abilities while maintaining their participation and improving the learning effect.

Interaction

We retained 70 publications that appear to centre around interaction (e.g., Alant & Dada, 2005; Chen, 2014; Clark, Draper, & Rogers, 2015; DuBois, Dueker, Anderson, & Campbell, 2008; Gomez, Wu, & Passerini, 2010; Ho & Dzeng, 2010; Liaw et al., 2010; Lin et al., 2012; Ma, 2012; Siampou et al., 2014; Ting, 2013; Xie, Miller, & Allison, 2013). These publications describe interaction as the involvement of learners with elements in the learning environment, including content (learning materials, object, etc.), the instructor (teacher, coach, trainer, etc.), other learners (peers, colleagues, etc.) and the interface (objects in the online or offline learning environment).

Some of the publications retrieved report on the positive influence of social interaction on self-regulation, whereby Ting (2013) and Reichelt et al. (2014) found in their experiments that communicative features, peer interaction and back-feedback gave learners more control over their learning. Kuo et al. (2012) emphasized in this respect that the method of the integration of collaborative learning mechanisms within an online inquiry-based learning environment has great potential to promote middle- and low-achievement learners' problem-solving ability and learning attitudes. Michinov and Michinov (2007) add to this that paying closer attention to social interaction is particularly useful during transition periods at the midpoint of an online collaborative activity. Liaw et al. (2010) found during a survey study that enriching interaction and communication activities have a significant positive influence on the acceptance of mobile-learning systems. Siampou et al. (2014) investigated whether the type of interaction influences the learners' modelling processes. Their results suggest that the online dyads focused extensively on the analysis and synthesis actions and their learning was higher than their offline counterparts. Lin et al. (2012) identified in a correlation study that the establishment of social interaction to promote intrinsic motivation increased positive affect and fulfilment in web-based environments. Ai-Lim Lee et al. (2010) found that interaction with the desktop virtual reality application only impacted learning effectiveness (positively). Gomez et al. (2010) emphasize the interaction between motivation and social interaction and perceived learning, concluding that when learners value these social interactions, they will enjoy learning more.

Other publications report on the negative influence of the lack of social interaction on a mix of learner variables. Artino (2009a) and DuBois et al. (2008) observed using an experiment that a lack of interaction results in a decrease in engagement and satisfaction and an increase in dropout risk. In summary, it can be observed that the publications retrieved report positively on the influence of social interaction for increasing cognitive (e.g., Siampou et al., 2014), metacognitive (e.g., Kuo et al., 2012) and motivational e.g., Lin et al. (2012) learner variables. A negative influence is seen with regard to motivation when there is a lack of social interaction.

Reflection

In total, 14 publications appear to focus on cues that increase the reflective practice of learners in blended learning environments (e.g., Aleven & Koedinger, 2002; Anseel, Lievens, & Schollaert, 2009; Ibabe & Jauregizar, 2010; Kim & Ryu, 2013; Martens, de Brabander, Rozendaal, Boekaerts, & van der Leeden, 2010; Mauroux, Konings, Zufferey, & Gurtner, 2014). Reflection cues are defined in these publications as prompts that aim to activate learners' purposeful critical analysis of knowledge and experience, in order to achieve deeper meaning and understanding. The publications describe three main types: first, reflection during action, which takes place while learners are performing a task; second, reflection about action, which is systematic and deliberate consideration of a task that has already been completed; and third, reflection before action, which involves proactive thinking about a task, which will soon be performed.

There is some evidence that reflection can be used to increase learner motivation, especially when learners are in a state of low motivation to learn (Ibabe & Jauregizar, 2010). The majority of evidence supporting the influence of reflection on self-regulation-influencing variables relates to cognitive learner variables. Anseel et al. (2009) concluded, in their investigation of reflection as a strategy for enhanced task performance, that reflection combined with feedback has a more positive impact than feedback alone on task performance. Ai-Lim Lee et al. (2010) and Aleven and Koedinger (2002), who used experiments, added to this that engaging learners in reflective thinking is a significant antecedent to learning outcomes and that engaging them in explanation helps learners acquire better-integrated knowledge.

In addition, a substantial number of publications were found that focus on metacognitive variables. Kim and Ryu (2013), for example, found that peer interaction and back-feedback gave learners more control over their learning; these learners scored significantly higher for metacognitive awareness and performance than the traditional peer assessment group, who in turn achieved higher scores for metacognitive awareness than a self-assessment group who received no peer interaction or back-feedback. Based on a survey study, Niemi et al. (2003) suggested that young learners gain new information about their learning strategies and skills through negotiation with peers and that this negotiation also helps more experienced learners strengthen their learning.

In summary, the publications retrieved report positively on the influence of reflection on cognitive (e.g., Anseel et al., 2009), metacognitive (e.g., Kim & Ryu, 2013) and motivational (e.g., Ibabe & Jauregizar, 2010) learner variables. Anseel et al. (2009) emphasize that learners' levels of learning goal orientation, need for cognition and personal importance affect the extent to which individuals engage in reflection positively. Ibabe and Jauregizar (2010) and Mauroux et al. (2014) supplement this claim with the finding that when learners have low levels of motivation and acceptance of reflection, the only type of reflection tool they will use are self-assessment tools.

Calibration

The search identified 15 publications which appear to centre around cues for calibration in blended learning environments (e.g., Anseel et al., 2009; Artino, 2009a; Artino & Stephens, 2009; Brusso & Orvis, 2013). These publications describe calibration cues as triggers for learners to test their perceptions of achievement against their actual achievement. They are used both to overcome deviations in learner's judgements from the facts by introducing notions of bias and also to address metric issues regarding the validity of cues' contributions to judgements. Two main types of calibration cues were identified in the publications retrieved: prompts that aim to trigger metacognitive monitoring, such as reviewing content, and secondly, checklists and timed alerts to summarize content and practice tests to help learners compare their own perceptions and the facts.

Using an experimental design Vighnarajah, Luan, and Abu Bakar (2009) found that learners reported practising different self-regulated learning strategies (intrinsic and extrinsic goal orientation, control of learning beliefs, rehearsal, elaboration, critical thinking, peer learning, and help seeking). The strategies that interested learners the least were task value, effort regulation, and metacognitive self-regulation. Artino (2009a) illustrated the importance of learner goal-setting by showing that learners with career aspirations directly related to the course content would be more likely to report adaptive motivation and academic success than their peers. Using a survey study, Brusso and Orvis (2013) found that learners who experienced a larger goal-performance discrepancy at the beginning of a course performed worse in the subsequent sessions than those whose performance more closely mirrored their goals. The two survey studies conducted by Brusso and Orvis (2013) and Anseel et al. (2009) suggest that a combination of reflection interventions and goal-setting instructions (looking back on past behaviour by means of coached reflection and managing future behaviour by setting goals) appears to be a particularly strong intervention. Artino and Stephens (2009) illustrate this by presenting two instructional strategies for helping learners identify and set challenging, proximal goals and for providing them with timely, honest, explicit performance feedback.

Despite the moderate number of publications retrieved, the evidence indicates the importance of helping learners make a reasonable estimation of the instructors' expectations and their own capabilities. The studies call for appropriate cues for task definition, goal-setting and planning in order to influence the cognitive (e.g., Brusso & Orvis, 2013) metacognitive (e.g.,Artino & Stephens, 2009) and motivational (e.g., Artino, 2009a) learning variables that in turn influence self-regulation.

Conclusions and discussion

The aim of this systematic literature review was to identify attributes of blended learning environments that support self-regulation. An inductive or bottom-up approach was used. Following the initial literature analysis, seven attributes were identified and defined. First, authenticity was defined as the real-world relevance of the learning experience (both task and learning environment) to learners' professional and personal lives. Secondly, personalization was defined as non-homogenous experiences related directly to the tailoring of the learning environment (name recognition, self-description, and cognitive situationing) to the inherent needs of each individual learner. Third, learner control was defined as an inclusive concept, which describes the degree to which learners have control over the content and activities (pace, content, learning activities and sequencing) within the learning environment. Fourth, scaffolding was defined as changes in the task or learning environment (support that diminished over time) which assist learners in accomplishing tasks that would otherwise be beyond their reach. Fifth, interaction was described as learners' involvement with elements in the learning environment (content, instructor, other learners, and interface). Sixth, reflection cues were defined as prompts that aim to activate learners' purposeful critical analysis of knowledge and experience (before, during, and after), in order to achieve deeper meaning and understanding. Finally, calibration cues were described as triggers for learners (forms, timed alerts, and practice tests) to test their perceptions of achievement against their actual achievement and their perceived use of study tactics against their actual use of study tactics.

While this systematic literature review has attempted to identify and define the seven attributes as clearly as possible, it remains unclear what the exact relationship is between each attribute and the self-regulatory behaviour exhibited by learners. It is beyond the scope of this review to address this problem directly. In what follows, however, we make a first attempt to explain the relevance of each attribute using the Four-stage Model of Self-regulated Learning developed by Winne and Hadwin (1998). As mentioned earlier, it is the first two phases of this model – task definition and goal-setting and planning – that are most susceptible to instruction, so the main focus will lie on these two phases (Butler & Winne, 1995; Winne & Hadwin, 1998; Zimmerman, 2000).

Attributes and their relation to the Four-stage Model of Self-regulated Learning

In promoting self-regulation, both constructivist and sociocultural theories stress the importance of building on learners' existing knowledge and skills (Harris & Pressley, 1991; Vygotsky, 1978). It has been argued that, rather than providing direct instruction about predefined strategies, teachers should provide support that assists learners to self-regulate their own learning effectively (Butler, 1998; Palincsar & Brown, 1988). Based on this premise, a search for attributes that support self-regulation in blended learning environments was performed. Authenticity and personalization in the environment seem to contextualize and individualize the conditions and standards needed to make appropriate judgements about the task at hand and thus direct goal-setting and planning. Both authenticity and personalization support learners in situating the task in a realistic, familiar context and tailor it to the general preferences of the learner. In doing so, the environment takes into account the cognition, metacognition and motivation of the learners and supports the identification of conditions (how the task at hand will be approached) and standards (criteria against which products will be evaluated) (Butler, 2002; Reeve & Brown, 1985). It is worth bearing in mind, however, that when learners have had negative prior experiences, they will judge the conditions and standards less accurately (Lodewyk, Winne, & Jamieson-Noel, 2009). Similarly, learner control and scaffolding seem to help learners maximize their degree of control over their own learning and evaluate their learning (comparing standards) more accurately (Perry, 1998; Perry et al., 2004) and thus set goals that are more appropriate and plan further actions. As the learners are allowed to choose how to learn more freely, and as the support provided is tailored and reduced over time, learners experience how products should be evaluated according to the standards they set themselves and thus how to maximize self-regulation. The relation between learner control and scaffolding is worth mentioning, because when learners have low self-regulatory skills, for example, a high degree of learner control in the environment will leave them wandering aimlessly unless they are supported by scaffolds that gradually disappear over time (Lynch & Dembo, 2004). Interaction and cues for reflection expose learners to the various procedures available (e.g., through social interaction, reflection questions, etc.), providing them with self-initiated feedback about their own performance and helping them to select appropriate procedures for tackling the task at hand (Kumar, Gress, Hadwin, & Winne, 2010). This supports learners in identifying the procedures needed to define and execute the task, which influences their planning of the actual performance. While reflection and interaction support practice retrospectively, they do not have an impact on faulty calibration mechanisms. Cues for calibration therefore need to be put in place to make learners with low self-regulatory abilities aware of such problems. Cues for calibration help learners assess their performance correctly and compare it to the standards they initially set and act upon any perceived deficit (Hadwin & Winne, 2001). Involving learners in processes of external feedback (e.g., by taking tests) will provide them with a realistic framework against which to compare themselves (Winne & Jamieson-Noel, 2002).

The attributes and their relation to current learning theories

To consolidate the relevance of the attributes identified for the design of blended learning environment, they were also tested against other well-established learning theories and instructional design models, with positive results. While conceptual transparency is sometimes lacking within and between these models, our results bear striking similarities to the Four Component Instructional Design model of van Merriënboer (1997), which focuses on task execution support. Van Merriënboer's model states that learners will be able to complete a task when there is a degree of (1) authenticity (van Merriënboer, 1997); (2) personalized task selection (Salden, Paas, & van Merriënboer, 2006); (3) learner control in selecting their own learning tasks (Corbalan, Kester, & van Merriënboer, 2009); (4) support for calibrating learners' goal directedness (van Merriënboer, 1997); (5) scaffolding for complex tasks to prevent cognitive overload (van Merriënboer, Clark, & De Croock, 2002); (6) reflection triggered by cues integrated with feedback (van den Boom, Paas, & van Merriënboer, 2007; Wouters, Paas, & van Merriënboer, 2009); and (7) interaction with peers (van Zundert, Sluijsmans, & van Merriënboer, 2010). It can also be observed that the attributes identified by the review presented here are among the basic components of any powerful learning environment (De Corte, Greer, & Verschaffel, 1996; De Corte, Verschaffel, Entwistle, & van Merriënboer, 2003) as well as a typical constructivist learning environment (Jonassen, 1999; Wilson, 1996). These conclusions support the view that the attributes of blended learning environments identified as supporting self-regulation can in fact be seen as basic attributes of any effective learning environment; they can therefore be found in learning theories and instructional design models that are not specifically related to blended learning. This finding contributes to the question raised by certain researchers of whether the concept of blended learning should be reconsidered (Oliver & Trigwell, 2005). Our findings do indeed suggest that the concept of blended learning could be simplified both theoretically and conceptually. The principal value of this review, however, lies in its identification of design features that foster learners' self-regulation. To the best of our knowledge, this is the first study of self-regulation to present such a framework of design attributes.

Limitations of the study

A number of limitations, both of the publications described and the systematic literature review itself, should be acknowledged. The publications retrieved for this contribution demonstrate both theoretical and methodological limitations and inconsistencies. With regard to methodology, we often see a lack of awareness about the studies' reliability issues. In many cases, only the group receiving treatment is described; pre- and post-tests are only administered to the experimental group; and/or no control group is included. Such methodological flaws make it difficult to ascertain the exact design of a study and gain insight into its validity. It also remains unclear in some cases which variables are targeted by the study design. A well-thought-out model of variables and their interactions and mediations would be beneficial for reviewing the literature and reflecting upon interactions and common characteristics in the wide-ranging field that is instruction and support in blended learning environments. Furthermore, the literature often reports on multiple related concepts at the same time (e.g., proactive stickiness, learning gratifications, computer self-efficacy, learning outcome expectations, social environment, interaction, learning climate, system characteristics, and digital material features). This makes it difficult to ascribe certain effects to specific interventions or variables.

A number of theoretical limitations were also evident in the publications retrieved. First, conceptual transparency, including situating the concepts within a broader theoretical framework or instructional theory, is problematic. Due to a lack of clarity about other potentially influencing variables in the model used, or the learning environment in which the study was conducted, it is sometimes difficult to determine which variable is responsible for which outcome. Secondly, the studies appear to make minimal use of instructional design approaches. Using such systematic approaches would help give more insight into the interventions and their conditions. Without a detailed description and specific design, however, study replication is impossible. The third and final remark is that the existing literature is often descriptive rather than theoretical or explanatory. Studies frequently reported on observations using surveys, for example, instead of researching the reasons behind these observations by conducting interventions and experiments. This point also influences the nature of the systematic literature review presented in this study. Specifically, the review is unable to describe in great depth which interventions are successful for which variables. In addition, it also describes the attributes that affect cognitive, metacognitive, and motivational variables rather than explaining, for example, the precise degree of learner control needed to evoke a change in motivation for learners with low self-regulatory abilities.

As stated above, the systematic review methodology also has its limitations. One limitation is the scope and level of detail provided about each of the attributes identified, which can be seen as a constraint for immediate application in practice (e.g., design of learning environments). The main focus of this review was to identify attributes rather than focus immediately on application; the output therefore remains descriptive. Accordingly, our first suggestion for future research is to undertake a deeper analysis of each of the attributes presented by performing an additional, extended literature review per attribute in order to gain a more profound understanding of the current situation. The second limitation concerns the development of the search string and the validity of the attribute categorization. The approach combined a theory-driven search string with inclusion and exclusion criteria; a twofold (peer-reviewed), double (manual versus bibliometric) check was also performed, resulting in a robust selection of publications. This contributes to the replicability and validity of the study and to the detailed demarcation of attributes. On the other hand, however, a reasonable number of potentially relevant publications (e.g., reviews of different support types, learner variables, or attributes) were excluded. Thirdly, while considerable effort was made to interpret the publications correctly and as intended by their authors, other potentially relevant findings may have been overlooked due to the explicit search for concepts relating to self-regulation in blended learning environments.

Despite the limitations mentioned above, this systematic literature review makes a number of useful contributions. It provides a clear overview of the existing literature by identifying and defining seven attributes that appear to be worth taking into account when designing blended learning environments that support self-regulation, namely authenticity, personalization, learner-control, scaffolding, interaction, and cues for reflection and calibration. In addition, one key finding will help further the debate on the relevance of models for designing blended learning environments: attributes of blended learning environments that support self-regulation appear to tie in closely with the attributes of any effective learning environment. Finally, this study has the potential to function as a basis for further research on the attributes of blended learning and technology-mediated environments that support self-regulation. It would be useful not only to review existing research further on self-regulation per attribute (as suggested above), but also to obtain more experimental evidence for each attribute. Such studies might involve the following steps: firstly, create a sound basis for comparison using a well-established instructional design model (e.g., Merrill, 2002; van Merriënboer, 1997) for the experimental and control conditions. Secondly, after administering a pre-test for one of the self-regulatory variables, a treatment can be implemented among an experimental group focusing on the attributes of self-regulation; this will help clarify how certain attributes relate to the variable being investigated. A third and final step would be to compare the post-tests of the experimental and control groups and describe any differences found. Using such an approach would enhance the replicability and validity of the study and help to unravel how and why the attributes identified here affect the variables responsible for learners' self-regulatory abilities.

Chapter Two

Description of external factors

The text of this chapter was published as a chapter in the book *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy* [Van Laer, S., & Elen, J. (2018). An Instrumentalized Framework for Supporting Learners' Self-regulation in Blended Learning Environments. In M. J. Spector, B. B. Lockee, & M. D. Childress (Eds.), *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy*: Springer, Cham.]

Introduction

In recent decades, interest in the use of blended forms of learning has increased considerably. This type of learning happens in an instructional context which is characterized by the deliberate combination of online and classroom-based interventions to instigate and support learning (Boelens et al., 2015). Recent research on the effectiveness of blended learning has led to a proliferation of studies that emphasize the importance of learners' self-regulation in such environments. Results show, for instance, that if learners are to succeed in blended learning environments, a greater amount of self-regulation is often required (e.g., Kuo et al., 2014). This finding raises questions about how blended environments can be (re)designed to overcome this issue and how learners' self-regulation can be supported in such environments.

In response to these questions, design guidelines have been derived from syntheses of research on particular elements of self-regulation, such as monitoring, self-efficacy, and metacognition. Such guidelines suggest embedding self-regulation training into instruction by, for example, modelling self-regulation, using cognitive apprenticeships, and providing attributional feedback to identify appropriate strategies (e.g., Ley & Young, 2001; Perry & Drummond, 2002; Perry et al., 2003). Although these studies seem to agree on the importance of self-regulation for learning and provide guidelines for embedding it in learning environments, they are rarely generalizable, nor have they been operationalized as (validated) instruments for describing learning environments. Consequently, no frameworks or systems are available (let alone instruments) for describing support for learners' self-regulation in blended learning environments. This observation is problematic since without such frameworks and instruments, the systematic description and (re)design of a (blended) learning environment is almost impossible.

The aim of this chapter is therefore to present an instrumentalized framework for the systematic description of support for learners' self-regulation in blended learning environments. This instrumentalized framework consists of a conceptual framework and an instrument, validated here in two empirical research cycles. The conceptual framework originates from an analysis of the literature (by Van Laer and Elen (2016)) on support for self-regulation and provides seven attributes that characterize blended learning environments' potential support for learners' self-regulation. The seven attributes in the conceptual framework are: authenticity, personalization, learner control, scaffolding, interaction, cues for reflection, and cues for calibration. The conceptual framework and the instrument constructed around it can assist in the description and characterization of blended learning environments, but do not propose empirical guidelines on (re)design.

The aim of the conceptual framework and instrument is to facilitate research and practice by taking a systematic approach to investigating and supporting learners' self-regulation in blended learning environments. Such an approach can serve as a starting point for redesign and, consequently, improved support for self-regulation. Before elaborating on the conceptual foundations of the framework presented by Van Laer and Elen (2016), we discuss the blended learning concept and its challenges, explain the need for systematic descriptions in environment design, and elaborate on how self-regulation is developed and can potentially be supported.

Blended learning and blended learning environments

Blended learning has become increasingly popular in recent years. Many definitions of blended learning describe it as a combination of online and face-to-face learning. Hence, it is assumed to combine the advantages of both modes of delivery (Graham et al., 2014). In line with this idea, blended learning is defined in this study as learning that happens in an instructional context characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning (Boelens et al., 2015). Nonetheless, the relation of blended learning to concepts such as the flipped classroom and hybrid learning is unclear, and the instantiation of the blend remains vague (Oliver & Trigwell, 2005). Despite this, blended learning as a notion is widely used in higher and adult education; K-12 education; and corporate training (Bonk, 2017).

Over the years, blended learning has been the focus of many research studies. The majority of studies on blended learning have focused either on comparing blended and face-to-face learning or on the characteristics that learners need to thrive in such environments (Deschacht & Goeman, 2015). With regard to the latter, research has identified that learners with high amounts of verbal ability and self-efficacy and learners with high self-regulatory capabilities often perform better in blended learning environments compared to learners who lack these capabilities (Kizilcec et al., 2017). Despite the importance of these types of research, hardly any research has discussed how to propel the quest for empirical evidence to support the design of blended learning environments in which less 'capable' learners can also find success.

The need for systematic descriptions

To be able to design appropriate solutions for educational problems, stakeholders supporting learners' self-regulation are advised to use a systematic approach. Instructional design, as the design of learning environments is often referred to, emphasizes a systematic approach and is concerned with understanding, improving and applying methods of instruction to shape learning environments

(Reigeluth, 2013). It is the process of selecting and configuring methods for bringing about the desired changes in learners' behaviour. The results of instructional design are often a blueprint for the development of the actual course (van Merriënboer & Kirschner, 2017). This blueprint prescribes which methods, and in which configuration, can be used in a specific context to support learners in their attempts to achieve instructional goals.

To be able to advance in the (re-)design of learning environments, it is necessary to evaluate the effectiveness of current instructional designs. There are two main reasons for this. The first one is to describe the instructional conditions under which learning is supported. The second one is to make systematic adaptations to these conditions to strive towards increased learning. Although the necessity of considering the learning environment in the design of instruction is widely recognized by instructional design theory, no significant attention seems to be given to describing them and using these descriptions to formulate questions and a context for verification and hypothesis testing (Shavelson, Phillips, Towne, & Feuer, 2003). This finding might be explained by the observation that most models approach the designs of learning environments as blank canvases to be drawn on. This is rarely the case in practice, however. Without a system to describe and characterize the learning environment, instructional design theory produces theoretically sound but practically unusable results, meaning no practical (re)design is possible.

Self-regulation and its influencing conditions

By definition, effective learners are self-regulating ones (Butler, 1998). Self-regulation is the process that unfolds when learners use metacognitive skills, in a particular context, to achieve goals both internal and external to themselves. Many models of self-regulation include or are constructed around four main cyclic stages: (1) task identification, (2) goal-setting and planning, (3) enacting, and (4) adaptation (for an overview see: Puustinen & Pulkkinen, 2001). When learners encounter a new task for the first time, they try to (1) identify or categorize it. While doing this, they develop perceptions of the task concerned. Based on these perceptions learners (2) set goals and plan how to achieve them. Once goals are set, learners use their (3) metacognitive knowledge and skills and act to achieve the goals set. Finally, when the learners are confronted with their actual achievements (for example through summative feedback), self-regulating learners may (4) adapt their studying techniques, keeping the freshly acquired experiences and their future needs in mind. Each of these stages of self-regulation is influenced by conditions within and external to the learner (e.g., Winne & Hadwin, 2013).

Variables within the learner

Research identified three major sets of variables in relation to differences in self-regulation: cognitive, metacognitive, and motivational ones. With respect to cognitive variables (e.g., Zimmerman & Schunk, 2006) two frequently investigated concepts are (a) learners' intelligence and (b) learners' prior domain knowledge. With regard to the latter, research showed that learners who had more prior domain knowledge used fewer information sources and focused more on sources related to appropriate strategies to regulate one's learning towards achieving the desired learning outcomes (Song et al., 2016). Intelligence proved to be positively related to metacognitive skilfulness, with learners with higher scores on intelligence being better able to select the desired metacognitive skills and thus self-regulate towards the desired learning outcome (Veenman, Elshout, & Meijer, 1997).

A second set of variables relates to metacognition (e.g., Borkowski et al., 1990). Two metacognitive domains related to learners' self-regulation can be extracted from literature. On the one hand there is metacognitive knowledge, which is the information needed to be able to select appropriate metacognitive skills. On the other hand there are the metacognitive skills themselves, which reflect learners' ability to make actual changes to their own behaviour. Results show that learners with a wide array of metacognitive skills use more varied strategies while studying compared to learners who are less skilled (Pintrich, 2002). According to the researcher, this difference can be attributed to a more skilful analysis of the situation, which may result in the selection of more appropriate strategies.

The last set of variables relates to motivation (e.g., Schraw et al., 2006). As self-regulation within educational psychology refers to settings in which goals are set not by learners alone, but also by formal institutions (and in ideal scenarios in mutual agreement), motivation is often seen in the light of learners' goal-orientation. Learners' goal-orientation encompasses different ways learners deal with the goals they receive and eventually appropriate. Learners can approach or avoid either performance or mastery. When learners have a mastery-approach orientation they internalize the goal as their own and are motivated to master the goal. When learners have a performance-avoidance orientation, however, they attempt to avoid appearing incompetent compared to others. One finding which illustrates the impact of goal-orientation on self-regulation is that learners who want to master a task consult materials outside of the course content, whereas performance-avoidance learners will stick to the task more rigidly and regulate their learning towards the desired outcome (Pintrich, 2002). Similar findings were retrieved in relation to Deci and Ryan's (2010) notion of internal and external motivation.

Variables external to the learner

Different stages, dimensions, and processes of self-regulation may be influenced by specific instructional interventions (Ifenthaler, 2012). As pointed out by Ley and Young (2001), several self-regulation interventions have been tailored to specific content, learners, or media. Interventions have been suggested for writing, reading comprehension, and mathematics (e.g., Schunk, 1998). Others have incorporated support for self-regulation into college learning-to-learn courses or in computer-mediated instruction (e.g., Winne & Hadwin, 2013). The literature contains only a limited number of studies that have focused on support for self-regulation in blended learning environments (Kassab et al., 2015). Some approaches have been directed toward specific populations such as children, adolescents, and learning disabled learners (Butler, 1998).

Although there is a substantial amount of research available that describes ways to support learners' self-regulation, there are several remaining issues that make the practical application of these guidelines impossible. First, while much research does consider self-regulation as an inherent part of learning, research that takes this perspective and presents concrete design guidelines is scarce. The guidelines formulated often see self-regulation as a specific goal (to design for) instead of as an inherent attribute of learning (Zimmerman & Schunk, 2006). This results in descriptions of interventions that focus on increasing specific elements of self-regulation (e.g., task definition, monitoring, etc.). Only a few studies attempted to combine findings from different backgrounds into a set of guidelines or principles towards a conceptual framework or emphasized the inconclusiveness of guidelines for learners with particular characteristics. Among those who attempted to come up with guidelines to support self-regulation were Ley and Young (2001), Perry and Drummond (2002) and Perry, Nordby, and VandeKamp (2003). Ley and Young (2001) proposed guidelines to design learning environments that support self-regulation:

a. To help learners prepare and structure an effective learning environment;
b. To organize instruction and activities to facilitate cognitive and metacognitive processes;
c. To use instructional goals and feedback to present the learner with monitoring opportunities; and
d. To provide learners with continuous evaluation information and opportunities to self-evaluate.

With regard to the conceptualization of self-regulation used in this chapter, the guidelines formulated by Ley and Young (2001) seem to relate most closely to the enacting and modifying phases of self-regulation (phases three and four, respectively). No indications are provided about how to support learners in identifying the task at hand or in setting appropriate goals and planning to achieve them, however.

Perry and Drummond (2002) and Perry et al. (2003) approached support for self-regulation in a broader, more general fashion. They suggested that:

a. Learners and instructors should function as a community of learners;
b. Learners and instructors should be engaged in complex, cognitively demanding activities;
c. Increasingly, learners should take control of learning by making choices, controlling challenge, and evaluating their work;
d. Evaluation should be nonthreatening. It is embedded in ongoing activities, emphasizes processes as well as products, focuses on personal progress, and encourages learners to view errors as opportunities to learn; and
e. Instructors should provide instrumental support to learners' learning, combining explicit instruction and extensive scaffolding to help learners acquire the knowledge and skills they need to complete complex tasks.

The guidelines of Perry and Drummond (2002) and Perry et al. (2003) seem to take a more holistic approach than those of Ley and Young (2001) and focus on interventions that trigger the four different phases of self-regulation through specific interventions (e.g., community of practice, assessment, etc.).

The literature review revealed no models for the design of learning environments that support learners' self-regulation dating from after 2003. After 2003, educational psychological research focused on specific metacognitive strategies and skills, rather than on learning environments as a whole. Although Ley and Young (2001), Perry and Drummond (2002) and Perry et al. (2003) established sets of guidelines for supporting self-regulation, to the best of our knowledge none of these guidelines have been either (a) translated into a generalizable conceptual framework for the support of self-regulation, or (b) operationalized to describe and characterize (blended) learning environments in a systematic way. This observation is problematic since without such approaches, no systematic investigations or empirical attempts at more effective (re)designs are possible (van Merriënboer & Kirschner, 2017). Without a systematic approach and framework for describing and characterizing learning environments, such guidelines might do more harm than good. This can be illustrated with the case of learner control, for example: depending on the learners' characteristics, increased learner control may be either beneficial or detrimental to effective self-directed behaviour (Duffy & Azevedo, 2015).

Problem statement

Research on self-regulation in blended learning environments shows that learners need to have specific characteristics and self-regulation abilities to be successful in such environments. Literature seems to provide only a limited set of guidelines on how to design blended learning environments in this respect. Although some fruitful attempts have been made to come up with sets of guidelines, more recent literature (e.g., Lallé, Taub, Mudrick, Conati, & Azevedo, 2017) has begun to acknowledge that insufficient empirical insights are currently available to distinguish which guidelines are most effective for which learners in which contexts. Yet, to be able to advance in our investigations of which support in blended learning environments is best for which learners, we do need conceptual frameworks, instruments, and methods to describe and thus to characterize learning environments. Such methods can serve as a starting point for empirical and more experimental investigations and might enable the field to provide guidelines and models on how to design blended learning environments that support learners' self-regulation. In the next section, we discuss the conceptual framework before explaining the development and validation of an instrument and method for describing and characterizing support for self-regulation in blended learning environments.

Conceptual foundations of the framework

Using a (n=95) systematic literature review (see original study for methodological details), Van Laer and Elen (2016b) identified seven attributes that support self-regulation in blended learning environments. The results of this literature review provided the conceptual foundations for the framework developed here. For each of the attributes, (i) a definition and (ii) evidence from the literature that demonstrate a potential link between the attribute and self-regulation were provided in Van Laer and Elen (2016). In what follows, we first summarize this information before describing (iii) the attributes' operationalization and illustrating them with examples. Finally, we (iv) instrumentalize each attribute as a number of questions. Table 1 presents a summary of the conceptual framework (see original study for references and in-depth theoretical background). In the second step, we elaborate on the development of the instrument and method for describing and characterizing blended learning environments.

Authenticity

Definitions of authenticity range from real-world relevance, needed in real-life situations, and of important interest to the learner for later professional life. Taking into account these definitions, Van Laer and Elen (2016) define authenticity as the real-world relevance of both the learning environment and the task.

Authenticity and self-regulation

The relation of authenticity to self-regulation has to do with the realistic and ill-structured nature of the learning environment and tasks presented to learners. Well-structured tasks (which are common in education) rarely challenge learners to explore tactics for learning, which may hinder their ability to reach their full potential (Perry & Drummond, 2002). More specifically, they are likely to undermine self-regulation, encourage only shallow processing, and limit performance (Salomon & Perkins, 1998). With regard to the learning environment, authenticity in the learning environment helps learners to develop adequate perceptions of their future professional context, improving their understanding of what is expected (Ley & Young, 2001). While authenticity is very important for self-regulation, moderation is essential. Not all learners will benefit equally from ill-structured authentic tasks and environments. Poorly structured authentic tasks and environments may increase learners' anxiety and may also be too challenging, leading to withdrawal instead of engagement (Winne & Hadwin, 2013).

Authenticity in learning environments

A large body of literature has investigated the design of authentic tasks and environments (e.g., Reeves & Reeves, 1997; Wiggins, 1993). According to this research, authentic learning environments are characterized by (a combination of): (1) Authentic contexts, or contexts that reflect how knowledge will be applied in real life. Research on authentic contexts shows that it is not sufficient to provide real-world examples to illustrate what is being taught. Instead, the value of authentic contexts lies in their complex, all-enveloping nature; (2) Authentic activities or ill-defined activities which present a single complex task to be completed over a sustained period of time, instead of a series of shorter disconnected examples; (3) Expert performance, which entails the facilitation of access to expert thinking, the modelling of processes, and access to the social periphery; (4) Multiple roles or different perspectives which enable learners to investigate the learning environment from more than one viewpoint, enabling and encouraging them to explore the learning environment repeatedly; (5) Collaborative knowledge construction, which refers to knowledge construction opportunities for learners to collaborate and thus to estimate their own perceptions of learning. Consequently, tasks assigned to a group instead of to an individual seem to be key to establishing such knowledge construction; (6) Tacit knowledge made explicit, or opportunities for learners to articulate knowledge already available within to foster planning of further learning; and finally, (7) Authentic assessment of learners' learning which provides the opportunity for learners to be effective performers with acquired knowledge, and to craft polished performances or products in collaboration with others. This requires the assessment to be seamlessly integrated with the activity, and to provide appropriate criteria for scoring varied products.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains authentic real-world relevance, the following questions were formulated:

- Is an authentic context provided that reflects the way the knowledge will be used in real life?
- Are authentic activities provided?
- Is access to expert performances and the modelling of processes provided?
- Are multiple roles and perspectives provided?
- Is support for collaborative construction of knowledge provided?
- Is articulation provided to enable tacit knowledge to be made explicit?
- Is authentic assessment of learning within the tasks provided?

Personalization

Personalization in this chapter is defined as the modification of the learning environment to the inherent needs of each individual learner. This definition is in line with current definitions that describe personalization as non-homogenous experiences related directly to the learner, associated with elements of inherent interest to the learner, and connected to topics of high interest value (e.g., Wilson et al., 2007).

Personalization and self-regulation

Current research literature emphasizes the connection between personal agency and self-regulation, and argues that personalized instruction results in a change of self-representation based on psychological needs such as competence (perceived self-efficacy), relatedness (sense of being a part of the activity) and acceptance (social approval), which are components of learners' self-regulation (e.g., Türker & Zingel, 2008). Evidence has also been provided of a relationship between personalization, learners' goal-setting and planning, performance, and self-reflection (e.g., Dabbagh & Kitsantas, 2004). By receiving modified instruction related to one's current skill-level, it might be possible for learners to monitor their learning more accurate and thus boost their learning. When the learning environment is aligned with learners' personal preferences, their interest might increase and thus self-regulation will be impacted positively. In conclusion, there seems to be a clear link between personalization and self-regulation particularly in the task identification and goal-setting and planning phase of learners' self-regulation.

Personalization in learning environments

Three major ways to incorporate personalization into learning environments could be identified (e.g., Devedžić, 2006; Martinez, 2002). (1) Name-recognition: This type of personalization aims at the acknowledgement of the learner as an individual. For example, the learner's name can appear in the instruction or previous activities or accomplishments that have been collected and stored can later be presented when appropriate; (2) Self-description: Self-described personalization enables learners, (using questionnaires, surveys, registration forms, and comments) to describe preferences and common attributes. For example, learners may take a pre-course quiz to identify existing skills, preferences, or past experiences. Afterwards, options and instructional experiences appear based on the learner-provided answers; The last type of personalization is based on (3) learners' cognitive needs: Cognitive-based personalization uses information about cognitive processes, strategies, and ability to deliver content specifically targeted to specific types (defined cognitively) of learners. For example, learners may choose to use an audio option because they prefer hearing text instead of reading it. Or, a learner may prefer the presentation of content in a linear fashion, instead of an unguided presentation with hyperlinks.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains personalization, the following questions were identified:

- Is the personalization name-recognized?
- Is the personalization self-described?
- Is the personalization cognitive-based?

Learner control

Learner control refers to the amount of control learners have over support in learning environments. Definitions vary from freedom of task-selection by the learner, control of learning sequences, allowing decisions on which contents to receive, allowing decisions on how specific content should be displayed and control over the pace of information presentation. Van Laer and Elen (2016) define learner control in line with these definitions and see learner control as the degree to which learners have or have not control over the pacing, content, learning activities and sequences.

Learner control and self-regulation

Theorists such as (Merrill, 2012) assert that learners need to be given control. In addition to this control supporting motivation, exercising control over one's learning can be a valuable educational experience in itself. The results can be experienced and the best tactics for different instructional situations can be discovered in the process. In this way, the exercise of learner control can be thought of as a precursor to the development of self-regulation. The idea that learner control is the fine-tuned application of self-regulation is based on the assumption that learners who command the greatest range and depth of learning skills will be the best equipped to handle learner control and other forms of instructional self-management (Resnick, 1972). From this perspective, it might be expected learner control can only be granted when learners possess the ability to effectively use it to purposefully direct their learning. If learners are not able to do so, they will lack to ability to regulate their learning and begin to drift (Lawless & Brown, 1997).

Learner control in learning environments

Literature reports on the manifestation of learner control often in four ways (e.g., Sims & Hedberg, 1995; Williams, 1993): (1) Control over pacing: Learners have control over the speed and time at which content is presented; (2) Control over content: The learner is permitted to skip over certain instructional units. This option generally refers to the selection of topics or objectives associated with a specific lesson, although it does not extend to a choice of which content items are displayed. This component of learner control does not focus on the micro level of interaction, in which the learner must make certain choices in response to questions or problems. Therefore, while the learner has control over the content selected for study, the actual presentation of that content has generally remained instructor driven. Thus, there would appear to be two levels of content control: one at which the learner chooses a module of study, and one at which the presentation and associated display elements are also controlled by the learner; (3) Control over learning activities: This type of control includes options for the learner to see examples, do exercises, receive information, consult a glossary, ask for more explanation, or take a quiz; Finally there is the (4) Control over sequence: Learners can skip forward or backward through activities or they are allowed to retrace a route through the material, and options to control when to view such features as content indexes or content maps. Sequence control refers to the order in which the content is viewed, and often is defined in terms of being able to move to and from content items.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains learner control, the following questions were identified:

- Is control over pacing allowed?
- Is control over content allowed?
- Is control over learning activities allowed?
- Is control over sequence allowed?

Scaffolding

Scaffolding in this chapter is defined as changes in tasks and the learning environment, so learners can accomplish tasks that would otherwise be out of their reach. This definition derives from a collection of different approaches to scaffolding which mainly emerged from design research on interactive learning environments. These approaches all emphasized that scaffolding involves providing assistance to learners on an as-needed basis, fading the assistance as learner competence increases (e.g., Wood, Bruner, & Ross, 1976). Based on these approaches a variety of design guidelines or principles have been proposed.

Scaffolding and self-regulation

According to Vygotsky (1978), learners improve when they are assisted by more advanced or knowledgeable sources of instruction (e. g., instructors or peers). The concept of zone of proximal development refers to "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). This external guidance or support helps learners monitor their current abilities and calibrate their further actions. Scaffolding also contributes to the planning and monitoring of learners. By providing them with suggestions for potential next steps, learners will be able to direct (regulate) their own learning more towards desired goals (Moos & Azevedo, 2009). The same goes for the use of metacognitive strategies, self-management, information seeking, and adaptive behaviour. Finally, scaffolding might also provide the necessary tools to support learners in making adaptations to one's personal learning environment and define the problems that need to be overcome (Feng & Chen, 2014). In conclusion, scaffolding can be seen as the temporal replacement of learners' self-regulation. Over time, the responsibility for it will shift towards the learner.

Scaffolding in learning environments

Three major ways in which scaffolding is represented in learning environments are (e.g., Garza, 2009; Puntambekar & Hubscher, 2005): (1) Contingency of support: Support is adapted to the current level of the learners' performance and should either be at the same or a slightly higher level. A tool for contingency is the application of diagnostic strategies. Such strategies often encompass small, recurring formative tasks to be able to monitor learners' current level. To provide appropriate support, it is key to determine the learners' current level of competence; (2) fading of support over time: As the ability of the learner increases, the support fades over time with regard to the level and/or the amount of it. Examples of such fading support is the elaborate explanation or instruction at the beginning of a course, there were later in the course fewer instruction is given for a similar task; Finally, there is the (3) Transfer of responsibility: As support fades, responsibility for the learner's performance of a task is gradually transferred to the learner. Responsibility can refer to cognitive (for example responsibility for the correctness of the task) and metacognitive activities (for example responsibility for the approach of the task) as well as to learners' affect.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains scaffolding, the following questions were identified:

- Is support tailored to the learner through continuous monitoring?
- Does the support fade over time?
- Is there a transfer of responsibilities over time?

Interaction

Van Laer and Elen (2016b) describe interaction as the involvement of learners with elements in the learning environment. In this chapter, we adopt the same definition. This definition encompasses the nature of interaction in various forms of learning environments and in a variety of ways, considering the learners' level of involvement in a specific learning opportunity and as the objects of interaction such as other participants or content materials. The nature of interaction is also dependent upon the contexts in which interaction occurs, in a face-to-face situation or at a distance.

Interaction and self-regulation

Previous research (e.g., Zimmerman & Schunk, 2006) emphasizes the importance of interaction in providing (a) modelling, (b) opportunities for guided practice, and (c) instrumental feedback to impact learners' self-regulation. Through these processes, learners develop competence with the task, content, and context, thereby becoming self-regulated learners. Self-regulated learners rely on internal standards, self-reinforcement, self-regulatory processes, and self-efficacy beliefs. Subsequently, by interacting with elements of the learning environment learners get to reflect and judge on their own performance. By interacting with peers, content, etc. self-evaluation, the use of metacognitive skills and the production of metacognitive knowledge, one's self-efficacy and test anxiety, and modelling capabilities are likely to increase and affect how learners regulate their learning.

<u>Interaction in learning environments</u>

Five types of interaction were observed in learning environments (e.g., Sutton, 2001; Woo & Reeves, 2007): (1) Learner-content interaction: This type of interaction is interaction between the learner and the content or subject of study. This type of interaction is often limited to a big portion of one-way communication with a subject expert (or medium), intended to help learners in their study of the subject; (2) Learner-instructor interaction: This type of interaction is interaction between the learner and the expert who prepared the subject material, or some other expert acting as instructor; (3) Learner-learner interaction: This type of interaction is between one learner and other learners, alone or in group settings, with or without the real-time presence of an instructor; (4) Learner-interface interaction: This type of interaction describes the interaction between the learner and the tools needed to perform the required task; and (5) Vicarious interaction: This final type of interaction takes place when a learner actively observes and processes both sides of a direct interaction between two other learners or between another learner and the instructor.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains interaction, the following questions were identified:

- Is learner-content interaction facilitated?
- Is learner-instructor interaction facilitated?
- Is learner-learner interaction facilitated?
- Is learner-interface interaction facilitated?
- Is vicarious interaction facilitated?

Cues for reflection

Dewey (1958) defined reflection as ‘‘active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends’’ (p. 9). Moon (1999) describes reflection as ‘‘a form of mental processing with a purpose and/or anticipated outcome that is applied to relatively complex or unstructured ideas for which there is not an obvious solution’’ (p. 23). Boud, Keogh, and Walker (2013) define reflection as ‘‘a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to a new understanding and appreciation’’ (p. 19). All three definitions emphasize purposeful critical analysis of knowledge and experience, in order to achieve deeper meaning and understanding, therefore reflection cues in this chapter will be identified as prompts that aim to activate learners’ purposeful critical analysis of knowledge and experience, in order to achieve deeper meaning and understanding.

Reflection and self-regulation

By reflecting on one's own learning, learners become aware of their learning processes and possible alternative strategies. This is important because the perception of choice is a critical aspect of self-regulation, and the awareness of alternatives is a prerequisite for changing less than optimal study habits (Boud et al., 2013). On the one hand, reflection promotes the development of the necessary cognitive structure; on the other hand, it makes this structure available for learning activities. Reflection can thus be conceived of as the bridge between metacognitive knowledge and metacognitive control (self-regulation), facilitating the transfer of metacognitive knowledge to new situations (Ertmer, Newby, & MacDougall, 1996). These processes affect not only learners' cognitive structures but also their ability to deal with them. Learners' self-explanation capabilities, their awareness of the learning process and their self-reflection ability (Michalsky & Kramarski, 2015) also seem to be related to how reflection impacts learners' self-regulation.

Cues for reflection in learning environments

Three types of cues for reflection can occur during instruction (e.g., Davis & Linn, 2000; Farrall, 2007): (1) Cues for reflection-before-action: These types of cues aim to trigger learners' proactive reflection. For example, learners are asked about what they think the upcoming task will be about; (2) Cues for reflection-in-action: These types of cues aim to trigger learners' reflection while they are performing a task and aim at encouraging learners to reflect upon if they needs to alter, amend, change what they are doing and being in order to adjust to changing circumstances, to get back into balance, to attend accurately, etc. Learners might benefit from checking with themselves if they are on the right track, and if not, what are better ways? For example, an instructor asks to review the actions they are undertaking; finally, there are (3) Cues for reflection-on-action: These types of cues attempt to trigger learners to systematically and deliberately think back over their actions. In other words, this type cues encourages learners to think back on what they have done to discover how knowing-in-action might have contributed to unexpected action. For example, learners are asked about their experiences regarding a task that is just finished. The more cues for reflection are given; the more likely it is that learners will actually use them. Diminishing the number of cues over time eliminates cue-dependency.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains cues for reflection, the following questions were identified:

- Does the reflection-for-action approach apply?
- Does the reflection-in-action approach apply?
- Does the reflection-on-action approach apply?

Cues for calibration

Van Laer and Elen (2016) define calibration cues as triggers for learners to test their perceptions of achievement against their actual achievement and their perceived use of study tactics against their actual use of study tactics. This definition is comparable to others who see these cues as prompts to compare learners' perceptions of achievement to the achievement compared with external standards and perceived use of study tactics and actual use of study tactics. Calibration concerns on the one hand the deviation of a learner's judgement from more objective measures, introducing notions of bias and accuracy and on the other hand metric issues regarding the validity of cues' contributions to judgements and the grain size of cues (e.g., Azevedo & Hadwin, 2005).

Calibration and self-regulation

If a learner encounters an impediment while pursuing a goal, the interruption triggers a reassessment of the situation (Carver & Scheier, 1990). Engaging in this reassessment leads learners to estimate how probable it is that they can achieve their goal if they invest further effort, modify their plan, or both. If confidence or hopefulness exceeds an idiosyncratic threshold, then the learner is likely to persevere and when a deficit between estimated performance and actual performance is identified to adapt the plan that has been guiding engagement and continue working toward the initial goal. At this point in the stream of cognitive processing, self-regulation has been exercised (Bandura, 1993). For learners to be able to achieve the desired learning outcomes, they need to calibrate their perception of the task at hand and the goals to be achieved.

Cues for calibration in learning environments

With regard to the design of cues for calibration in learning environments five methods could be identified (e.g., Nietfeld, Cao, & Osborne, 2006; Thiede, Anderson, & Therriault, 2003): (1) Cues for delayed metacognitive monitoring: This type is based on a phenomenon labelled 'the delayed judgement of learning effect' that shows improved judgements after a learning delay similar to improved achievement associated with distributed sessions over time. For example, learners might be first asked to highlight a text and at a later time evaluate the highlighted content relative to how well it is understood, how easily it can be retrieved, and how it relates to the learning objective. In this case, learners are asked to evaluate previous made judgements; (2) Forms for summarizing: Summarizing information seems to improve calibration accuracy. It is suggested that the summaries are more effective when forms and guidelines are provided. For example an instructor gives the learners the task to summarize a specific content component and to review it using a correction key; (3) Timed alerts: Thiede et al. (2003) state that summarizing information after a delay improved calibration accuracy; (4) Review of “right” information: Learners have a tendency to select ‘‘almost learned’’ or more interesting content for restudy. If learners were to rate test items on judgement of learning and interest they could be provided feedback indicating that selection of content for restudy based on interest and minimal challenge may not be the best choices. For example an instructor advices the learners to select exercises that are challenging for them; finally, (5) Effective practice tests: Learners might need to be aware of the change in behaviour they should make. By informing them on the mistakes they already made, learners might direct further attempts. For example, an instructor gives the results of the previous test as guideline for the completion of the next test.

To instrumentalize the abovementioned characteristics with the aim of determining whether a given learning environment contains cues for calibration, the following questions were identified:

- Is a strategy applied to guide learners to delay metacognitive monitoring?
- Is a strategy applied for the provision of forms that guide learners to summarize content?
- Are timed alerts given that guide learners to summarize content?
- Is a strategy applied for helping learners review the ‘‘right’’ information?
- Is a strategy applied for effective practice tests that provide learners with records of their performance on past tests as well as items (or tasks) on those tests?

In summary, based on the description of each of the attributes presented above, an instrumentalized version of the framework was developed. This instrument was used to describe support for self-regulation in blended learning environments. The instrument can be found in Appendix 1. In the following section, we will discuss the validity and reliability of the instrument.

Table 1.

Overview of the conceptual framework presented, based on the Van Laer and Elen's (2016) seven attributes (see original study for references and in-depth theoretical background).

Attribute and definition	*Manifestation in learning environments*	*Relation to self-regulation*
Authenticity *The real-world relevance of on the learning environment and the task.*	• Authentic context • Authentic activities • Expert performance • Multiple roles • Collaborative knowledge construction • Tacit knowledge made explicit • Authentic assessment	• Exploration of tactics for learning • Planning and self-monitoring • Information-seeking behaviour • Need to self-regulate, adopting strategies and attuning to the goal, adopted forms of SR, and learning as identity development. • Intrinsic goal orientation, task value, use of elaboration strategies, critical thinking, and metacognition
Personalization *The modification of the learning environment to the inherent needs of each individual learner.*	• Name-recognition • Self-described • Cognition-based	• Interest value • Self-representation, self-efficacy, relatedness, and social approval • Goal-setting and planning, performance, and self-reflection
Learner control *Learners having or having not control over the pacing, content, learning activities and sequences.*	• Control over pacing • Control over content • Control over learning activities • Control over sequence	• Self-control • Instructional self-management • Metacognitive skilfulness • Development of learning strategies • Planning and goal-setting • Rehearsal and self-checking
Scaffolding *Changes in the task and learning environment, so learners can accomplish tasks that would otherwise be out of their reach.*	• Contingency • Fading over time • Transfer of responsibility	• Planning and monitoring • Strategy use • Self-management, information seeking, and adaptive behaviour • Self-structuring and problematizing
Interaction *The involvement of learners with elements in the learning environment.*	• Learner-content interaction • Learner-instructor interaction • Learner-learner interaction • Learner-interface interaction • Vicarious interaction	• Self-evaluation • Strategy use • Metacognitive knowledge • Self-efficacy and test anxiety • Modelling
Cues for reflection *Prompts that aim to activate learners' purposeful critical analysis of knowledge and experience, in order to achieve deeper meaning and understanding.*	• Reflection-before-action • Reflection-in-action • Reflection-on-action	• Cognitive structures and abilities • Self-explanation • Metacognitive knowledge and metacognitive control • Awareness of learning process • Self-reflection ability
Cues for calibration *Triggers for learners to test learners' perceptions of achievement against their actual achievement and their perceived use of study tactics against their actual use of study tactics.*	• Delayed metacognitive monitoring • Forms for summarizing • Timed alerts • Review of "right" information • Effective practice tests	• Reassessment • Goal-orientation • Task identification • Problem solving • Cognitive strategies, problem solving strategies, and critical thinking skills, knowledge of cognition, regulation of cognition, self-efficacy, and epistemology

Method

In the introduction of this chapter the conceptual foundations of the framework based on Van Laer and Elen's (2016) attributes that support self-regulation were described resulting in an instrument to describe the support for learners' self-regulation by learning environments. For each of the attributes, we (i) formulated a definition, (ii) gathered findings from the literature that demonstrate a link between that attribute and self-regulation, (iii) elaborated the attribute's operationalization and illustrated it with examples, and finally (iv) instrumentalized each attribute as a number of questions. Based on this instrument two empirical research cycles were used to investigate the suitability of the instrument for both research and practice. Below the procedure followed is presented.

Research design

To construct the instrument and achieve high reliability and validity, a validating approach was used. According to Andersson and Bach (2005) such an approach includes the following elements. First, there is the design and development phase of the instrument, based on a conceptual framework. The result of this is the translation of the conceptual framework into an instrument, which is then embedded in a methodology to assure high reliability and validity. Finally, both the instrument and the methodology are tested and optimized when needed by continuously challenging them to assure further replicability. For the design, development and validation of the instrument presented in this chapter, Andersson and Bach's (2005) elements were captured in three phases. The first phase included the elaboration of the seven attributes as defined by Van Laer and Elen (2016) into a conceptual framework and the translation of this framework into an instrument to describe the support of learners' self-regulation in blended learning environments. This phase was reported upon in the previous section of this chapter. The second phase (first empirical research cycle) included embedding the instrument in a methodology and the first time use of this methodology. In the third and final phase, (second empirical research cycle) modifications were made and the methodology was applied for the second time in a different context.

Phase 1

Based on the work of Van Laer and Elen (2016b) a conceptual framework was constructed. This framework consists of seven attributes that support learners' self-regulation in blended learning environments:

- *Authenticity:* real-world relevance of the learning experience to learners' lives and professional context;
- *Personalization:* tailoring of the learning environment to the inherent preferences and needs of each individual learner;
- *Learner control:* degree to which learners have control over the content and activities within the learning environment;
- *Scaffolding:* changes in the task or learning environment which assist learners in accomplishing tasks that would otherwise be beyond their reach;
- *Interaction:* learning environment stimulating learners' involvement with elements of and in the learning environment;
- *Reflection cues:* triggers aiming at activating learners' purposeful critical analysis of knowledge;
- *Calibration cues:* triggers for learners to test their perceptions against their actual performance and study tactics.

The combination of these attributes characterizes the support system of learners' self-regulation in the learning environment from different but related theoretical perspectives. The validation of the instrumentation of the conceptual framework entailed:

a. The formulation of questions to test for indicators of each attribute
b. The use of these questions to describe and hence characterize support for self-regulation in blended learning environments.

By operationalizing the conceptual framework as guidance questions, an instrumentalized framework was created. This instrumentalized framework was used during the testing and optimization phases (Phases 2 and 3).

Phase 2

The second phase of the instrument validation took place in a study aiming at the identification of the relation between designs of blended learning environments that support self-regulation and learners' learning outcomes. During this study, the instrument was used for the first time.

Sample

We used four blended learning courses taught in two centres for adult education in Flanders, the northern region of Belgium. The four courses were categorized as blended learning courses as they deliberately combined online and classroom-based interventions to instigate and support learning (Boelens et al., 2015). All the courses covered the same subject, 'Introduction to basic statistics'. The topics included means, modes, frequency tables, etc. Each course had an identical length of eight weeks. Learners took the course in the first semester of the school year. Both schools were similar in size and context. They were located near a major city and had similar heterogeneous target groups and institutional needs. Both of them were among the largest of their kind and leading institutions of adult education in Flanders, each providing over 50 courses and catering for over 1000 learners.

Blended learning courses

In line with the operationalization of blended learning, all of the courses involved in the study used a deliberate mix of face-to-face lessons and online lessons. Each face-to-face lesson lasted three hours either from 09:00h to 12:00h or from 14:00h to 17:00h. The learners were expected to spend the same amount of time on the online lessons. In the first school, each course addressed five topics: quantitative and qualitative characteristics of data, representative surveys, descriptive tables, presentation of statistical data using ICT, and the use of grouped data. Course 1 contained two face-to-face meetings, one at the start and one on the day of the examination. During the first lesson, the instructor introduced the materials and methodology of the course. Following this introduction, eight online lessons were provided. Course 2 included five face-to-face lessons and five online lessons. It started and ended with a face-to-face lesson. Between these, a face-to-face or online lesson took place every other week. During the face-to-face lessons, the instructor briefly summarized the content of the instructional videos and presentations provided in the online lessons. In both courses, each topic started with the presentation of ‘Theory’, including general definitions and different examples. At the end of the conceptual part, an individual research project was introduced both via the online learning environment and by the instructor. The conceptual part was followed by ‘Exercises’; each of the exercises was framed in a different context. After the completion of the last exercise of each topic, a test followed. In the second school, Course 3 was divided into seven weekly meetings. The course consisted of three consecutive topics: ‘Data collection’, ‘Data collection’, and ‘Statistical key concepts’. Five of the weekly meetings were in a face-to-face format during which both the instructor and learners used online materials. Finally, Course 4 started with a face-to-face session, during which the instructor introduced the individual research project, the learning materials, and the methodology of the course and gave a brief overview of the entire course. Seven online lessons were then provided.

Procedure

First, a back-up was made of all online components (virtual learning environment) of the four blended learning environments. These back-ups were uploaded to our servers for description. Subsequently, each off-line component (classroom environment) was registered using an audio-visual recorder.

These recordings were also uploaded onto the server for description. The researcher and a (non-domain-expert) colleague functioned as raters.

In blended learning environments it is a challenging task to find a unit of analysis that encompasses both the online and offline context. It is almost impossible to parse these media into comparable 'chunks'. The use of equal chunks of information is important because changes to the size of this unit will affect description decisions and comparability of outcome between different models (Cook & Ralston, 2003). To assure that different raters using the same instrument see the blended learning environment under investigation in the same fashion literature suggest to identify a consistent 'theme' or 'idea' (unit of meaning) as the unit of analysis (e.g., Henri, 1992). This is because themes and topics can carry on over the boundaries of the online and offline contexts and often entail the same elements (see Strijbos, Martens, Prins, and Jochems (2006) for a more in-depth discussion of the issue of unitization). To overcome the issue of varying units of analysis due to differences in proportion online and offline components the raters agreed to use a unit of analysis, which related to the topics addressed. The two raters coded the four environments completely and independently by reviewing both the online and offline components of the course and filling out the descriptive instrument for each of the topics addressed.

The instrument was translated into an Excel document to ease the data collection. Raters were not able to answer the conceptual questions at once. A mean score would be calculated based on the answers gathered for each of the questions. To be able to apply such an approach a scoring scheme based on a Likert-type scale was introduced. For each question, a score needed to be assigned. Important is that the scoring is based on occurrence, not on, for example the quality of the materials as assumed by the scorer. The scoring possibilities were: 1=Never, 2=Little, 3=Somewhat, 4=Much and 5=Always. When a score of 1 (Never) is given, this means that there is not the slightest relation between the unit observed and the question raised. When score 2 (Little) is given, there are minimal (implicit) references to the question. Score 3 (Somewhat) is answered when there are clear (explicit) references to the question. Score 4 (Much) is answered when there is a systematic integration of the characteristic addressed in the question throughout the unit. Finally, the score 5 (Always) is given when consistent throughout the unit every element contains the characteristic addressed in the question. As the instrument was developed in Excel, the observations (and scoring) could be summarized in a bar chart. This chart makes it easy to interpret the scores with regard to the inclusion of the different attributes, the individual scores for each of the units and even the entire course.

Based on the raters' scoring the inter-rater score was calculated. In this chapter inter-rater reliability is defined as the extent to which different raters, each describing the same content, come to the same decisions (Rourke, Anderson, Garrison, & Archer, 2001). In this phase among other coefficients the Kendall's W (also known as Kendall's coefficient of concordance) is used to investigate inter-rater reliability. This coefficient is particularly of interest for the purpose of the method presented. It is a normalization of the statistic of the Friedman test, and can be used for assessing agreement of ordinal variables (Likert-type scale) among multiple raters. Kendall's W ranges from 0 (no agreement) to 1 (complete agreement) and is reported with a significance score. After the inter-rater score was calculated, both raters met to discuss features of the instrument that were not clear.

Results

Based on the reports of the two raters the Kendall's W was calculated. It became clear that there was high agreement (Fleiss, 1993) between both raters, $W = .683$, $p < .033$. Both raters agreed (Schmidt, 1997) that with regard to the attributes that support self-regulation, authenticity of the different learning environments differed depending on the nature of the topic. Authenticity was observed more when the topic was in direct relation to applications of a task (for example the individual 'research' project learners had to do). Personalization in the online learning environment was primarily focused on the presentation of different contextualized exercises and on the choice learners had in selecting a topic to work on in their individual project. Personalization in the face-to-face context was mostly done by addressing learners by their name or by presenting examples from learners' professional or private life. Further, the instructors delivered instruction mainly in a one-size-fit all approach. Learners were allowed much more learner control in the online learning environment compared to the face-to-face environments. In the online learning environments, they were free to select the sequence of topics; all topics were visible from the first lesson onwards. Nonetheless, learners did not have control over what activity to do in which topic; these were selected by the instructors. In the face-to-face context, learners were allowed to take control over additional exercises when others were still working on previous ones. Scaffolding throughout the duration of the course was done by shifting responsibility towards the learner. A lot of support was provided when learners solved exercises; the individual project received the least support. In the face-to-face context, instructors tailored support to the learners' capabilities by giving personal (verbal) feedback. In the online learning environments, instructors did not tailor support to the learners. The difference in interaction between the face-to-face and online contexts was remarkable. In the online learning environment, interaction focused on learner-content and learner-interface interaction. In the face-to-face context, interaction was more focused on learner-instructor and learner-peer interaction. Finally, both cues for reflection and for calibration were addressed the least in all environments described. Reflection cues for one's own learning were not provided, neither before, during nor after one's actions. If reflection cues were given, they entailed hypothetical mistakes learners could make while solving a specific exercise. Finally, some feedback was provided on specific content elements. In either case, no action was expected from the learners. The graphical representation of the four different courses can be found in Figure 1.

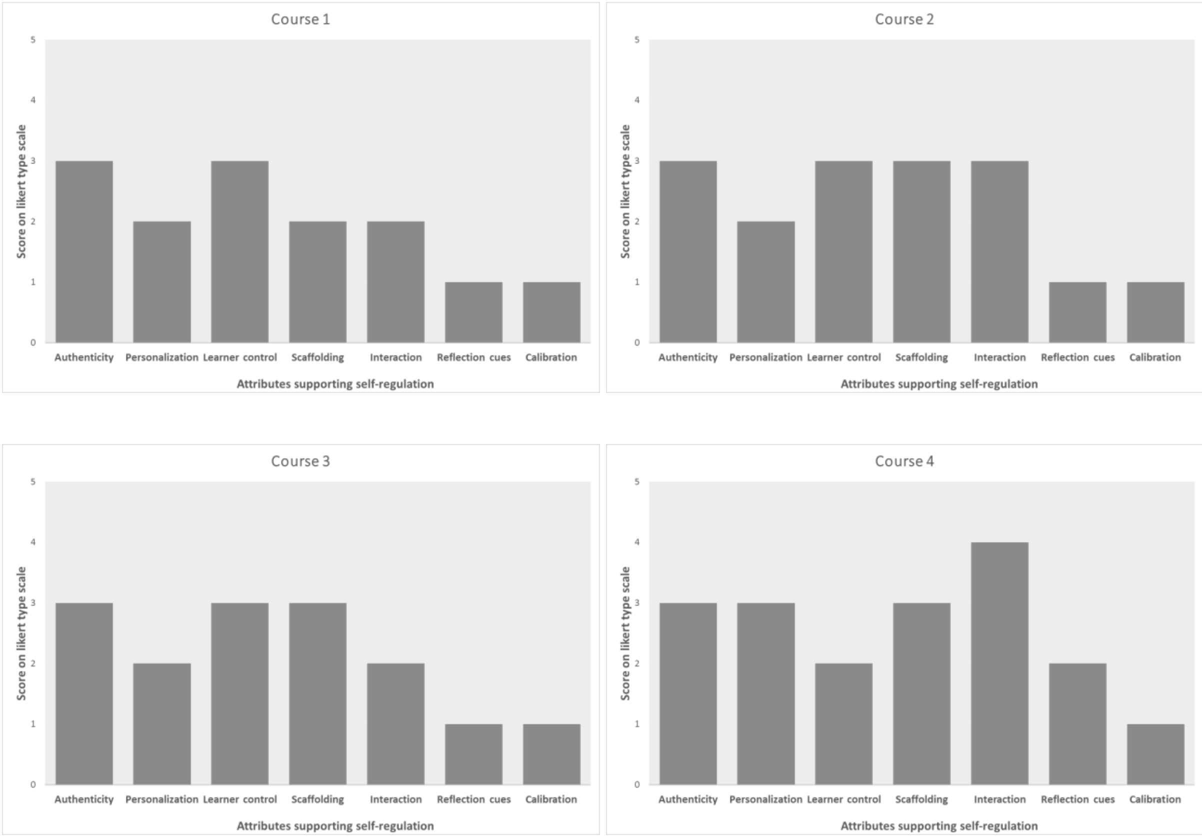

Figure 1. Mean score of attributes identified for each course in schools 1 and 2.

Based on their experiences, both raters discussed issues related to the use of the instrument and formulated recommendations for further development. Two issues arose. The first issue was the lack of concrete guidelines on how to interpret each attribute and its questions. The second issue related to the use of the Likert-type scales to report the occurrence of each of the attributes in the targeted blended learning environments. Although the Kendall's W was high, both researchers had the feeling that they did not had the same understanding of when to give what score on the Likert-type scale. To overcome these issues and to increase the inter-rater reliability further we aimed in phase three to improve the methodology used.

Phase 3

In the third phase, which took place in a study investigating the impact of learners' characteristics on their behaviour in blended learning environments, modifications were made based on the experiences of the first application of the instrument. These modifications included the integration of a two-hour rater training session and a rater manual to the methodology. Secondly, the instrument was applied for the second time in a different context.

Sample

We used two blended learning environments employed during a freshmen's Business Communication course taught at a university in the Philippines. The courses entailed three different modules. Topics addressed in the course were: writing letters, giving presentations, etc. Each course ran for eight weeks. The courses had different constellations of both online and offline components.

Blended learning environments

The first Business Communication course contained two face-to-face meetings, one at the start and one on the day of the examination. During the first lesson, the instructor introduced the materials and methodology of the course. Following this introduction, five online lessons were provided. The second course included four face-to-face lessons and two online lessons. It started and ended with a face-to-face lesson. In-between of these, every other week a face-to-face or online lesson took place. During the face-to-face lessons, the instructor provided the learners with the needed information and exercises to master the goals of the course. During the online lessons, the learners received extra exercises and small tasks. For both environments, each module started with the presentation of 'Theory', including general definitions and several examples. The conceptual part was followed by 'Exercises'; each of the exercises was framed in a similar context. After the completion of the last exercise of each topic, a practical test followed.

Procedure

Comparable to the previous phase, all online components (virtual learning environment) and off-line components (classroom environment) were registered. All the data was also uploaded onto the server for description. In contrast to the previous phase, four raters were involved in the description of each module of the two blended learning environments. The raters were the researcher, the instructor, one domain-expert-colleague, and one non-domain-expert colleague of the instructor.

Based on the reflections of phase two, two extra tools (rater training and rater manual) were used to improve the reliability of the descriptive instrument. On the one hand, a 2-hour rater training session was developed based on the conceptual background of the framework and the procedures to ensure reliability and validity. Three main actions were undertaken during the training. The first relates to the identification of a unit of analysis among the raters. During the training, the raters identified and agreed on a suitable unit of analysis for the description of the targeted blended learning environments. A second action related to the scoring of the different attributes. The raters discussed and agreed on when they would give each score to a question using the same scoring guidelines as used during phase one. The last action was the discussion of each of the attributes and their operationalized concepts and examples. In addition, all the guidelines formulated were also described in a rater manual developed to support the raters during the scoring. This manual contained the conceptual background of the framework and the procedures to ensure reliability and validity.

After the training, the four raters coded the two environments completely and independently by reviewing both the online and offline components of the course and filling out the descriptive instrument for each of the topics addressed. Finally, the inter-rater score was calculated in a similar fashion as in phase two.

Results

Based on the reports of the four raters the Kendall's W was calculated. The results showed that in phase two there was high agreement (Schmidt, 1997) between the four independent raters, $W = .776$, $p < .000$. These results show that the four raters highly agreed that both courses could be rated equally for all seven attributes. Authenticity of the both courses was similar, but differed depending of the nature of the topic. Authenticity was observed more when the topic was in direct relation to applications of a task (for example writing a complaint letter, compared to the introduction of the formal rules of writing a letter). Personalization in the online learning environment was primarily focused on the presentation of different contexts exercises could take place in. In both the online and offline environment, learners were for example free to choose what product they wrote a complaint letter for. Further, the instructors (both online and offline) delivered instruction mainly in a one-size-fit all approach. Learners were allowed equal learner control in the online learning environment compared to the face-to-face environments. In the online learning environments, they only were able to start exercises of each topic once the instructor made the exercises available. Similar, in the offline environment learners did not have control over what activity to do in which topic either. Scaffolding throughout the duration of the course was done by shifting responsibility towards the learner. A lot of support was provided when learners solved exercises in both contexts. In the face-to-face context, instructors tailored support to the learners' capabilities by giving personal (verbal) feedback. In the online learning environments, instructors did tailor support to the learners via the discussion forum. Although interaction was facilitated differently, the face-to-face and online contexts contained similar amounts of interaction. In the online learning environment as well as in the offline environment, interaction focused on learner-learner and learner-instructor interaction. Finally, both cues for reflection and for calibration were addressed the least in both courses. Reflection cues for one's own learning were provided, neither before nor during learners' exercises. If reflection cues were given, they focused only on prior-performance, they never looked into the future, nor did they investigate ongoing action. Some feedback was provided on specific content elements. In either case, no action was expected from the learners. It was concluded that all attributes were manifested equally in both course so that it was possible to compare both courses throughout. The graphical representation of the two different courses can be found in Figure 2.

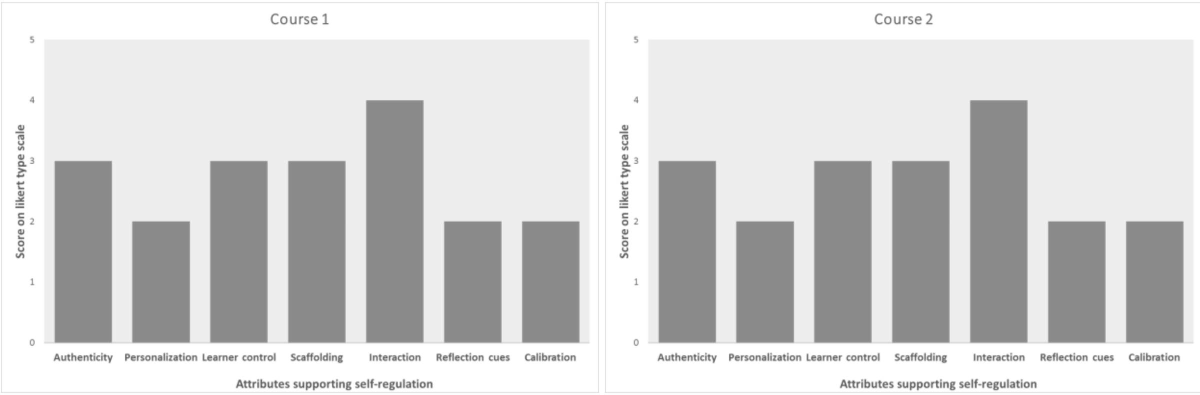

Figure 2. Mean score of attributes identified for each course.

Discussion and conclusions

This chapter presented an instrumentalized framework based on which support for learners' self-regulation in blended learning environments can be described and characterized. A conceptual framework was provided, consisting of seven attributes that support learners' self-regulation in blended learning environments. The combination of these attributes comprises a support system for learners' self-regulation in the learning environment. For each of the attributes, (i) a definition was formulated, (ii) findings from the literature that demonstrate a potential link between the attribute and self-regulation were gathered, (iii) the attribute's operationalization was developed and illustrated via examples, and finally (iv) each attribute was instrumentalized as a number of questions which together make up the overall instrument.

The next step was the development and validation of an instrument (and methodology) for describing and characterizing the support of learners' self-regulation in blended learning environments. In phase two the instrument achieved high reliability (W = .683, p < .033) for the entire sample coded, without the need for substantial rater training or guidance. In phase three the results showed that when the rater training (unit of analysis, scoring and discussion of the attributes) was applied and the raters were provided with a raters manual, inter-rater reliability among four learners increased significantly W =

.776, $p < .000$. The results of both phases indicate that the instrument is a reliable and valid instrument for its purpose.

The conceptual framework and current guidelines

Based on the outcomes of the instrumentalization of the conceptual framework we compared the conceptual framework presented in this chapter to on the one hand two highly regarded sets of guidelines related to the support of self-regulation (i.e., Ley & Young, 2001; Perry & Drummond, 2002; Perry et al., 2003) and on the other hand to more up-to-date literature focusing on guidelines for each of the attributes separately, often taking into account learner characteristics. We found that the conceptual framework presented in this chapter encompasses (though on different levels) the same elements as both sets of guidelines and current literature. In a post-hoc qualitative analysis it became clear that:

Authenticity as perceived in our framework relates closely to elements described by Perry and Drummond (2002) and Steiner (2016), who emphasize that learners should be engaged in authentic, complex, cognitively demanding activities. Complex authentic tasks address multiple goals, and result in the production of extensive knowledge and strategies (McCardle & Hadwin, 2015). Ley and Young (2001) and Oxford (2016) place similar emphasis on the nature of the learning environment in maximizing learners' learning.

With regard to *personalization*, Ley and Young (2001) and Guerra, Hosseini, Somyurek, and Brusilovsky (2016) indicate that when learners relate to the learning environment they will be able to identify information needed for their learning more appropriately. Perry and Drummond (2002) and Tabuenca, Kalz, Drachsler, and Specht (2015), on the other hand, add to this that personalization provides support for each learner's strengths and weaknesses.

Regarding *learner control*, Perry and Drummond (2002) and more recent Duffy et al. (2015) suggest that learners should take control of learning by making choices, controlling the level of challenge, and evaluating their work by doing so they are more likely to persist when difficulties arise (Stevenson, Hartmeyer, & Bentsen, 2017). For Ley and Young (2001) learner control relates to giving learners the possibility to deal with distractions and organize the learning environment according to their own needs (Murray, 2014).

With regard to *scaffolding* both Ley and Young (2001) and Perry and Drummond (2002) and many more in recent years (e.g., Lin, Lai, & Chang, 2016) indicate that the key to scaffolding is decreasing instrumental support for learners' learning and combining explicit instruction and extensive scaffolding to help learners acquire the knowledge and skills they need to complete complex tasks.

Regarding *interaction*, Perry and Drummond (2002) and Järvelä, Järvenoja, Malmberg, Isohätälä, and Sobocinski (2016) indicate that learners should actively interact with others to construct new insights and strategies to deal with changes. Ley and Young (2001) and Kuo et al. (2014) emphasize that learners should constantly be exposed to examples and interactions showing a variety of strategies they are able to apply.

Finally, in line with the conceptual framework presented in this chapter, the sets of guidelines proposed by Perry and Drummond (2002) and Ley and Young (2001) and current literature (e.g., Bannert et al., 2015; Verpoorten, Westera, & Specht, 2017) also considers *cues for reflection* (triggers for monitoring) and *cues for calibration* (effective monitoring) to be essential. This body of literature emphasize the organization of instruction and activities to support metacognitive processes and the use of instructional goals and feedback to present the learner with monitoring opportunities.

The investigation of current guidelines to support learners' self-regulation in the light of the conceptual framework described in this chapter shows that the framework presented here contains similar elements as included in the guidelines proposed by Perry and Drummond (2002), Perry et al. (2003) and Ley and Young (2001) and by more to date literature on each of the attributes separately. This finding not only validates the conceptual basis of our framework but may also serve as a starting point for its further elaboration towards guidelines for designing blended learning environments supporting learners' self-regulation based on ongoing empirical trials.

The instrumentalized framework and designing blended learning

Despite its conceptual similarities to the models described above, the instrumentalized framework presented in this study does not suggest any guidelines on how to (re)design blended learning environments to support learners' self-regulation. Nor does it provide a clear demarcation between the different attributes, as to date no such demarcation has been established conclusively in the literature. Instead, the aim of the instrumentalized framework presented in this chapter is to help researchers and practitioners characterize and describe blended learning environments by identifying these attributes and operationalizing them as an instrument. This is achieved using a systematic approach to investigating and supporting self-regulation in blended learning environments. An important remark with regard to the latter is that while using this instrumentalized framework can improve the design of the blended learning environment with regard to support for self-regulation, this can only be achieved through continuous redesign and testing against empirical trials.

Limitations and considerations

While the instrumentalized framework presented has proven its value for research and practice, certain considerations and limitations should be pointed out. A first set of considerations relates to the underlying conceptual framework. As argued by theorists of the self-regulation concept, self-regulation is influenced by variables within and external to the learner (Winne & Hadwin, 2013). This chapter focuses on the latter type of variables, yet self-regulation theory hypothesizes that combinations of the two types determine the self-regulatory behaviour of learners, resulting in different impacts for learners with different learner variables. Although the conceptual framework presented does not give guidelines on how to operationalize each of the attributes in relation to learner variables, it provides the means to investigate them in relation to each attribute. A good example of such an investigation might be a study investigating the amounts of learner control beneficial for skilled learners versus inexperienced learners (e.g., Niemiec, Sikorski, & Walberg, 1996). Further research is still needed to clarify the relation of each of the attributes to learner variables.

With regard to the attributes themselves, it must be acknowledged that the conceptual framework only provides principles for describing and thus characterizing blended learning environments, not for designing them. Although this gives a clear idea of how each attribute can be defined and identified within blended learning environments, it also leads to unclear demarcations and overlap. It should be kept in mind that the aim of this instrumentalized framework is to enable the characterization of the blended learning environment, not its redesign. To be able to identify and analyse new research and insights, which could contribute to the characterization of blended learning environments, Van Laer and Elen's (2016) systematic review should be repeated over time. The way in which the attributes are currently described and illustrated is conceptually up-to-date, but the literature is rather dated. In addition, the framework ignores the possibility that certain combinations of attributes might be more beneficial than others. Such hypotheses are often illustrated by research findings that highlight (for example) that a combination of cues for both reflection and calibration have a higher impact on learning than when only cues for reflection are provided (Bannert et al., 2015). Further research is needed to investigate which combinations of attributes are most suitable for which types of learner.

The final consideration in relation to the conceptual framework is the focus on blended learning. As each of the attributes was derived from research deliberately aimed at combined online and offline interventions, we expect the framework to be applicable to blended learning environments. Based on previous findings about the impact of technology on learning (e.g., Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011) we hypothesize that the conceptual framework can also be applied in purely online and purely offline contexts. Further research on the applicability of the framework in purely online or offline environments would improve the generalizability of the conceptual framework.

A second set of considerations relates to the instrument itself. On the one hand, there is the grainsize used for the description of the occurrence of each of the attributes. In contrast to frameworks which focus on detailed descriptions of learning environments (per minute or hour), we adopted the ‘principle’ approach in a context where units of analysis are the themes, modules or topics covered over a number of weeks. Although this approach is common practice in instructional design theory (e.g., Merrill, 2012), it is rarely applied to investigating support for learners’ self-regulation from an educational-psychological perspective (Winne & Hadwin, 2013). However, as in Perry et al. (2003), such an approach might also be desirable, especially for feasible course (re)design.

On the other hand, there is what appears to be the quantitative, summative approach to the instrument. Because we used an Excel spreadsheet to score each attribute, it might appear that each unit of the course is scored based on quality. As mentioned above, however, this is not the aim of this instrument (see Likert-type scale used). The sole goal of the instrument is to map the actual character of a blended learning environment. Based on this state redesigns can be made, which can be evaluated using any subsequent changes in learners' self-regulation.

Conclusions

While the instrumentalized framework presented has its limitations and further research is needed to optimize its capabilities, this chapter has attempted to illustrate that it contributes to existing literature and practice in two ways. Firstly, by providing both a conceptual framework and an instrument focusing on the characterization of support for learners’ self-regulation, we are to the best of our knowledge the first to focus on support for self-regulation in blended learning environments. The instrumentalized framework makes it possible (a) to describe and thus characterize blended learning environments in terms of self-regulation; (b) to provide, based on this characterization, a starting point for investigations to overcome design issues related to learners’ self-regulation in blended learning environments (e.g., Kuo et al., 2014); and (c) to advance the design of blended learning environments more systematically by monitoring its characteristics.

Secondly, research and practice will benefit from this more systematic approach to describing and characterizing support for self-regulation in blended learning environments. The ability to describe (blended) learning environments in a systematic and replicable way opens doors to an array of research opportunities and practical interventions and thus facilitates further investigation of self-regulatory issues. It also makes it possible to investigate the impact of each attribute and combinations of attributes in relation to differences in learner variables, thus allowing designers to target learners' self-regulation more accurately.

Chapter Three

Measuring self-regulated learning

The text of this chapter is under review for publishing in the special issue: Measurements of learning - Emerging chances and challenges of process measures in *Frontline Learning Research*. [Van Laer, S., & Elen, J. (2018). Towards a Methodological Framework for Sequence Analysis in the Field of Self-Regulated Learning. *Frontline Learning Research*, **under review**.]

Introduction

Over the last five decades, multiple theoretical conceptualizations and practical operationalizations have been proposed for self-regulated learning (SRL), shifting the focus from SRL as an aptitude to SRL as an event (e.g., Endedijk et al., 2016; Panadero, Klug, & Järvelä, 2016; Winne, 2016). Besides this shift, technological developments have meant that computer log files now have a role to play in investigations of learners' SRL. From both theoretical and practical perspectives, computer log files are an interesting avenue for investigating learners' SRL (e.g., Azevedo & Hadwin, 2005; Winne, 2005; Zimmerman & Schunk, 2001). On the one hand, their sequenced structure means that computer log files possess time-related characteristics relevant to the current conceptualization of SRL as an event (e.g., Azevedo, 2014; Ben-Eliyahu & Bernacki, 2015; Molenaar & Järvelä, 2014). On the other hand, their unobtrusive nature enables us to observe traces of SRL in learners' behaviour in ecologically valid contexts (e.g., Bourbonnais et al., 2006; Hine, 2011).

While sequence-based analysis has only become popular as a means of investigating the time-related characteristics of SRL within the last ten years, other fields of research (e.g., bioinformatics, chemistry, marketing, and sociology) have longstanding traditions in the use of such analyses. Insights gained from these fields may serve as a basis for applying sequence analysis in investigations of SRL (e.g., Perer & Wang, 2014; Winne & Baker, 2013). A decade of log file sequence analysis in SRL research has produced a large amount of relevant work (e.g., Azevedo, Taub, & Mudrick, 2015; Bannert, Molenaar, Azevedo, Järvelä, & Gašević, 2017; Molenaar & Järvelä, 2014; Roll & Winne, 2015) and a variety of methodological approaches. While theory-driven approaches for example prefer to recode log files to theoretically meaningful events, predefine the length of an ideal sequence, or set the threshold for significance (e.g., Roll & Winne, 2015; Winne, 2010), data-driven approaches often prefer to extract the most common sequences from the data, regardless of their content and length (e.g., Bannert et al., 2017; Beheshitha, Gašević, & Hatala, 2015). Differences with regard to the statistical analyses used can also be found. Some researchers investigate the occurrence of for example particular sub-sequences as varying from learner to learner and apply multi-level analysis (e.g., Taub, Azevedo, Bouchet, & Khosravifar, 2014; Taub, Azevedo, Bradbury, Millar, & Lester, 2018),while others focus on clusters of learners and instead apply chi-square analysis (e.g., Van Laer & Elen, 2016a; Van Laer, Jiang, & Elen, 2018) or variance analysis. Still others argue that statistical analysis based on sub-sequences is insufficient to establish a full picture of learners' learning patterns and prefer to use stochastic models based on the entire sequences to operationalize the investigation of learners' behaviour (e.g., Bannert et al., 2015). This multitude of approaches demonstrates not only the diversity of opportunities, but also the lack of consensus regarding the most appropriate methods. This lack of consensus often results in fragmentation, leading to non-transparent research practices and research reports, hampering the validation and testing of methods and thus the advancement of the investigation of SRL through sequence analysis. In line with this observation, researchers have been emphasizing the need for a methodological framework to guide the application of log file sequence analysis in SRL research since 2014 (e.g., Azevedo, 2014; Bannert et al., 2014; Molenaar & Järvelä, 2014). Such a methodological framework could, on the one hand, provide a decision-tree-like approach to choosing which analysis to perform when (Schnaubert, Heimbuch, & Bodemer, 2016) and, on the other hand, offer guidelines for reporting on each of the steps taken and considerations made. Yet, to date, no methodological frameworks have been proposed (e.g., Segedy & Biswas, 2015; Winne, 2014), hindering our ability to validate, duplicate, and so to demonstrate progress in the use of sequence analysis in SRL research and our search for the most appropriate methods (Kuhn, 2012).

Therefore, in this manuscript we discuss a methodological framework for the application of sequence analysis in the field of SRL. To do so, we first make a case for why such a methodological framework is necessary. Secondly, we propose a set of guidelines which may serve as a starting point for the construction of a framework. With a methodological framework in place, the investigation of time-related characteristics in SRL using sequence analysis could evolve towards (1) the use of transparent methods, (2) comparative studies, and (3) empirical and ecological applications, supporting both research and practice. In what follows, we first define sequence analysis, elaborate on its link to SRL and introduce the most common phases in its operationalization, providing an illustrative example from one of our own studies. The illustrative example used in this manuscript is not intended as a good practice, but a demonstration of the complexity of sequence analyses and the decisions to be made. At the end of this introductory section, we outline the operational efforts made in the search for tangible proof of progress in sequences analysis for the investigation of learners' SRL as a method. Based on insights gathered from the introductory section, the second section proposes a set of guidelines upon which framework construction can be based. In the third and final section, we elaborate on the implications for research and practice and suggest further directions in the construction of a methodological framework for sequence analysis in the field of SRL.

Sequence analysis

A sequence (β) is an ordered list of elements (β = < A, C, B, D, E, G, C, E, D, B, G >) (Zhou, Xu, Nesbit, & Winne, 2010). Such elements can be physical, behavioural, or conceptual in nature. The analysis of a sequence makes it possible to discover hidden time-related relations between different sequences, parts of these sequences, and the individual elements within these sequences (Antunes & Oliveira, 2001). Sequence analysis therefore is indispensable in many application domains (e.g., bioinformatics, chemistry, marketing, sociology, and education) (Liu, Dev, et al., 2016) and approaches are plentiful. For example in bioinformatics sequence analysis is the process of investigating a deoxyribonucleic acid (DNA) sequence to understand its features, function, structure, or evolution (e.g., Lubahn et al., 1988; Stackebrandt & Goebel, 1994). In chemistry, sequence analysis comprises the determination of the sequence of a polymer formed of several monomers (e.g., Martin, Shabanowitz, Hunt, & Marto, 2000; Van Krevelen & Te Nijenhuis, 2009). In marketing, sequence analysis on its turn is often used in analytical customer relationship management applications, such as next product to buy models (e.g., Kumar, Venkatesan, & Reinartz, 2004; Prinzie & Van den Poel, 2007). In sociology, sequence methods are increasingly used to study life-course and career trajectories, patterns of organizational and national development, conversation and interaction structure, and the problem of work and family synchrony (e.g., Bonin, Vogel, & Campbell, 2014; Stark & Vedres, 2012). Finally, in recent years the field of education also gained interest in the investigation of sequence data. Methods have been increasingly used in the context of data analysis to investigate learning processes (Reimann, Markauskaite, & Bannert, 2014). One distinct area of learning research in which sequence-analysis methods have been used is SRL-research, in particular for studying regulation and metacognition in students' learning through computer log files (e.g., Azevedo, Moos, Johnson, & Chauncey, 2010; Zhou et al., 2010). Computer log files gathered from learners' interaction with online learning environments are the most know and potentially the least obtrusive way of gathering data with regard to learners' SRL behaviour. Such log files are gathered through clickstreams. Clickstreams are also known as click paths, or the route that learners choose when clicking or navigating through an online learning environment. A clickstream is a list of pages visited by a learner, presented in the order the pages are visited (also defined as the 'succession of mouse clicks' that each learners makes). Based on the sequence of the visited pages, researchers attempt to map learners' SRL processes.

Self-regulated learning and its measurement

As learning in general is seen as an activity performed by learners rather than something happening to them as result of instruction (e.g., Bandura, 1989; Oliver & Trigwell, 2005) it entails a self-regulated process through means of which learners' regulate their behaviour according to the instructional demands (Zimmerman & Schunk, 2001). To be successful learners, learners need to self-regulate their learning. This assumption is evidenced by a substantial body of literature showing scores on self-regulated-learning-related variables to be strongly positive correlated and to have causal relations with scores on performance-related variables (e.g., Daniela, 2015; Lin, Coburn, et al., 2016). The theoretical conceptualization of SRL evolved from SRL as an aptitude to SRL as an event. The aptitude approach on the one hand sees SRL as in-person, across situations (aggregated over or abstracted from behaviour), and stable from a certain age onwards (e.g., Veenman, 2007; Winne & Perry, 2000). The event approach, on the other hand, conceptualizes SRL as a cyclical process unfolding in roughly three phases (forethought, performance and evaluation) (e.g., Boekaerts, 1992), influenced by variables internal and external to the learner (e.g., Winne & Hadwin, 1998). Additionally, the event approach also sees SRL as covert in nature and so requires inferencing through learners' behaviours and behavioural consequences (e.g., Veenman, Prins, & Verheij, 2003). Although both approaches are still used in research, over the past three decades the event approach gained considerable interest and dominated the investigation of learners' SRL (see: Puustinen & Pulkkinen, 2001).

In line with the shift of conceptualization of SRL, also the conceptualization of measurement approaches to capture it evolved. Measurements shifted from single measurements administered before or after the execution of a task to continuous measurements administered during the execution of the task (Winne & Perry, 2000). The latter type of measurement is referred to as an on-line measurement whereas the former is referred to as the off-line measurement of SRL (Pintrich, 2004). Following the shift in conceptualization of the SRL concept, the use of offline measurements based on learners' perceptions (e.g., self-reports) came under stress (Endedijk et al., 2016). This is mainly because these types of measurements assume learners are capable to predict, reflect, or estimate in general terms (prior or after a task) how they will act in a certain context and subsequently rely on learners' perceptions about their own SRL rather than on the actual account of SRL they exhibit (Veenman et al., 2014). The interest in sequence data and sequence analysis in SRL taps in into the cyclical nature of SRL and has been particularly fuelled by improvements in technical capabilities. The recording of learning-related behavioural data that are suitable for quantitative analysis has become almost effortless and unobtrusive for the learners in computer-based learning environments (Winne et al., 2017), making this type of data particularly interesting for both practice and research. Examples of this usefulness are, the mining of theory-based patterns from big data to identifying SRL strategies in massive open online courses (Maldonado-Mahauad et al., 2018), the finding of traces of SRL in activity streams (Cicchinelli et al., 2018), or the assessment of online learning material and its relation to learners' quantitative behaviour patterns and their effects on motivation and learning performance (Yang et al., 2018). Applications are plentiful.

Sequence analysis in the field of self-regulated learning

In the field of SRL in general sequence analysis refers to a sequence as an ordering of observable behavioural events preceded and followed by an unknown behavioural state (e.g., Du, Plaisant, Spring, & Shneiderman, 2016; Köck & Paramythis, 2011). Simply put, each change of state is an event, and each event implies a change of state (Müller et al., 2010). For example, an assumed behavioural state could be reading a content page in an online learning environment, while clicking the calendar tool would be an observable behavioural event that changes the behavioural state of a learner to viewing the calendar page. Through the investigation of ordered observable behavioural events (sequence), researchers try to gain insights in the unknown behavioural states learners are in (Molenaar & Järvelä, 2014). This investigation leads to three types of research questions: (1) questions about the nature of the sequences of the observed events, (2) questions about variables that affect those sequences, and (3) questions about the variables affected by the sequences (Abbott & Tsay, 2000).

To gain a brief insight into the variety of approaches that can be used to handle each of these questions, below we illustrate how the investigation of them can be operationalized. This will be done based on three common phases in the investigation of sequential data in the field of SRL (e.g., Liu, Dev, et al., 2016; Zhou, 2016). These phases are: (1) the pre-processing phase, (2) the mining and characterization phase, and (3) the analysis phase. Secondly, we provide an illustrative example highlighting (1) the complexity of sequence analysis, (2) the theoretical and methodological choices and considerations to be made, and (3) the reporting of the methods used, illustrating the need for agreed upon frameworks to be able to conduct and report sequence analyses transparently.

Data structure

As the raw computer log file data gathered functions as the input and absolute basis for sequence analysis (Coronel & Morris, 2016), we will start with the description of the data structure of sequence data before elaborating on the different phases of sequence analysis itself. The most common data format of raw computer-log-file data is the time stamped event (TSE) format (Gabadinho, Ritschard, Mueller, & Studer, 2011). A TSE-dataset contains at least three columns: (1) the timestamp of the observable behavioural event, (2) a personal identifier of the learner, and (3) an event name (of the observable behavioural event). Examples of event names are the names of each element in the online learning environment (e.g., discussion form, content page, exercise, etc.), areas on the screen learners clicked, or clicking actions (e.g., Caprotti, 2017; Cicchinelli et al., 2018; Maldonado-Mahauad et al., 2018).

Pre-processing

In a first phase of the sequence-analysis method the raw data is pre-processed (e.g., Zhou, 2016). This pre-processing phase generally consists of two steps. The first step relates to the question: “Is there a need for recoding the raw data?” If there is a need (i.e., deductive approaches) to recode the raw data, this happens using an action library. Such a library specifies the links between the observed events and the recoded, conceptualized concept. Examples of these practices include action libraries based on the strict recoding of events or clusters of events using SRL theories (e.g., Winne et al., 2017), originating from either think-aloud coding schemes or pure theoretical conceptualizations (e.g., Bannert et al., 2015; Taub et al., 2018). Another illustration is the coding of computer log files using a tool-related coding scheme (e.g., Lust, 2012; Lust, Vandewaetere, Ceulemans, Elen, & Clarebout, 2011; Siadaty, Gašević, & Hatala, 2016a). If there is no need (i.e., inductive approaches) to recode the data, the raw data (as is) can be used (e.g., Kurki, Järvenoja, Järvelä, & Mykkänen, 2017; Van Laer & Elen, 2016a). The second step in the pre-processing phase involves assigning an ordered list of events to each learner, resulting in a single sequence per user (Gabadinho et al., 2011). While the chronological ordering of the observed events suffices for the investigation of the sequential nature of such a sequence, the investigation of the temporal characteristics of a sequence will require the calculation and addition of the distance (time) between consecutive events to the sequence. Based on the compilation of a single sequence per learner, sub-sequences and models can be mined and characterized.

Mining and characterization

After the raw data is pre-processed to a single sequence per learner, research questions related to the characteristics of sequences can be investigated. Research questions are plentiful and pertain to the investigation of either whole sequence (β) or sub-sequences (α). A sub-sequence (α) is part of a sequence (β) if the sub-sequence (α) can either directly (α = < B, D, E, G >) or indirectly (α = < C, E, G, E >) be formed from the sequence (β = < A, C, B, D, E, G, C, E, D, B, G >) (Zhou et al., 2010). The most common approach to mining and characterizing sequences and sub-sequences is called the algorithmic approach (e.g., Kinnebrew, Loretz, & Biswas, 2013; Perez et al., 2017; Poole, Lambert, Murase, Asencio, & McDonald, 2016). This approach assumes the relation between the different events is unknown and therefore attempts to create meaning from the events that have already occurred by investigating the statistical relationships among them (Breiman, 2001). Efficient algorithms for discovering these characteristics have been proposed in statistical literature. The prominent algorithms are those of Bettini, Wang, and Jajodia (1996), Srikant and Agrawal (1996), Mannila, Toivonen, and Verkamo (1997), Zaki (2001) and Masseglia, Teisseire, and Poncelet (2002). All the algorithms require parameter settings. Examples of these parameter settings are (1) time constraints of the occurrence of an event or sub-sequence, (2) a method for counting the occurrences of events and sub-sequences, and (3) a threshold for the identification of frequently occurring events and sub-sequences. Once the parameters are defined, of-the-shelve software tools makes it possible to apply algorithmic approaches and to identify typical sequences (models), frequent events, and frequent sub-sequences.

Common platforms for performing this identification include PROM (process mining workbench), developed by Van der Aalst (2016), SPAM (Sequential Pattern Mining) by Ayres, Flannick, Gehrke, and Yiu (2002), or the TraMineR (trace mining in R) package developed for R-statistics by Gabadinho et al. (2011). An extensive overview of algorithmic tools can be found in Slater, Joksimović, Kovanovic, Baker, and Gasevic (2017). Besides the algorithmic approach described above, there are also other approaches (for an extensive overview see: Poole et al. (2016)). Examples are theory-driven approach (e.g., Cleary, 2011) which hypothesize the characteristics of sequences and sub-sequences and stochastic approach focussing on whole-sequence modelling (e.g., Biswas, Jeong, Kinnebrew, Sulcer, & Roscoe, 2010; Jeong, Biswas, Johnson, & Howard, 2010). Once sequences and sub-sequences are mined for and characterized they can be used as variables in statistical trials.

Analysis

When investigating sequences in the light of SRL, we may be interested to know how sequences or sub-sequences are impacted by variables internal or external to the learners (e.g., Winne & Baker, 2013). For example when providing an instructional intervention to learners, we might want not only to see the change in learners' learning outcomes but also the change in the occurrence of particular sequences or sub-sequences. Another example might be that we want to compare sequences or sub-sequence of learners with low or high motivation (e.g., Duffy & Azevedo, 2015; Jovanović, Gašević, Dawson, Pardo, & Mirriahi, 2017). In other words we may want to explore which sequences or sub-sequences discriminate most when different groups' sub-sequences or averaged sequence are compared. To answer such questions, various approaches have been proposed for the incorporation of sub-sequences and sequences as dependent variables. The approach of Studer, Mueller, Ritschard, and Gabadinho (2010) consists of measuring the strength of association of each sequence or sub-sequence with the considered covariate and selects the sequence or sub-sequences with the strongest association. The association is measured with the Pearson independence Chi-square. The most discriminant one is the one with the highest Chi-square. Another approach proposed by Kinnebrew et al. (2013) relies on multiple comparisons by t-test statistics between groups based on the considered covariate. The t-test is not used to prove that the groups of sequences differ. Instead, it is employed as a heuristic for identifying more interesting sub-sequences in an exploratory analysis. This is done for example by determining with 95% confidence that a frequent sub-sequence is shown to be different between the groups. Besides these common methods multi-level modelling (e.g., Taub et al., 2016), regression analyses (e.g., Segedy, Kinnebrew, & Biswas, 2015), or Spearman correlation analysis (e.g., Kizilcec et al., 2017) are also used.

Besides the investigation of variables influencing sequences, we can also investigate the influence of sequences on another variable. In the field of SRL an example could be the impact of the occurrence of a specific sequence on group performance (e.g., Molenaar & Chiu, 2015). Such research questions investigate the dissimilarities between different sequences (e.g., Abbott & Tsay, 2000; Aisenbrey & Fasang, 2010). These dissimilarities are commonly measured using the optimal matching edit distance. The optimal matching edit distance is defined as the minimal cost of transforming one sequence into the other (e.g., Biemann & Wolf, 2009; Mazon, Rossi, & Toledo, 2014). The transformation operations considered by the optimal matching edit distance are (1) the insertion/deletion cost and (2) a change in the temporal distance resulting in the transformation from one sequence or sub-sequence to another. Event dependent costs can be specified both for the insertion/deletion of an event as well as for a one-unit change in the temporal distance of given events. Both the insertion/deletion and temporal distance cost result in a distance matrix between sequences themselves. This matrix can then be used in classification methods as well as in scaling methods to investigate the relation between various sequences (e.g., Maldonado-Mahauad et al., 2018; Segedy et al., 2015).

An illustrative example of sequence analysis

Earlier we provided a condensed overview of different choices to be made at each phase of the sequence analysis process. To further illustrate the complexity of sequence analysis, the choices to be made, and the reporting of the methods used we provide an example of a study applying sequence analysis. In the study presented, we investigated the impact of reflection cues on learners' SRL. An event approach to SRL was chosen focussing on SRLs' cyclical, influenceable, and covert nature. SRL was operationalized through learners' learning behaviour and learners' learning outcomes. Two research questions were addressed: the first one investigated the impact of reflection cues on (a) learners' learning behaviour and (b) on learners' learning outcomes. The second research question investigated how learners' learning outcomes related to by learners' learning behaviour. To answer these questions, a 2x2 mixed factorial design was applied and data was gathered from 60 learners in second chance adult education. Half of the group was exposed to additional cues for reflection; the learners in the control group were not. Learners' behavioural data existed of computer-log-file data gathered through an online learning environment in an ecologically valid setting. Learners' learning outcomes were assessed through cognitive (domain knowledge), motivational (goal orientation), and metacognitive (learning effort and learning confidence) tests and questionnaires. The computer-log-file data gathered had the TSE-format. The event names were actions learners' could perform in the online learning environment (i.e., post in the discussion forum; submit assignment; etc.). As a unit of analysis we used the entire eight week course and instructional stability throughout the eight weeks was described using the instrument of Van Laer and Elen (2018). No validated operationalizations of sequence analysis based on the conceptualizations of the cyclical, influenceable, or covert nature of SRL could be retrieved to direct the operationalization of our investigation. To deal with the issue of the lack of operationalizations, we decided to follow an approach staying as close to the observed data as possible. An inductive rather than a deductive approach was followed to avoid non-transparent alignment between conceptualization and operationalization. In line with this approach, we limited the assumptions made by (1) taking only into account observed overt events, (2) focussing only on the sequential aspects of computer-log-file data, and by (3) not conceptualizing the evolution of SRL through the course of SRL resulting on directly observable patterns via frequent sub-sequences rather than the extraction of behavioural models.

The pre-processing of the data resulted in one (eight week long, +/- 10000 events) sequence of ordered raw behavioural events per learner. No recoding was applied, nor was time between events calculated. In the mining and characterization the TraMineR algorithm (Gabadinho et al., 2011) was used in R-statistics to investigate learners' sequences through the investigation of directly observable patterns via frequent sub-sequences. The identification of frequent sub-sequences was based on (1) the time constraints of the occurrence of events in the observed sub-sequences, (2) a counting method for counting the occurrences of sub-sequences, and on (3) a threshold for the identification of frequently occurring sub-sequences. As only directly observable sub-sequences were targeted, the parameter for the distance between events was set to one, representing that only events directly observed before or after a certain event could be seen as part of a sub-sequence. The counting method chosen was selected arbitrary, based on the occurrence of sub-sequences over the different learners. The frequency threshold was set to 25% meaning that at least 25% of the learners should exhibit the sub-sequence to be counted as frequently occurring. 688 frequent sub sequences were observed.

Next, we investigated frequent sub-sequences' relationship with (1) the condition learners were in (impact of cues on behaviour) and (2) learners' learning outcomes (relations between outcomes and behaviour). In the analysis phase, the frequent sub-sequences were used as dependent variables. For this analysis, chi-square tests were used containing the frequent sub-sequences for discriminating the groups and the variables that defines the groups (condition and learners' learning outcomes). Based on these tests, the effect sizes were calculated using Cramer's V. The Cramer's V expresses the relation between a certain discriminating frequent sub-sequence and the learners' characteristics and is reported in a value between zero and one. The closer to one the higher the relation is. Cohen (1988) refers to small (≤.30), medium (≥.30 and ≤50), and large (≥.50) effect sizes.

With regard to the first research question dealing with the investigation of the impact of reflection cues on (a) learners' learning behaviour and (b) on learners' learning outcomes, learners in the experimental condition were shown to make significantly more use of sub-sequences consisting of events related to assignments and tasks, communication, and assessment. Furthermore, both conditions showed a significant increase in domain knowledge and learning confidence and a decrease in performance goal approach. Learners in the experimental condition who received cues for reflection scored significantly higher on performance goal approach compared to the learners in the control condition. As for the interaction effect between time and condition, learners in the experimental condition scored significantly higher for performance avoidance approach compared to their counterparts. This result was unexpected in the light of the aim of the study (Van Laer et al., 2018). Finally, with regard to the second research question dealing with the investigation of how learners' learning outcomes related to by learners' learning behaviour, it became clear that changes in learning behaviour seemed to be linked to learning outcomes (performance avoidance approach). Results showed that differences in learners' learning behaviour were observed when learners had different performance avoidance approach scores.

Towards tangible proof of progress

As research aims at either at building or testing theory, the research cycle moves from description, to explanation, to testing with repeated iterations through this cycle (Van der Merwe, 2013). Throughout this iterative process, descriptive models are expanded into explanatory frameworks that are tested against reality until they are eventually developed into theories as research study builds upon research study. The result is to validate and add confidence to previous findings, or else invalidate them and force researchers to develop more valid or more complete theories (Meredith, 1993). In this way both (1) theoretical conceptualizations of the theory under investigation and their (2) operationalization through measurements are continuously updated and refined. As illustrated throughout the different paragraphs presented above, different operationalizations of sequence analysis can be made. The illustrative example has shown one of these operationalizations.

To be able to monitor methodologies' evolution towards tangible proof of progress and so secure the iterative research cycle, the literature on advances in research methodology (e.g., Beach & Pedersen, 2013; Lupia & Alter, 2014) proposes three indications of such an evolution. The first one is the transparency of the method applied (Moravcsik, 2014). Transparently reported methods permit scholars to assess research and to communicate with one another. Unless other scholars can examine evidence, parse the analysis, and understand the processes by which evidence and theories were chosen, why should they trust and thus expend the time and effort to scrutinize, critique, debate, or extend existing research? As demonstrated earlier, a lot of explorative work on the use of sequence analysis has been done, yet most of the studies do not seem to report in detail on the different phases of sequence analysis or on the parameter settings involved in each of them, hampering a thorough study of the method applied. When literature on the investigation of SRL through sequence analysis reports on the log file data structure (e.g., Biswas, Roscoe, Jeong, & Sulcer, 2009; Duffy & Azevedo, 2015; Lazakidou & Retalis, 2010), it often does this through elaborating on the events traced: clicks, pages, specific cognitive or metacognitive activities, and so on. Despite the information on the events traced, additional information on the structure of the data, such as the timestamp interval or type of timestamps, session identifiers, etc., is hardly provided. This information is important to distinguish which pre-processing steps are possible or desirable (e.g., calculation of time between events, grouping of learners or individuals, etc.). With regard to this pre-processing phase, in the best cases researchers acknowledge they developed a set of filters or recoding algorithms to remove irrelevant information from the raw log files, with the aim of presenting the relevant information in a compact format that is suitable for further analysis (e.g., Jeske, Backhaus, & Stamov Roßnagel, 2014; Paans, Molenaar, Segers, & Verhoeven, 2018). Nonetheless they hardly ever elaborate on which information was discarded and what made the researcher assume this information could be classified as irrelevant. When for example action libraries are used (e.g., Bannert et al., 2014; Goldberg et al., 2014) researchers elaborate on the coding scheme, but lack to state how the 'raw' events are recoded and what the reliability of this recoding was like. Without this information it is impossible to distinguish which coding scheme is most reliable and works best for what data. In line with this, no studies seem to be available which argue for the selection of a certain coding scheme or elaborate on why a certain coding scheme is preferable over another. With regard to the mining and characterization of sequences, most of the current literature seems to indicate which algorithms are used to identify or mine (frequent) sub-sequences. Nonetheless, the authors rarely seem to address the assumptions underlying the algorithm used (e.g., Balderas, Dodero, Palomo-Duarte, & Ruiz-Rube, 2015; Lan & Lu, 2017) or the procedure followed to select the appropriate algorithm (e.g., Kizilcec et al., 2017; Maldonado-Mahauad et al., 2018), let alone the parameter settings applied when mining for sub-sequences. The same is the case when the (frequent) sub-sequences are used as dependent or independent variables. The analysis methods used to answer similar research questions vary from researcher to researcher (Ahmadpour & Khaasteh, 2017; Cerezo, Esteban, Sánchez-Santillán, & Núñez, 2017; Chen, Breslow, & DeBoer, 2018). Traditional cluster analysis and predictive apriori algorithms are used to identify sets of successful learner and environmental characteristics impacting performance, without any explanation of why a certain approach might be considered superior to another. The multitude of methods and the observation of the lack of transparency make the studies unreplicable.

The second characteristic relates to the availability of comparative research designs (e.g., Bureau & Salomonsen, 2012; Peterson, 2005). Comparison is one of the most powerful tools used in intellectual inquiry, since an observation made repeatedly is given more credence than a single observation. Put simply, as argued by Mills, Van de Bunt, and De Bruijn (2006) the main goal of comparative research is to search for or identify variance or similarity. Although there is quite some comparative research on the measurement of SRL, the majority of it focusses at best on the comparison of online behaviour event measurements (i.e., sequence analysis) with offline perception event measurements (i.e., self-reports) (e.g., Cho & Yoo, 2017; Hadwin, Nesbit, Jamieson-Noel, Code, & Winne, 2007). Even at the most basic level of comparison, namely the use of different coding schemes to recode the 'raw' event captured in log files, there seems to be hardly any evidence on which coding scheme results in the most accurate results under which conditions (Azevedo, 2014). Although there are useful summaries of approaches and tools (e.g., Slater et al., 2017) as well as ample ideas on how to apply sequence analysis (e.g., Azevedo, Moos, et al., 2010; Winne, 2018; Winne et al., 2017), no discussion of different sequence analysis methods could be found in the field of SRL. Based on this observation, research comparing different sequence analysis approaches for SRL seems to be missing. This would lead to the identification of commonalities and differences between methods adding to the validation of the method.

The third and final characteristic is the application of a method in empirical ecologically valid settings (e.g., Chambless & Ollendick, 2001; Rotter, 1954). Only when methods can be applied in different contexts and situations, they can propel and more importantly validate investigations. Although there have been attempts in the field of self-regulated learning to operationalize insights drawn from experimental settings in ecologically valid empirical contexts, these attempts are mainly based on a mixture of insights obtained from the experimental setting, accompanied by a data-driven approach to overcome the gaps left by the experimental approach (e.g., parameter settings, coding events, identification of sub-sequences) (e.g., Hsu, 2018; Ifenthaler, Gibson, & Dobozy, 2018; Taub et al., 2018). No clear attempts to apply and transfer insights between settings seem to be made so far.

In summary, it becomes clear that a lot of work still needs to be done. It seems that none of the three indications for tangible proof of progress already has been achieved for the use of sequence analysis in the field of SRL. In line with this finding already in 2014, Roger Azevedo pointed out that researchers investigating sequence data recoded the data different, made diverse statistical and theoretical assumptions regarding the data collected, and that too easily inferences were drawn from the sequential and temporal unfolding data. His call for action was in vane and repeated multiple times (e.g., Molenaar & Järvelä, 2014; Winne et al., 2017), supported by the expression of the need for standards and frameworks to align the investigation of sequence data in the field of SRL (e.g., Bannert et al., 2015). Partly, the aim of this manuscript is to add to the body of literature calling for standards, protocols, and frameworks that can be tested and validated. By providing general guidelines contributing to a framework for the use and reporting of sequence analysis for SRL this manuscript aims to propel the establishment of sequence analysis as a research method.

Problem statement

As illustrated in the current section, sequence analysis in the field of SRL is an umbrella term covering a large variety of approaches. With regard to the log file data format and the pre-procession phase it often seems unclear how researchers devise and deploy the data scrubbing, cleansing, recoding, or the cleaning processes (e.g., Clarke, 2016; Müller, Naumann, & Freytag, 2003; Rahm & Do, 2000). With regard to the mining and characterization phase and to the analysis phase hardly any explicit references seem to be made to the basis of specific decisions. Current research makes it hard to distinguish which parameter settings were derived from literature or which ones were set arbitrary, nor why this is the case. No arguments are given on why a certain approach is considered above another one (e.g., Poole et al., 2016; Stark & Vedres, 2012). The multitude of approaches and considerations does not yet seem to be condensed into a transparent methodological framework for sequence analysis, nor do these approaches seem to contribute yet to tangible proof of progress in the investigation of learners' SRL using sequence analysis based on computer log files. Without such a framework it is impossible to test, falsify or modify approaches to sequence analysis and so spark the investigation of learning through sequence analysis. In the next section we propose a set of guidelines functioning as a potential starting point for the construction of a transparent methodological framework to communicate approaches of sequence analysis in the field of SRL.

Guidelines on the use of sequence analysis in the field of self-regulated learning

As illustrated throughout the introductory section of this manuscript, the operationalization of sequence analysis to investigate learners' SRL using computer log files is shaped through many practical choices and theoretical assumptions. Whereas in the previous sections we highlighted the need for a methodological framework, in what follows we propose a set of guidelines functioning as a potential starting point for the construction of such a framework. We offer guidelines in two main areas. The first one relates to the alignment of the conceptualization and the operationalization of the different components of SRL. The second one relates to the enactment of the operationalization of the selected sequence analysis approach.

Alignment of conceptualization and operationalization

Singleton, Straits, and Straits (1999) see alignment of conceptualization and operationalization as one of the key features to scientific and methodological success. They refer to the process of conceptualization as the act of defining the different components of a phenomenon under investigation and to operationalization as the practical result of the conceptualization act. In line with this definition, we explore the operational impact of the current conceptualization of SRL. As presented in the introduction, current conceptualizations of SRL focus on its cyclical, influenceable, and covert nature (e.g., Winne & Hadwin, 1998). In what follows we relate these three general conceptions to practical consequences in the operationalization of the selected sequence analysis approach chosen. Even when these three conceptions are not at the basis of the conceptualization of SRL, the conceptions below might shed light on the relation between on the one hand the conceptualization of the phenomenon under investigation and the selected operationalization of sequence analysis.

The cyclical nature of self-regulated learning

The idea of SRL phases unfolding in different cyclical phases raises questions concerning (1) the dynamics of these cyclical SRL process, (2) the sequential patterns within it, as well as (3) the development of the cycle over time. Each of these questions bring the notion of sequentiality and temporality to the discourse on SRL (e.g., Molenaar & Järvelä, 2014). While in the literature on SRL the 'temporal' and 'sequential' notion is often used intertwined (Knight, Wise, & Chen, 2017), literature on sequence analysis from other fields of research makes a clear distinction. Temporality refers to the passage of elapsed time and comes with a collection of related concepts such as duration, rate, and acceleration (Blikstein, 2011; Haythornthwaite & Gruzd, 2012). Sequentiality is used to refer to the order of events and transitions between different events, without explicit reference needed to duration or passages of time (Biswas et al., 2010; Halatchliyski, Hecking, Goehnert, & Hoppe, 2014). As a first consideration, when for example incorporating only sequential characteristics of SRL, the construction of a single sequence per learner in the pre-processing phase will consist of the chronological ordering of events, assuming time between each events' timestamp of secondary interest. When in contrast also temporal characteristics of SRL are taken into account, the construction of learners' single sequences will include the calculation of the time between the consecutive events' timestamps and the inclusion of these calculations in further analyses. The latter poses additional conceptual questions to the status of this calculation. Does it for example represents a single hidden unknown state or is it instead an indication of involvement with the environment? A second consideration relates to the developmental characteristic of the behaviour observed. When SRL-development over time is assumed (e;g., Andrade & Evans, 2015; Huang, Klein, & Beck, 2017) a whole-sequence approach might be preferred over a sub-sequence approach that does not consider such a development (in the time frame of investigation) (Winne & Hadwin, 1998). Both will affect further analyses. As demonstrated above while briefly reviewing the conceptualization of the cyclical nature of SRL, a clear link between (1) the conceptualization of the sequential and temporal characteristics of SRL and its practical operationalization and (2) the developmental characteristics of SRL over time and its operationalization in practice seem necessary to be able to study the sequence analyses applied.

The influenceable nature of self-regulated learning

With regard to how SRL comes to be, recent event theories regard SRL as influenced by variables internal and external to the learner (Veenman et al., 2006). In general research identifies three major sets of internal variables influencing SRL: cognitive (e.g., Zimmerman, 1986, 1990, 1998; Zimmerman & Pons, 1986), metacognitive (Borkowski et al., 1990; Pressley et al., 1987) and motivational variables (e.g., Butler & Winne, 1995; Schraw et al., 2006; Schraw & Moshman, 1995; Zimmerman, 2000). A substantial body of literature identifies external variables at different grainsize levels influencing learners' SRL. Dignath and Büttner (2008) for example point in their meta-analysis that (1) instruction of cognitive strategies (i.e., rehearsal, elaboration, and organizational strategies) affected learners' SRL significantly. The same was observed for (2) instruction of metacognitive strategies (i.e., planning, monitoring, and evaluation), (3) promoting metacognitive reflection, and (4) instruction of motivation strategies. Another example is the literature review of Van Laer and Elen (2016a) identifying seven attributes of learning environments that support learners' SRL. The combinations of the abovementioned internal and external variables make up the timeframe in which SRL needs to be investigated. Under this conceptualization, each change in either variables internal and / or external to the learner will influence learners' SRL (e.g., Greene & Azevedo, 2007; Winne & Hadwin, 1998). Thus without the appropriate timeframe in which to investigate learners' SRL insights might be hard to gather. So, the main consideration with regard to the influenceable nature of SRL relates to the unit of analysis. The size of the allowed timeframe affects the operationalization of sequence analysis for example through the parameter settings while mining and characterizing sequence and sub-sequence. When for example both internal and external variables are regarded as stable throughout the investigative trial the timeframe might stretch over the entire trial. If in contrast the variables are assumed to be variable at a certain rate, the timeframe might want to match this rate as much as possible. As illustrated before the characterization of sequences and sub-sequences relies amongst others on specifications with regard to the time constraints of the occurrence of an event or sub-sequence. The time dimension raises questions concerning the maximal distance between events (Molenaar & Järvelä, 2014). Moreover, we may consider two or more events form a relevant sequence or sub-sequence only if they occur within a given distance of each other (maximal timespan). For example when they occur in a time window in which both variables within and external to the learner are assumed to be constant. For example completing an exercise right after viewing a content related page might not mean the same as completing that same exercise twenty events after viewing the content related page (e.g., Du et al., 2016; Jovanovic, Pardo, Mirriahi, Dawson, & Gašević, 2017). To conclude, it seems that to be able to study the sequence analyses applied, the operationalization of the unit of analysis (e.g., through parameter settings) as conceptualized through the influenceable nature of SRL needs to be elaborated. Elaborating on the relation between unit of analysis and parameter settings allows us to assess the suitability of the decisions made.

Covert nature of self-regulated learning

Current conceptualizations assume SRL operates at different levels of the cognitive system and so regulates lower order cognitive processes that, in turn, shape learners' overt cognitive behaviour (Roth, Ogrin, & Schmitz, 2016). This conceptualization results in the assumption that SRL occurring in each of the SRL phases cannot be directly observed as it manifests in overt cognitive behaviours (Williamson, 2015) and through behavioural consequences like learners' learning outcomes (Veenman & Alexander, 2011). For instance, when a learner recalculates the outcome of a mathematical equation, it is assumed that a SRL monitoring or evaluation process must have preceded this overt cognitive activity of recalculation. As illustrated in the introductory section, conceptualization of the covert nature of SRL can be based on the relation between the overt behavioural events with SRL-influencing constructs (e.g., tool-use, engagement, etc.) or directly with SRL-related activities (e.g., goal-setting and planning, monitoring, etc.) (e.g., Azevedo et al., 2015; Bannert et al., 2015; Lust, 2012). Depending on the conceptualization of (a) the covert nature of SRL and (b) how this nature can be uncovered through the overt behavioural events observed through computer log files, a link will be constituted with the operationalization of this covert nature through the establishment of action libraries (Zhou, 2016). When an action library is used, overt behavioural events (or sets of events) are recoded into more meaningful learner behaviour or SRL behaviour. Although this practice is common when following a deductive research approach, action libraries often have a different level of granularity as they are developed through other online event measurements (i.e., think aloud trials) (Azevedo, 2014). Comparing the micro-level approach followed through using computer log files with the codes abstracted from think aloud trails might be problematic given the different grain-size (e.g., Al Mamun, Lawrie, & Wright, 2017). In summary, when operationalizing the covert nature of SRL via recoding data using different grainsizes (i.e., computer log files and think aloud data), clearly the relationship between observed behaviour and assigned codes needs to be made explicit and communicated transparently.

Enactment of the operationalization of sequence analysis

Proctor, Powell, and McMillen (2013) see enactment as the step following the conceptualization and operationalization of a research method. They identify enactment as the systematic application of the operationalized concepts. As illustrated before, the quest for tangible proof of progress lies in transparently reported methods and procedures permitting scholars to assess research and to communicate with one another (e.g., Beach & Pedersen, 2013; Lupia & Alter, 2014). With regard to the enactment of the operationalization of the selected sequence approach, we focus on two components: systematic account of the operationalization and transparent parameter settings.

Systematic account of the operationalization

The operationalization of sequence analysis starts from gathered data with a specific structure and unfolds roughly in three phases. In the first phase, the pre-processing phase, a single sequence per learner is constructed. In the second phase, sequences and frequent sub-sequences are mined and characterized. Identified sequences and sub-sequences can function as either dependent or independent variables. Although general approaches such as the one described above have been usefully proposed by for example Zhou (2016) and Liu, Dev, et al. (2016), current research fails to go much beyond the vagueness level of this general approach. As demonstrated a multitude of decisions need to be made in the chain of sequence analysis (Roll & Winne, 2015). Keeping systematicity and transparency in mind, detailed accounts of each of these phases would increase replicability (e.g., Moravcsik, 2014). Systematic accounts of the enactment of the operationalization of sequence analysis might start with a description of the raw data gathered. This not only means reporting on the environment in which the data was gathered, but also the actual structure of the dataset extracted, including for example the database structure. In the pre-processing phase systematicity and transparency might be accomplished through elaborating (among others) on the data cleaning process, the recoding procedure (if applicable), and the transformations applied (if applicable). With regard to the mining and characterization of the sequences and sub-sequences this might be done through a clear account of the different steps taken in the mining and characterization process, including for example a detailed explanation of the algorithm used and the parameters set. Finally in the analysis phase transparency and systematicity might be accomplished by the presentation of the output format of the previous phase and the analysis approach chosen (with its key figures).

Transparent parameter settings

It is clear that the conceptualization of a theory cannot account for each variation in operationalization nor for the justification of each parameter setting (Bannert et al., 2017). Nonetheless, decisions need to be made to derive useful approaches. Regardless of the inductive or deductive approach to the conceptualization of SRL, transparency and courage on the part of the researchers is essential to report in detail which parameter settings are derived from theory and which are arbitrary (e.g., Chia-Wen et al., 2011). The degree to which this is possible on either side is irrelevant to the argument, as long it is clear which parameter settings are used for what reason or considering what assumption. An example of such a practice was presented in the illustrative case. No theoretical evidence could be found to determine the frequency threshold for identifying frequent sub-sequences. In this case, it was reported that an arbitrary cut-off was set at 25%.

Implications and conclusions

Although the use of sequence analysis in the field of self-regulation is one of the last decade, a lot of valuable work has been done to propel the investigation of learners' SRL through sequence analysis. Despite these efforts, no methodological framework seems to be available for the systematic application and reporting of sequence analysis in the field of SRL. Because of the lack of such a framework, tangible proof of progress is difficult to achieve and so the evolution of sequence analysis to investigate SRL seems to be hampered. To illustrate the need for such a methodological framework we provided in the introduction of this manuscript a brief overview of the variability of current operationalizations and illustrated one such approach. From the pre-processing phase onwards, over the mining and characterization phase, up to the use of the identified sequences and sub-sequences as dependent and independent variables, a multitude of conceptual and operational choices need to be made. Therefore, in this manuscript we aimed to foster discussion on a methodological framework for the application of sequence analysis in the field of SRL which would make replication, falsification, and validation possible. To do so, in addition to the case built in the introduction section, we proposed in the previous section a set of guidelines functioning as a potential starting point for the construction of a framework. These guidelines were centred on two key areas. The first area focussed on the alignment of the conceptualization of the different components of SRL and the operationalization of the selected sequence analysis approach (e.g., Singleton et al., 1999). The other area focussed on the enactment of the operationalization of the selected sequence analysis approach (e.g., Proctor et al., 2013). With regard to the former four guidelines were proposed relating to the current conceptualization of SRL that relate to: (1) the sequential and temporal characteristics of SRL; (2) the development through time of SRL; (3) the unit of analysis imposed by the factors influencing SRL; (4) the matching-granularity as linked to the covert nature of SRL. With regard to the enactment of the operationalization of the sequence analysis approach two guidelines are proposed related to: (1) the systematic account of the operationalization; and (2) the transparent communication of parameter settings. Although this manuscript does not pretend to provide solutions nor to be exhaustive with regard to possible approaches to sequences analysis in the field for SRL, on the one hand it highlights the need for a transparent and systematic methodological approach. On the other hand, it also identifies guidelines that might function as a basis for further construction of such a methodological framework for the use of sequence analysis in the field of SRL. Keeping in mind the nature of the guidelines provided, we might wonder whether the guidelines are simply 'common sense' and applicable to many other research methods. The latter is certainly the case, yet guidelines have not been constructed before for the investigation of sequence analysis for SRL. With regard to the 'ordinariness' of the guidelines provided in this manuscript, there is an abundance of systematic methodological literature reviews (e.g., Kallio, Pietilä, Johnson, & Kangasniemi, 2016; Kelly et al., 2014; Mertens, 2014) illustrating that guidelines similar to the ones suggested in this manuscript might be beneficial for a broad range of research methods and also that without such guidelines, the quest for tangible proof of progress is more than likely to be unsuccessful.

Implications

When a methodological framework is in place the investigation of time-related characteristics in SRL, using sequence analysis might evolve to (1) transparent methods, (2) comparative studies, and (3) empirical and ecological applications, supporting both research and practice. Such a framework enables researchers to use the framework to describe and compare current approaches to sequence analysis. A solid description of these approaches, their reproduction and validation first in similar, later in different contexts. The former will allow us to apply the insights gathered not only under very strict conditions in one particular situation but is likely to foster empirical and ecologically valid trails. The latter would be useful for researchers and practitioners using sequence analysis for example to inform the design of their course. By having a methodological framework at their disposal, selecting the most appropriate sequence analysis approach for their needs is facilitated. The sooner we are able to compare, validate, and establish sequence analysis methods, the more quickly we can make progress in the investigation of SRL through learners' learning behaviour.

Further directions

As it was not our aim to present a fully developed methodological framework for the use of sequence analysis in the field of SRL, in future investigations it might be interesting to further detail the conceptual assumptions related to the investigation of time-related characteristics of SRL and their relation to methodological operationalizations. This could be done by incorporating more theoretical research on the investigation of self-regulated learning and extract the possible methodological consequences for the operationalization of the theoretical conceptualizations proposed. Another avenue might be the integration of non-content-related research on sequence analysis to further investigate the operational possibilities of the method to further investigate the conceptual assumptions made by choosing a particular approach over another. By doing so a protocol, standard, or framework can be established as a method for the use of sequence analysis which can then be tested, validated and modified to further optimize the use of sequence analysis for the investigation of SRL.

Conclusions

First, the manuscript built a case for the need of a methodological framework for the application of sequence analysis in the field of self-regulated learning. Secondly, it provided a ground for further discussion on the construction of such methodological framework, raising questions about both the conceptualization and the operationalization of sequence analysis in the field of SRL. Additionally it provides guidelines and possible directions supporting sequence analysis as a method in the field of SRL. Applying sequence analysis as a method in the field of SRL in a more systematic and transparent way might support the development of the method towards more transparency, comparative studies, and empirical and ecological applications, supporting both research and practice. As demonstrated throughout the manuscript it seems that it is not the amount of data gathered that will help us gain insights, but rather the way we analyse them and the thoroughness of that analysis. This manuscript by no means implies that the overview of operationalizations is exhaustive or complete, nor does is pretend to provide a best practice or example through the illustrative example. Instead, it aimed to provide a transparent and verifiable framework to discuss the method we see as potentially powerful for investigating learners' SRL. Such a framework challenges the assumptions made, approaches taken, and thus propels the investigation of learners' SRL through computer log files to new heights.

In conclusion, the guidelines proposed and their underlying call for transparency and systematicity through the construction of a methodological framework for the use of sequence analysis in the field of SRL can potentially transcend the use of sequence analysis for computer log files and go as far as to other log file methods investigating the temporal and sequential nature of phenomena. As the literature on the investigation of for example eye movement (e.g., Kiefer, Giannopoulos, Raubal, & Duchowski, 2017; Lorigo et al., 2008) or skin conduction (e.g., El-Sheikh, 2007; Haufler et al., 2017) log files seems to experience similar issues, also these fields of research might benefit from the general guidelines formulated in the manuscript presented (e.g., Kuhn, 2012). Although the focus in this manuscript is only on one rather specific approach to sequence analysis, the quest for transparency and systematicity is one that relates to all investigations, especially when it comes to new complex methods that require abundant data processing in order to make them meaningful.

SECTION TWO

Validation of the conceptual framework

Chapter Four

External factors and self-regulated learning

The text of this chapter was published as a descriptive study in *Technology, Knowledge and Learning*. [Van Laer, S., & Elen, J. (2016). Adults' Self-Regulatory Behaviour Profiles in Blended Learning Environments and Their Implications for Design. *Technology, Knowledge and Learning*, 1-31.]

Introduction

Blended forms of learning have become increasingly popular (Garrison & Kanuka, 2004; Garrison & Vaughan, 2008; Graham, 2006; Spanjers et al., 2015). Learning activities within blended environments are supported by a large variety of online and face-to-face instructional interventions. As a result of this variety, blended learning environments (BLEs) differ widely in the technologies used, the extent of integration of online and face-to-face instruction and the degree to which online activities are meant to replace face-to-face instruction (Smith & Kurthen, 2007). Despite their popularity, it remains unclear under what conditions these environments are successful (e.g., Oliver & Trigwell, 2005). One important observation is that blended learning seems to be especially challenging for learners with lower self-regulatory abilities, while those with higher self-regulatory abilities seem to do well in these environments (e.g., Barnard et al., 2009; Lynch & Dembo, 2004). To date, however, it is not clear how the design of the environment affects the self-regulatory behaviour of the learner. Our limited understanding is problematic since without this information, we cannot develop evidence-based interventions and redesigns that support self-regulation and thus make learning more effective. The aim of this study was therefore to identify learners' self-regulatory behaviour profiles in BLEs and to relate these profiles to the design of the environments.

Blended learning environments

This study focuses exclusively on BLEs. In their editorial for the *Journal of Educational Media*, Whitelock and Jelfs (2003) described three definitions of the concept of blended learning. The first definition (based on Harrison (2003)) views blended learning as the integrated combination of traditional learning with web-based online approaches (Bersin & others, 2003; Orey, 2002a, 2002b; Singh et al., 2001; Thomson, 2002). The second one considers it a combination of media and tools employed in an e-learning environment (Reay, 2001; Rooney, 2003; Sands, 2002; Ward & LaBranche, 2003; Young, 2001) and the third one treats it as a combination of a number of didactic approaches, irrespective of the learning technology used (Driscoll, 2002; House, 2002; Rossett, 2002). Driscoll (2002, p. 1) concludes that 'the point is that blended learning means different things to different people, which illustrates its widely untapped potential'. Oliver and Trigwell (2005) add that the term remains unclear and ill-defined. Taking these observations into account, the definition used in this study is as follows: 'Blended learning is learning that happens in an instructional context which is characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning. Learning happening in purely online or purely classroom-based instructional settings is excluded' (Boelens et al., 2015).

Self-regulation in blended learning environments

In this study, learning is seen as an activity performed by learners in a proactive manner, rather than as something that happens to them as a result of instruction (Bandura, 1989; Benson, 2013; Knowles et al., 2014). Learning is seen as a self-regulated process (Zimmerman & Schunk, 2001). Various self-regulated learning theories have been founded on this perspective. Self-regulation in this study is seen as: 'The deliberate use of metacognitive skills, in a particular context, to achieve goals both internal and external to the learner.' Based on this definition, the Winne and Hadwin (1998) model was selected to reflect upon the self-regulatory behaviour of learners, since it has a number of characteristics that makes it very suitable for our purpose. These characteristics will be described in more detail later. Winne's Four-stage Model of Self-regulated Learning (Butler & Winne, 1995; Winne, 1995, 1996; Winne & Hadwin, 1998; Winne & Perry, 2000) describes four stages: (1) task definition, during which learners develop perceptions of the task concerned, (2) goal-setting and planning, (3) enacting the tactics and strategies chosen during goal-setting and planning, and (4) metacognitively adapting studying techniques, keeping future needs in mind. Each of these phases consists of five elements (COPES): (1) conditions, which affect how a task will be engaged with, (2) operations: cognitive processes and tactics learners employs, (3) product: information created by operations, (4) evaluations: feedback about products (internal or external), and (5) standards: criteria against which products are monitored. The theory emphasizes that learners who are prompted to process effectively in stage one (task definition) and stage two (goal-setting and planning) are more likely to have accurate expectations of the task (Winne & Hadwin, 1998). Finally, each stage and its elements are influenced by certain conditions. Winne and Hadwin (1998) identify task-related conditions (e.g., time constraints, available resources and social context) and cognitive-related conditions (e.g., interest, goal orientation and task knowledge) that influence how a certain task will be engaged with (Winne & Hadwin, 1998). Cognitive conditions are learners' epistemological beliefs, prior knowledge (all information stored in the long-term memory) and motivation (Winne & Hadwin, 1998). In this study, the focus lies on the task-related conditions, more specifically on the role of the design of BLEs. Identifying the impact of differences in BLE design makes it possible to attribute certain learners' self-regulatory behaviour to specific design features. Based on this notion more precisely targeted interventions will be possible.

The Four-stage Model of Self-regulated Learning has a number of characteristics that suit the purposes of this project very well. First, the model looks beyond the focus on purely instructional stimuli and their effects on learning, contesting the assumption that all learners process the stimuli as intended (Winne, 1982). The authors see learners as active agents (Winne, 1982, 1985, 2006) or mediating factors in the instructional process (Keller, 2010b; Winne, 1982). As the learners in this project are seen as having difficulties with regulating their own learning, this scope allows us to highlight the suitability of particular designs for certain learners and to work toward ‘more inclusive’ environments better understood by different types of learners. A second consideration is that on the one hand, the model gives clear indications, about which phases should be targeted, namely task definition followed by goal setting and planning (Winne & Hadwin, 1998). On the other hand, each phase (one to four) incorporates the COPES process, which makes up the cognitive system (Greene & Azevedo, 2007). The cognitive system explicitly models how work is done in each phase and allows for a more detailed look at how various aspects of the COPES architecture interact (Greene & Azevedo, 2007). This approach allows us to make interventions that are as targeted as possible focussing on areas that can be impacted (e.g., conditions by supporting task definition, planning and goal-setting). Third, with monitoring and control functioning as the key drivers of regulation within each phase, Winne and Hadwin's model (1998) can effectively describe how changes in one phase can lead to changes in other phases over the course of learning (Greene & Azevedo, 2007). This allows the model to explicitly detail the recursive nature of self-regulation (Greene & Azevedo, 2007). Fourth, the model holds a behavioural focus on self-regulation, in contrast with a focus on self-reports. This together with previous considerations aligns strongly with the focus of this project. On the one hand, because the main focus of this project lies on the support of and changes in learners’ self-regulatory behaviour (by mapping their behaviour instead of asking for their perceptions). On the other hand, because the recursive nature of self-regulation underlines the evolving nature of it and the need of monitoring change over time. The final reason for this model’s suitability is that it separates task definition, goal setting, and planning into distinct phases. This allows more pertinent questions to be asked about these phases than would otherwise be possible, when focusing on instructional interventions alone (Greene & Azevedo, 2007; Winne & Marx, 1989).

Adults in blended learning environments

Research on BLEs generally praises the flexibility and suitability of such environments for adult learners (Ausburn, 2004). Adult learners are often described using the andragogy model developed by Knowles et al. (2014). In Malcolm Knowles’s work, andragogy is defined more precisely as a specific theoretical and practical approach. It is based on a humanistic conception of self-directed, autonomous learners, as well as teachers as facilitators of learning (Hansman, 2008). Others have stressed for example autonomy, self-direction, and affinity for real-life learning as key characteristics of adult learners (see e.g., Brookfield, 1986; Caffarella & Merriam, 2000; Tough, 1978). Questions could be asked about how BLEs deal with adults that do not have these characteristics, for example second chance learners (Connolly et al., 2007). The andragogy focuses rather on the abilities of the learner (adult in their learning and in regulating their learning). In this study, we focus on learners in second-chance education. This type of education is specifically targeted at individuals who, for a variety of reasons, never attended school or left school either before completing the level of education in which they were enrolled or completed the level but wished to enter an education programme or occupation for which they were not yet qualified (UNESCO, 2011). By providing these second chances, second chance education prevents isolation from the labour market and employability (Nordlund, Bonfanti, & Strandh, 2015). These learners have often negative prior experiences with education and dropped out of school early. When such learners enter a BLE, they may face different challenges due to their lack of self-regulation. This claim is supported by the to-date research that suggest BLEs to require a large amount of self-regulation on the part of learners (Bonk & Graham, 2012; Collis et al., 2003). Learners need to have, when they learn in such environments, different self-regulation related skills (e.g., Lynch & Dembo, 2004; Sharma et al., 2007). Such skills are: e.g., motivation, internet self-efficacy, time management, study environment management, and learning assistance management. Based on this claim it seems that BLEs work fine for adults with proper self-regulatory skills, but that they may fail to address the needs learners with lower self-regulatory skills (Cennamo et al., 2002).

Attributes that support self-regulation in blended learning environments

As indicated above, different stages, dimensions, and processes of self-regulation may be influenced by specific instructional interventions (e.g., Bannert, 2009; Ifenthaler, 2012; Winne & Hadwin, 1998). As pointed out by Ley and Young (2001), several self-regulation interventions have been tailored to specific content, learners, or media. Interventions have been suggested for writing (Graham et al., 1998), reading comprehension (Pressley et al., 1998), and mathematics (Schunk, 1998). Others have incorporated support for self-regulation into college learning-to-learn courses (Hofer et al., 1998) or in computer-mediated instruction (Winne & Stockley, 1998). No attempts in the literature could be found for blended learning environments. Some approaches have been directed toward specific populations such as children (Biemiller et al., 1998; Corno, 1995), adolescents (Belfiore & Hornyak, 1998), and learning disabled learners (Butler, 1998). Although there is a substantial amount of research available that describes ways to support learners' self-regulation, there are several outstanding issues that make the practical application of these guidelines impossible. First, we were unable to find any research that addresses self-regulation as an inherent part of learning. The guidelines formulated often view self-regulation as a specific goal (to design for) instead of as an inherent attribute of learning (Schunk & Zimmerman, 2003). Only a few studies attempted to combine findings from different backgrounds into a set of guidelines or principles for a theoretical framework. Based on this notion, Van Laer and Elen (2016b) identified, using a systematic literature review (n=95), seven attributes that support self-regulation in BLEs. The first one is authenticity, or the real-world relevance of the learning experience to learners' lives. Secondly, there is personalization, defined as the tailoring of the learning environment to the inherent preferences and needs of each individual learner. Third, learner control is the degree to which learners have control over the content and activities within the learning environment. Fourth, there is scaffolding, defined as changes in the task or learning environment, which assist learners in accomplishing tasks that would otherwise be beyond their reach. Fifth is interaction, or in what way the learning environment stimulates learners' involvement with this environment. Sixth are reflection cues, which are prompts aiming at activating learners' purposeful critical analysis of knowledge. Finally, there are calibration cues that are triggers for learners to test their perceptions against their actual performance and study tactics. The combination of these attributes configures the support system of learners' self-regulation in the learning environment. For a more detailed overview, see appendix 1 and 2.

Measuring self-regulation

Measurements of self-regulation have a long history in research (Veenman et al., 2006; Winne & Perry, 2000; Zimmerman, 2008). Conceptual understanding evolved from self-regulation as an aptitude (stable character) to self-regulation as an event (turbulent character). When self-regulation is measured as an aptitude, a single measurement, aggregates over, or abstracts some quality of self-regulation. (e.g., Endedijk et al., 2016; Pintrich, Smith, García, & McKeachie, 1993; Weinstein, Zimmerman, & Palmer, 1988). These instruments often rely on self-reports of learners. Many authors consider the results of self-reports instruments to be poor indicators of the actual regulation activities that students use while studying (Perry & Winne, 2006; Pintrich, 2004; Veenman et al., 2006). The measurement of self-regulation as events, in contrast, is based on multiple self-regulation events (Winne & Perry, 2000). Endedijk et al. (2016) reported on online (during the task) and offline (after the task) methods. These types of measurements appear to be more suitable for finding relations between specific aspects of real time self-regulatory behaviour in authentic contexts (Zimmerman, 2008) and have the potential to be more accurate than retrospective self-reports that require recall of actions and thoughts (Winne et al., 2006). The measurement of events in online environments is often described. Azevedo (Azevedo, Johnson, Chauncey, & Burkett, 2010; Harley, Bouchet, Hussain, Azevedo, & Calvo, 2015) uses MetaTutor to trace data. Winne follows a similar approach with nStudy (Winne, 2015, 2016; Winne & Hadwin, 2013; Winne et al., 2006). Both MetaTutor and nStudy are online platforms that aim to support learners' studying. At the same time, they are also able to track learners' behaviour for research purposes. Although this type of research reports on the self-regulatory behaviour of learners, it focusses solely on experimental settings and is mainly based on frequency and diversity of actions, related to performance. By applying such approach, they often lack to address the typical ecological setting of a classroom (restrictions in variables to trace, etc.) and the cyclic nature of self-regulation (based on the sequencing of events). During this study both frequency and diversity and the sequencing of events, based on ecological learners' log-files, will be taken into account.

Problem statement

Although research stresses the suitability of BLEs for adults (Brookfield, 1986; Caffarella & Merriam, 2000; Tough, 1978), research on second chance education shows that such learners are not necessarily typical 'adult learners' (Connolly et al., 2007). Research on self-regulation in blended-learning environments regularly reports the importance of specific self-regulatory abilities learners need, to be able to benefit from BLEs (e.g., Lynch & Dembo, 2004). Second chance learners often lack these abilities. Without identifying the relationships between learners' self-regulatory behaviour and the design of BLEs it is not possible to determine how design features impact learners' self-regulatory behaviour, or, consequently, to implement targeted (re)designs to overcome the problems that for example learners in second-chance education encounter. To be able to design BLEs that support self-regulation, an answer to the following research question is needed:

'What learners' self-regulatory behaviour profiles can be identified in BLEs and how do they relate to the design of these environments?'

By answering this research question, this study on the one hand presents learners' self-regulatory behaviour profiles in BLEs and on the other hand, reveals the relation between these profiles and the design of BLEs.

Method

To answer the research question, a mixed method approach was used containing three major steps. First, the learning environments were described using self-regulatory attributes of BLEs. Second, learners' self-regulatory behaviour was identified in each learning environment. Finally, a comparison between the different learning environments (and the learners' behaviour in them) was made to explore the possible relationship of the design of the learning environment on the behaviour of learners within the environment.

Context, population and sample

Six blended learning courses were targeted within two centres of adult education in Flanders, the northern region of Belgium. All the courses covered the same subject, ‘Introduction to basic statistics’ within second chance education. Topics included were means, modes, frequency tables, etc. Each course had an identical length of eight weeks. Learners took the course in the first semester of the school year. The population was divided over the six blended learning courses (n=120). All learners were aged above eighteen, had a wide diversity of prior experiences both professional and educational, some of them working already for many years, others did not have any prior experience related to work. Each of them was enrolled in the second-chance education track, as they did not have a diploma of secondary education. They had different social backgrounds and occupations, ranging from ex-convicts to successful CEOs. Finally, their language levels for Dutch were sufficient (as tested at the enrolment of the program, and the distribution by sex was comparable. Both schools were similar in size and context. Due to the different architecture (database structure) of the virtual learning environments of both schools there will be reported on school-level. If conclusions are drawn there will be checked if they can be drawn over the two schools.

Measurement instruments

Description of blended learning environments that support self-regulation

To describe both the on- and off-line components of the six learning environments targeted, an observation framework was developed based on the attributes as identified by Van Laer and Elen (2016b). See appendix 1 and 2 for further details. The methodology used (see: De Wever, Schellens, Valcke, & Van Keer, 2006; Jorgensen, 1989) contains three phases (selection of content, the selection of a unit of analysis and the examination of the reliability of the instrument). For the face-to-face observations, everything the instructor said during the class was recorded, transcribed, and selected for analysis. In addition, when the teacher explicitly referred to the syllabus, that specific part of the syllabus was also selected for analysis. For the observation of the online environment, we applied the same additional guideline. By choosing fixed units (Rourke, Anderson, Garrison, & Archer, 2001), topics addressed during the course (e.g., ‘Data collection’, ‘Data processing’ and ‘Statistical key concepts’), a clear unit of analysis was selected (De Wever et al., 2006). Such a topic contained a set of instructions aiming at fostering learning opportunities for learners based on a predefined set of goals. To describe the attributes observed in the learning environment, each question (see appendix 1) was answered by giving a score on a Likert-type scale (never-little-somewhat-much-always) and providing the related evidence and comments. Finally, to test this methodology, a pilot study was done. The instrument was tested using multiple raters (n=4). The results from the reliability analysis showed a Kendall's W of 0.62, what according to Cicchetti (1994) is good. This indicates that the instrument developed, is reliable as far as describing the learning environment is concerned.

Analysis

Each attribute was analysed using the leading questions (Appendix 1). An Excel document was made including tabs per topic, an overview of the course and a graphical overview of the attribute per topic for the overall course. Each topic addressed was described. For each topic, the presence of the attributes was investigated. When an answer on a leading question was given, a short summary of evidence for this answer was given. When all questions for a certain attribute were answered, a mean score of attributes was calculated per course. This was done for all topics within each course, and visualized. Finally, after the descriptions of each BLE were made, their scores on each Likert-type scale were gathered in a matrix (Appendix 3). Based on the matrix it became clear how the seven attributes were present in each course and how the courses compared with one another.

Self-regulatory behaviour in blended learning environments

As mentioned before, to investigate the self-regulatory behaviour of learners' in six blended learning courses, an event approach was used. The methodology was based on the ideas of Hadwin et al. (2007) and Azevedo, Johnson, et al. (2010) and modified to the (ecological) needs of this study. The approach included first a traditional cluster analysis. This to determine if clusters based on self-regulatory behaviour could be identified based on the amount and diversity of interactions with the online learning environment. Using frequency is the traditional approach for analysing learners' self-regulatory behaviour (Azevedo, Cromley, Winters, Moos, & Greene, 2005; Järvelä, Järvenoja, & Malmberg, 2012; Manlove, Lazonder, & de Jong, 2007). In contrast to previous research (see above) we did not include time-spend-per-tool, this because, in our opinion the traces gathered are rather events (clicks, contributions, etc.) then states (reading, summarizing, etc.) (Agrawal & Srikant, 1995; Zaki, 2001). We opted to include diversity because there is evidence that this might say something about learners' regulation strategies (Azevedo, 2005). Based on this analysis, per institution learners were assigned to a specific cluster. Secondly, event sequence analysis was used to investigate learners' behaviour. The TraMineR–package (Gabadinho et al., 2011) in R-statistics was used to determine if certain sequences are reported more frequently and if they are, significantly different for each cluster.

Structure of online learning environments investigated

As both schools have the same learning content management system (Moodle), they are comparable in nature. This means that both environments contain the same ecological log file data. These log files are long lists (+10,000 items) of chronological events. An event is an interaction of the learner with the environment. Only log files at course level were taken into account. Although the back-end of both online learning environments was quite similar, there were some differences. School B uses a remarkable amount of SCORM-packages. These packages are learning materials that can be uploaded to the online learning environment. The use of these types of packages affects the structure of the log files. Due to this reason, it is not possible to recode and combine variables of both schools in advance and results and analyses needed to be reported per school. Although this might be a limitation regarding transparency, it is still possible to compare and generalize (over the two schools) the observations made after individual analysis. Appendix 4 shows the traced variables per school, including the significance in occurring in the different clusters.

Analysis

To identify possible clusters of self-regulatory behaviour in both schools, first cluster analysis based on diversity and frequency of events was done to deduce individual differences in learners' self-regulatory behaviour. A K-means cluster analysis was performed in R on the standardized trace variables. Outliers, defined as learners who did not interact with the environment more than ten times and did not obtain a grade for their course were excluded. To define the clusters in terms of the self-regulatory behaviour learners' represent, a MANOVA was executed. Follow-up one-way ANOVAs showed which variables report significantly different values for different clusters. Secondly, cluster analysis based on the sequence of events was done using sequenced timings of events. Event sequences are the chronological listening of all events. Using the seqefsub() function of the TraMineR package (Gabadinho et al., 2011) in R, frequent event sub-sequences were looked for. While using the seqecmpgroup() function for examining differences in cluster-solutions, based on the discriminant event sequences, was used. To control the relation between self-regulatory behaviour and performance, the relation of cluster membership with performance was examined. Although the relation between self-regulation and performance is often studied (e.g., Schunk & Zimmerman, 1994), we checked, using a MANOVA, for significant influence of the cluster membership, compared to the scores learners obtained. Finally, to answer the overall research question, on the one hand a chi-square test of independence was administered for both schools to investigate if the environment potentially influenced the occurrence of certain clusters. On the other hand, the relation between the integration of attributes that support self-regulation (sum scores of attributes per environment) and cluster membership was uncovered by running a multinomial logistic regression.

Results

To be able to design BLEs that support self-regulation, an answer to the following research question is needed: “What learners’ self-regulatory behaviour profiles can be identified in BLEs and how do they relate to the design of these environments?”. First, the design of each course (per school) will be addressed. Secondly, the self-regulatory behaviour of the learners involved (per school) will be investigated. Thirdly and finally, the relation between both the design of the learning environment and learners’ self-regulatory behaviour will be examined.

The six blended learning courses involved

<u>**Schools**</u>

The first school (A) is situated near Hasselt. This school for adult education is one of the biggest in Flanders (the northern region of Belgium) with over 50 course offered and over 1000 learners taking them. Four blended learning courses described where targeted in this school. Two different instructors co-designed and individually delivered two courses each. The second school (B) is situated near Antwerp, the second largest city in Flanders. Like the previous school, also this one is one of the biggest in Flanders with over 75 course offered and over 1500 learners taking them. Two blended learning courses were targeted. Both courses were designed and delivered by the same instructor. All six blended learning course have the same topic. The courses are numbered one to six. Below there will be elaborated on each’s design, based on the seven attributes that support self-regulation.

School A

Each course in this school addressed five topics. Environment one contained two face-to-face meetings, one at the start and one on the day of the examination. During the first lesson, the instructor introduced the materials and methodology of the course. Subsequently, eight online lessons were provided. Environment two included five face-to-face lessons and five online lessons. It started and ended with a face-to-face lesson. In-between of these, every other week a face-to-face or online lesson took place. During the face-to-face lessons, the instructor mainly repeated the online lesson. Environment three was designed by the same instructor as the previous course and duplicated to another context. The only difference was that this course consisted out of three face-to-face lessons and six online lessons. Finally, environment four had seven face-to-face lessons and one online lesson (due to a holiday on a course date). For all environments, each topic started with the presentation of 'Theory', including general definitions and different examples. At the end of the theoretical part, an individual research project was introduced. The theoretical part was followed by 'Exercises'; each of the exercises was framed in a different context. After the completion of the last exercise of each topic, a test followed. Only one chance was allowed.

Regarding the attributes that support self-regulation, authenticity of the different learning environments differed depending of the nature of the topic. Authenticity was observed more when the topic was in direct relation to applications of a task (for example the individual 'research' project learners had to do). Personalization in the online learning environment was primarily focused on the presentation of different contextualized exercises and on the choice learners had in selecting a topic to do their individual project on. Personalization in the face-to-face context was mostly done by addressing learners by their name or by presenting examples from learners' professional or private life. Further, the instructors delivered instruction mainly in a one-size-fit all approach. Learners were allowed much more learner control in the online learning environment compared to the face-to-face environments. In the online learning environments, they were free to select the sequence of topics; all topics were often visible from the first lesson onwards. Nonetheless, learners did not have control over what activity to do in which topic. The instructors defined these. In the face-to-face context, learners were allowed to take control over additional exercises when others were still working on previous ones. Scaffolding throughout the duration of the course was done by shifting responsibility towards the learner. A lot of support was provided when learners solved exercises; the individual project received the least support. In the face-to-face context, instructors tailored support to the learners' capabilities by giving personal (verbal) feedback. In the online learning environments, instructors did not tailor support to the learners. The difference in interaction between the face-to-face and online contexts was remarkable. In the online learning environment, interaction focused on learner-content and learner-interface interaction. In the face-to-face context, interaction was more focussed on learner-instructor and learner-peer interaction. Finally, both cues for reflection and for calibration were addressed the least in every environment described. Reflection cues for one's own learning were not provided, neither before, during nor after one's actions. If reflection cues were given, they entailed hypothetical mistakes learners could make while solving a specific exercise. Finally, some feedback was provided on specific content elements. In both cases, no action was expected from the learners. In figure 1, the results for each of the courses (environments) can be found.

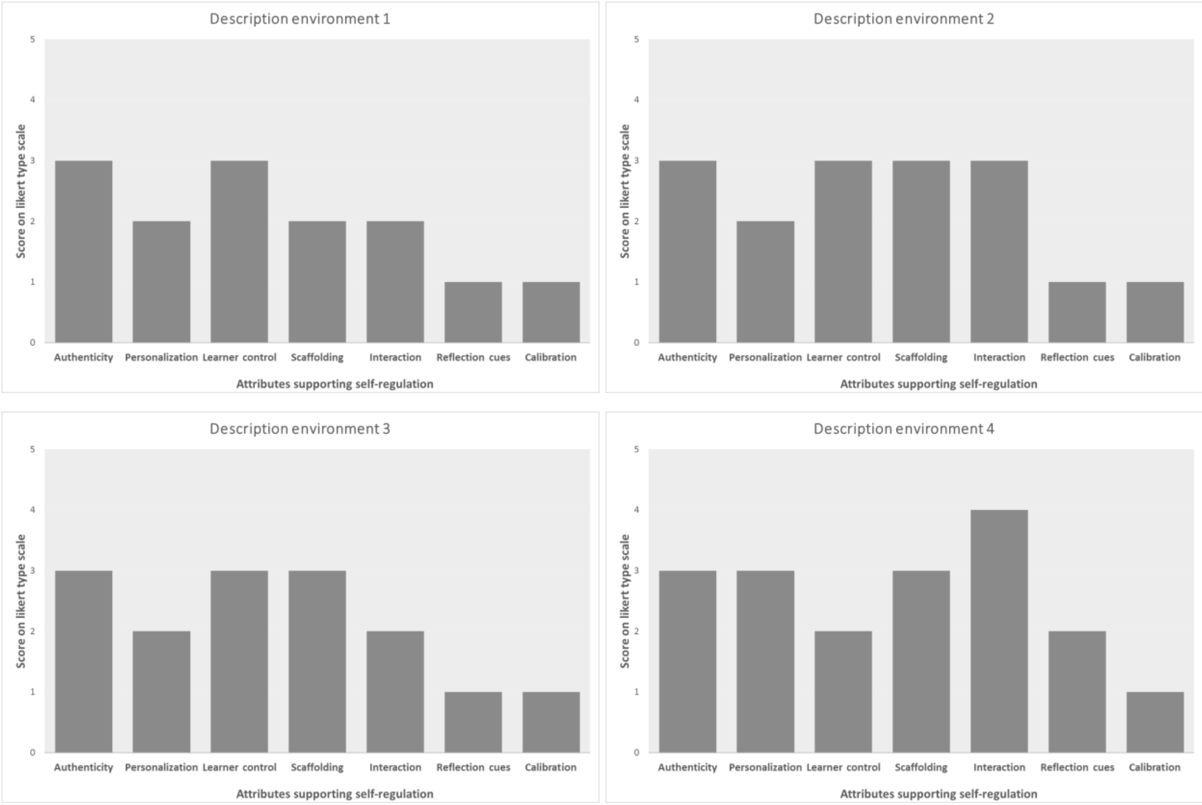

Figure 1. Amount of attributes identified for each environment of school A.

School B

Environment five was structured in seven weekly meetings. The course consisted of three consecutive topics ‘Data collection’, ‘Data collection’, and ‘Statistical key concepts’. Five of the weekly meetings were in a face-to-face format during which both the instructor and learners used online materials. Environment six started with a face-to-face session, during which the instructor introduced the individual research project, the learning materials, and the methodology of the course and gave a brief overview of the entire course. Following this session, seven online lessons were provided.

Likewise in school A, authenticity of the learning environment differed depending on the nature of the topic. Personalization was focused on the use of learners’ names and only in the face-to-face context. Instruction was mainly delivered in a one-size-fit all approach. In the face-to-face context, learners did not have any control over pace, content and learning activities. This contrasted very much with the situation in the online environment in which learners had ultimate freedom. Scaffolding throughout the duration of the course was done based on tailored support for the learners. Neither fading of support nor a transition of responsibility toward the learner could be observed. As in the other courses, interaction was often observed. Nonetheless, collaboration between peers was only minimally observed. Finally, cues for reflection and for calibration were addressed the least, compared to the other attributes described. Figure 2 shows the observations for these courses.

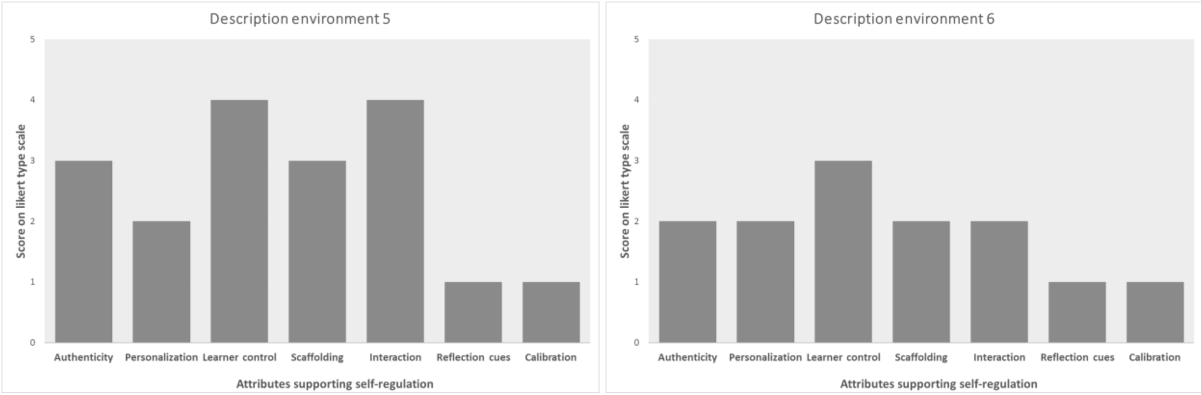

Figure 2. Amount of attributes identified for each environment of School B.

Learners self-regulatory behaviour in blended learning environments

<u>School A</u>

Based on, on the one hand the cluster analysis using frequency and diversity and on the other hand, patterns and discriminating sequences, the behaviour traced via ecological data was investigated. In School A (n=76) three clusters were identified. Using a MANOVA significant differences between the traced variables (independent) clusters (dependent) were found F (72, 76) = 5.12, $p < .001$; Wilk's Λ = 0.029, partial $\eta^2 = .83$. One-way ANOVAs showed that twenty of the traced variables have significantly different values for learners in different clusters (see figure 3 and appendix 4). The analysis indicated that the amount of interaction learners had with (1) information such as the course home page (course viewed) (F (2,73) = 9.564, p = .000) and topic pages (course module viewed) (F (2,73) = 10.325, p = .000); (2) on the one hand engagement in discussions (discussion made) (F (2,73) = 9.904, p = .000) and on the other hand viewing them (discussion viewed) (F (2,73) = 9.243, p = .000); (3) formal submissions of tasks (test made) (F (2,73) = 36.914, p = .000) and assignments (assignment submitted) (F (2,73) = 27.110, p = .000); and finally (4) consultation of scores (user score) (F (2,73) = 33.565, p = .000) and results (submission form consulted) (F (2,73) = 17.934, p = .000) have a different appearance between clusters. Forty-one learners belonged to Cluster 1, twenty-two to Cluster 2 and thirteen to Cluster 3.

The event sequence analysis (Associated Pearson Residual of the chi-square test, residuals ≤ -2 less frequent and ≥ 2 more frequent) showed that learners in Cluster 1 used sequences like ‘(course module viewed) – (discussion made)’ (r = 1.50, $p < .001$) much more frequent than their counterparts from Cluster 2 (r = -0.53, $p < .001$) and three (r = -1.98, $p < .001$). Remarkably, both clusters behaved opposite from Cluster 1. Results also showed that learners from Cluster 2 used the sequence ‘(test made) – (user score)’ significantly more (r = 0.39, $p < .001$) than learners in Cluster 1 or three. Learners from Cluster

1 ($r = 1.62$, $p < .001$) seemed to prefer to ask questions using the discussion forum before taking a test '(discussion made) – (test made)' more than the other two clusters.

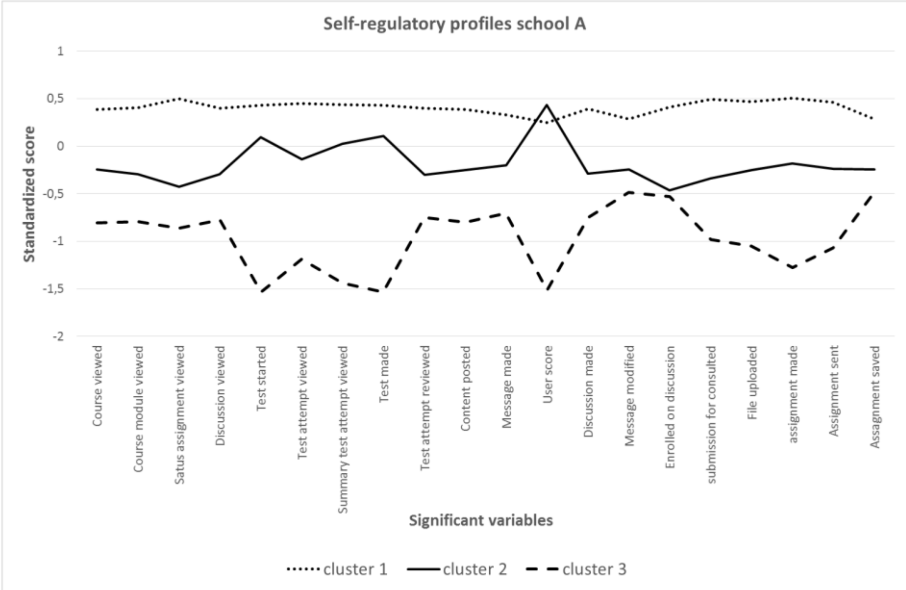

Figure 3. Three clusters of School A based on the significant different variables plotted on the standardized mean scores.

<u>School B</u>

For School B (n=44) the same approach was adopted. Three clusters were identified. A MANOVA showed significant differences between clusters F (50, 30) = 15.46, $p < .001$; Wilk's Λ = 0.001, partial η^2 = .96. One-way ANOVAs indicated that thirteen of the traced variables have significantly different values among clusters (see: figure 4). The analysis indicated that the amount of interaction learners had with information such as (1) the course home page (course viewed) (F (2,39) = 26.067, p = .000), topic pages where the different course topics are delivered (course module viewed) (F (2,39) = 15.255, p = .000) and SCORM-packages opened (F (2,39) = 17.958, p = .000); (2) engagement in discussions (discussion made) (F (2,39) = 6.847, p = .000) and on the other hand viewing (discussion viewed) (F (2,39) = 8.288, p = .000); (3) formal submission of tasks (test made) (F (2,39) = 65.924, p = .000) and assignments (assignment submitted) (F (2,39) = 42.525, p = .000); and finally, (4) the consultation of scores (user score) (F (2,39) = 34.565, p = .000) and results (submission form consulted) (F (2,39) = 8.249, p = .001) seemed to have a different appearance between clusters. Eleven learners belonged to Cluster 1, nineteen to Cluster 2 and twenty-one to Cluster 3.

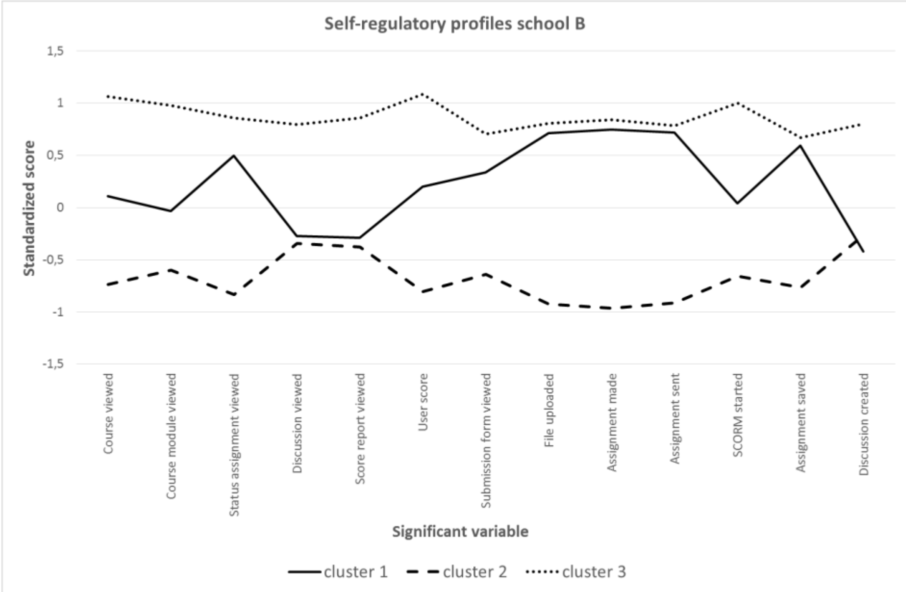

Figure 4. Three clusters of School B based on the significant different variables plotted on the standardized mean scores.

The event sequence analysis (Associated Pearson Residual of the chi-square test, residuals ≤ -2 less frequent and ≥ 2 more frequent) showed that learners in Cluster 3 used sequences involving the discussion forum (r = 3.2, p < .001) more compared to Cluster 1 (r = -1.45, p < .001) and two (r = -1.38, p < .001). Learners from Cluster 1 used the sequence '(test made) – (user score)' significantly more (r = 2.52, p < .001) than learners from Cluster 3 (r = 0.96, p < .001) and two (r = -2.67, p < .001). These were learners from Cluster 3 (r = 3.27, p < .001) who seemed to prefer to ask questions using the discussion forum before taking a test '(discussion made) – (test made)'. Learners from Cluster 1 (r = -1.25, p < .001) did not view the discussion forum before taking a test '(discussion viewed) – (test made)'. Learners in Cluster 2 interacted with the learning environment significantly less than the other two clusters.

Relation between self-regulation attributes and cluster membership over both schools

To investigate the relation between cluster membership and the design of BLEs a chi-square test of independence was calculated (for both schools). This test compared frequencies of cluster membership for the different environments learners were in. Significant interactions were found for both schools, School A (χ^2 (6) = 28.81, p < .001) and School B (χ^2 (2) = 13.85, p = .001). This result indicates that the environment influences the occurrence of certain profiles. Due to the similar cluster characteristics, significant variables and event sequences, it is reasonable to treat them as comparable. Cluster 1 (School A) and Cluster 3 (School B) were combined in profile one; Cluster 2 (School A) and Cluster 1 (School B) were combined in profile two; and Cluster 3 (School A) and Cluster 2 (School B) were combined in profile three. When the three clusters of each school were matched, a logistic regression was conducted to analyse whether the amount of attributes that support self-regulation in BLEs (sum score per environment) influences the number of learners per profile identified. A test of the full model against a constant only model was significant, indicating that the score for attributes that support self-regulation a course gets influences the amount of learners per profile (χ (6) = 40.324, p = .025). Parameter estimates showed that when the score for self-regulation increases with one point the chance to belong to Cluster 2 (Wald = 4.267, p = .039) or three (Wald = 5.255, p = .022) decreases. Exp(B) shows that when the score for self-regulation increases with one point, that for both learners in profile two (OR = 0.79 (95% CI 0.64 to 0.99), p = 0.039) and three (OR = 0.73 (95% CI 0.64 to 0.99), p = 0.022) the chance is large (for profile two 21% and for profile three 27%) to belong to profile one.

Conclusions and discussion

The aim of this study was to identify learners' self-regulatory behaviour profiles in BLEs and relate them to the design of the environments. The research involved three major steps: (1) the description of the environments; (2) the identification of the behaviour profiles; and (3) the investigation of the relationships between the previous two.

In the first step, we described six blended learning courses within two Flemish schools (A and B) for adult education, using a framework of self-regulatory attributes. Authenticity, personalization, learner control, scaffolding, and interaction were all observed frequently in the six BLEs. Reflection and calibration cues were least often observed in all of the BLEs.

Secondly, we identified three similar learner self-regulatory behaviour clusters in the two schools. Each of these clusters relate closely to earlier research done by Vermunt and Vermetten (2004), who identified self-regulating, external regulating and lack of regulation profiles. Cluster 1 (School A) and Cluster 3 (School B) shared the same characteristics. Learners with this profile used a wide diversity of learning resources (content, discussion forum, etc.). Nonetheless, they did not seem to check their scores very often. Learners with this profile seem to prefer to consult the discussion forum. Reflecting on the self-regulation model of Hadwin and Winne (1998), it seems that these learners prefer to evaluate their perceptions and products of learning using resources that can help them generate rich information about their performance. They do not seem to need explicit scores and are able to monitor their own learning and make internal judgements about task success and relative productivity. We named this group 'internal regulators'. These regulators are able to regulate their learning based on feedback of a formative nature.

Cluster 2 (School A) and Cluster 1 (School B) shared the same characteristics. Learners with this profile use the features related to content, assignments, scores, and results. They seem to be very score-oriented. They do interact with content on a moderate basis (significantly less than the internal regulators). They send in assignments and react to messages. They do not interact on the discussion forum, however, but do check their user scores often. Based on the Winne and Hadwin (1998) model, this type of learner seems to favour external evaluation (or binary outcome feedback) arising from performance above formative feedback. As these learners value the outcomes of learning most highly, we named this profile 'external regulators'.

Cluster 3 (School A) and Cluster 2 (School B) were also found to share the same features. The final self-regulatory profile we identified consists of mis-regulating learners. These learners seem to lack direction and do not interact with either embedded or non-embedded instruction. According to the Winne and Hadwin (1998) model, this type of learner deliberately chooses not to participate because they realize that what is asked of them does not match their needs. On the other hand, it is also possible that these learners are unable to regulate their own learning. Our analysis did indeed show that membership of this cluster had a significant negative impact on performance (ANOVA, F (2,73) = 19.880, p = .000).

During this second step of the study, it was interesting to note that internal and external regulators seem to focus on different aspects of self-regulation, in line with Butler and Winne (1995). Although there is no evidence in this study that learners with internal regulating profiles struggle more than external regulating profiles or vice versa, some remarks can be made about their differences. First, internally generated feedback is inherent to task engagement (Butler & Winne, 1995). Such feedback inevitably involves learners' making judgements about both task success and the productivity of various tactics and strategies. Second, the use of outcome feedback to self-regulate provides the least guidance on how to self-regulate (Butler & Winne, 1995). Its benefits depend very much on learners' being attentive to cues and their own performance during studying, having accurate memories of the learning process when consulting outcome feedback, and being sufficiently strategic to generate effective internal feedback about predictive validities. Figure 5 provides an overview of the differences between the internal and external regulator profiles.

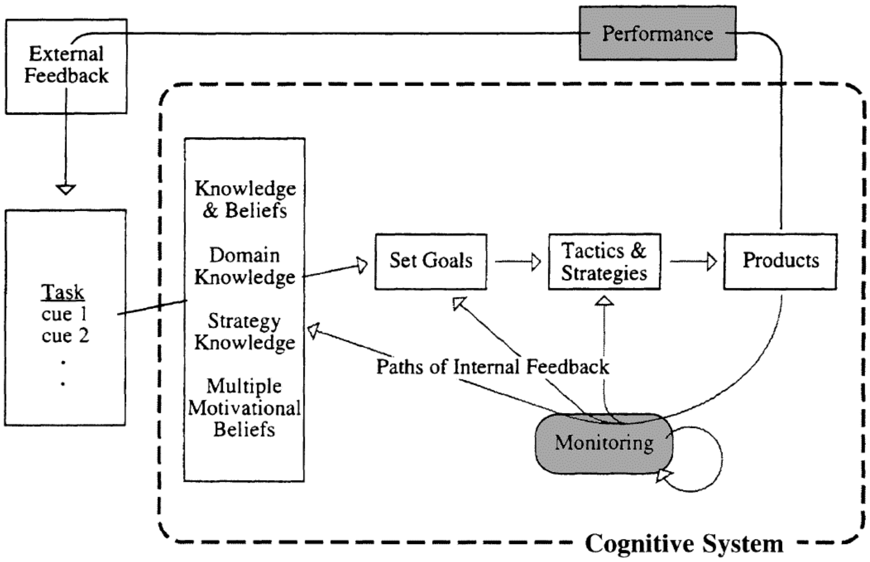

Figure 5. Butler and Winne (1995) model of self-regulation. From: Butler, D. L., & Winne, P. H. (1995). Feedback and self-regulated learning: A theoretical synthesis. *Review of educational research*, *65*(3), 245-281.

In the third and final step of the study, we investigated the relationship between the design of the learning environments and the learners' behaviour within those environments. As the sum score on self-regulation increases, the chance of mis-regulators shifting profiles increases significantly. This result indicates that better integration of attributes that support self-regulation in BLEs helps mis-regulators become internal or external regulators. Although neither internal nor external regulators can be classified as better self-regulators, it seems that mis-regulators (based on their behaviour and its relation to performance) are less successful. Therefore, it would be beneficial to increase the extent to which self-regulation attributes are included in the design of BLEs, especially to enable mis-regulators to shift profiles. These results are comparable with previous research on designing learning environments for self-regulation that demonstrates the importance of informed environmental design (e.g., Azevedo & Hadwin, 2005; Boekaerts & Corno, 2005; Dabbagh & Kitsantas, 2004; Schraw et al., 2006).

This study sheds some light on the relation between BLEs and learners' self-regulatory behaviour, but there are still some issues to overcome. A mixed method approach was used to collect both refined qualitative and quantitative traces. On the qualitative side, we were able to produce very rich descriptions of BLEs. However, the focus on attributes that support self-regulation meant that a considerable number of other variables related to the overall quality of the design (e.g., presentation, demonstration, and application principles) were neglected. First, the process of visualizing the environments, 'scoring' them for occurrence, and then reporting on the major observations might have a negative effect on the descriptions' granularity. Second, as the main focus of the study was to identify learners' behaviour in BLEs, rather than the attributes that influence learners' behaviour most and under what circumstances, we used sum scores. This meant, however, that it was impossible to investigate each environment's relationship to the learners' behaviour. Furthermore, the question remains whether it is the quality or the quantity of each attribute that influences this behaviour. Similarly, the quantitative aspect of the study was also influenced by certain limitations. First, the number of participants made it difficult to generalize about the results. Due to feasibility issues, it was not possible to increase the number of courses described or respondents included. On the other hand, though, we saw that the TraMineR package in R-statistics that we used for the event sequence analysis was tested to its limits due to the huge number of traces. This limitation means that, to date, we have only been able to extract event sequences containing two variables per sequence. Finally, research on learning strategies shows that small contextual changes can have a major effect on how learners self-regulate. Keeping this in mind, the grain size of the description tool used to map the BLE might influence the interpretation of the relationships found in this study.

In order to overcome the issues mentioned above, further research is needed to develop the methodology used to identify learners' behaviour in ecological BLEs. A first step might be to refine the grainsize of the instrument used to map both the online and offline learning environments. It would also be beneficial to investigate each of the attributes through an extensive review of the literature and/or to perform interventions to ascertain the relation between each attribute and learners' behaviour. In addition, we would recommend operationalizing the self-regulation concept defined by Hadwin and Winne (1998) and establishing an action library to improve the identification of learners' self-regulation. Such an action library would help to categorize the ecological trace variables into meaningful (coded) variables. By sequencing these variables, more detailed insights can be gained into the self-regulatory behaviour of learners. Applying such an approach could improve the reliability of the methodology for measuring learners' self-regulation.

Although this study has its limitations, it suggests innovative approaches to describing and analysing BLEs from a self-regulatory perspective. First, it offers at least a starting point for further research. Others have often failed to describe blended learning designs before and after intervention. Secondly, this study uses learners' actual behavioural traces in the environment rather than learner self-reporting. While there is already some literature on this trend, few studies have favoured ecological data and many prefer pre-designed surveys for gathering trace data (e.g., Azevedo, Johnson, et al., 2010; Harley et al., 2015; Winne, 2015, 2016; Winne & Hadwin, 2013; Winne et al., 2006). This study shows in a very modest way that, even in ecological trace data, particular combinations of variables may be able to explain some aspects of learners' self-regulatory behaviour. This data-driven approach might be a promising approach to further inform designs of learning environments. Finally, by relating the designs of BLEs to learners' self-regulatory behaviour in BLEs, a first attempt was made to establish a new perspective on the redesign of BLEs specifically based on learner behaviour. This research adds to the body of research that emphasizes the importance of design for self-regulation. Future research could investigate the more systematic integration of attributes that support self-regulation in BLEs.

Chapter Five

Internal factors and self-regulated learning

The text of this chapter is under review for publication in *Computers in Human Behavior*. [Van Laer, S., Bartolata, J., Meneses, M., Bellena, G., and Ignacio, M., & Elen, J. (2018). Uncovering the Relation Between Learners' Characteristics and Their Self-Regulatory Behaviour Patterns in Blended Learning Environments. *Computers in Human Behavior*, **under review**.]

Introduction

The personal computer and the Internet have caused a revolution in education (Spector, 2015). Over the years, blended forms of learning have become increasingly popular (Bates, 2005; Spanjers et al., 2015). "Blended learning is learning that happens in an instructional context which is characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning" (Boelens et al., 2015). Research on blended learning often praises the flexibility and suitability of blended learning environments for learners with beneficial constellations of cognitive, motivational, and metacognitive characteristics (e.g., Means, Toyama, Murphy, & Baki, 2013; Picciano, Dziuban, & Graham, 2013). Despite this, it remains unclear under what conditions these blended learning environments are successful (Means et al., 2013; Oliver & Trigwell, 2005) and why they seem more successful for some learners than for others (Lynch & Dembo, 2004; Wang, Shannon, & Ross, 2013). It seems that blended learning environments, as they are currently designed, work well for learners who demonstrate the self-regulatory behaviour needed to comply with the instructional demands of such environments, but that those same environments may fail to address the needs of learners who do not demonstrate the required behaviour (Barnard-Brak, Lan, & Paton, 2011; Barnard et al., 2009; Cennamo et al., 2002). To be able to address not only learners who suit the design of the blended learning environment, but also other types of learners (different levels of cognition, motivation, and metacognition) more insight is needed into how to design adequate blended learning environments (Adekola, Dale, Powell, & Gardiner, 2016; Connolly et al., 2007; Güzer & Caner, 2014). The limited insight available into the design of blended learning environments is problematic since without this information, evidence-based interventions and redesigns are almost impossible. In order to elaborate a model for designing blended learning environments that support learners' self-regulation and thus make learning more effective, this study addresses the following research question: "How do learners' characteristics relate to learners' self-regulatory behaviour in blended learning environments?".

Self-regulation in blended learning environments

In this study, self-regulatory behaviour is seen as "the use of metacognitive skills, in a particular context, to achieve goals both internal and external to the learner". Based on this definition, the Winne and Hadwin (1998) model was selected to reflect upon the self-regulatory behaviour of learners. Winne's Four-stage Model of Self-regulated Learning (Butler & Winne, 1995; Winne, 1995; Winne & Perry, 2000) describes four stages: (1) task definition, during which learners develop perceptions of the task concerned; (2) goal-setting and planning; (3) enacting the tactics and strategies chosen during goal-setting and planning; and finally (4) adapting studying techniques, keeping future needs in mind.

Additionally, each stage and its elements are influenced by certain conditions. Winne and Hadwin (1998) identify external conditions (e.g., time constraints, available resources and social context) and internal conditions (e.g., interest, goal orientation and task knowledge) that influence how a certain task will be engaged with (Winne & Hadwin, 1998). The Winne and Hadwin (1998) model was chosen since it has a clear behavioural focus on self-regulation as a series of events, rather than as an aptitude (Endedijk et al., 2016).

Conditions influencing self-regulation

External conditions

As indicated above, research on self-regulated learning reveals that learners often fail to control and regulate their learning activities in blended learning environments due to a deficit in the skills necessary to cope with the demands of such environments. As in any learning environment, different instructional interventions are needed to promote learners' learning and to support learners in taking appropriate action to do so. Based on this notion, Van Laer and Elen (2016b) identified seven attributes that support self-regulation in blended learning environments. The first of these is *authenticity*, or the real-world relevance of the learning experience to learners' lives. Secondly, there is *personalization*, defined as the tailoring of the learning environment to the inherent preferences and needs of each individual learner. Third, *learner control* is the degree to which learners have control over the content and activities within the learning environment. The fourth attribute is *scaffolding*, defined as changes in the task or learning environment, which assist learners in accomplishing tasks that would otherwise be beyond their reach. Fifth is *interaction*, or the way in which the learning environment stimulates learners' involvement with this environment. The sixth is *reflection cues*, which are prompts designed to activate learners' purposeful critical analysis of knowledge. Finally, there are *calibration cues*, triggers for learners to test their perceptions against their actual performance and study tactics. The combination of these attributes comprises the support system of learners' self-regulation in the learning environment.

Internal conditions

Although self-regulation seems to be influenced by external conditions, which lead to various decisions and learning outcomes (e.g., Panadero, Jonsson, et al., 2016; Perels et al., 2007), ultimately the learners themselves (and their cognitive, metacognitive, and motivational characteristics) influence and affect learning processes the most (e.g., Bransford et al., 2000; Endedijk et al., 2014; Zimmerman, 2002). In line with the Winne and Hadwin model (1998) in this study we focus on (a) prior domain knowledge, (b) expectancy-value, and (c) metacognitive awareness as internal conditions influencing learners' self-regulation.

Prior domain knowledge relates to how competent learners already are at a task. Learners who can automatically and seemingly effortlessly retrieve effective knowledge from memory, have minimal needs to deliberately self-regulate (Greene & Azevedo, 2007). An example of how learners' prior knowledge influences self-regulation processes might be the difference between an expert and a learner who is a novice. The latter faces quite a different task, one in which self-regulation can substantially enhance achievement (Winne & Butler, 1994). As widely demonstrated in the literature on expertise, the more extensive one's prior domain knowledge is, the less there is a need to search for, use, and regulate metacognitive tactics or strategies when grappling with complex tasks or when attempting to learn information in the domain (e.g., Lesgold et al., 1988; Song et al., 2016).

With regard to the use of expectancy-value as a motivational characteristic Wigfield and Eccles (2000) advanced a model of motivation based on efficacy, expectancies, and task value. This model focuses on learners' expectations for success on upcoming tasks, the values, and the affect learners assign to this task. The expectancy-value theory includes three components: value (intrinsic and extrinsic goal orientation and task value), expectancy (self-efficacy and control of learning), and affect (test anxiety). Moos (2014), Duffy and Azevedo (2015), Nelson et al. (2015) and Conley (2012) provided evidence for the impact of the task value, expectancy and affect component on learners self-regulation processes. They identified that learners with differences in intrinsic motivation, extrinsic motivation, or task value significantly differed in the extent to which they monitored their goals and so self-regulated their learning.

Finally, metacognitive awareness relates to knowledge of study tactics and strategies. Metacognitive awareness includes three types of knowledge. The first is declarative knowledge (that describes what a tactic or strategy is), the second is procedural knowledge (of how to use a strategy), and the third is conditional knowledge about a strategy's utility (that is, when and where a strategy can be used to meet particular purposes and how much effort is involved in using it). Bannert et al. (2015) and Bannert et al. (2015) investigated, in an experimental study, whether metacognitively aware learners showed different navigation behaviours compared to learners who were less metacognitively aware. Results showed that learners who configured their own metacognitive prompts and learned with them, showed significantly different navigation behaviour in the learning session afterwards compared to learners in the control condition. Similar results were obtained by Azevedo et al. (2016).

Self-regulation and learner behaviour

Due to the shift in perspective on self-regulation, traditional off-line measures can no longer be argued to fully capture the nature of self-regulation (e.g., Azevedo, Moos, et al., 2010; Reimann, 2009; Schoor & Bannert, 2012; Schraw, 2010; Winne, 2010). Generally, such off-line measures concern learners' self-reports gathered prior to or after task performance. The fundamental problem of the off-line nature of self-reports is that it requires learners to reconstruct their earlier performance. This reconstruction process might suffer from memory failure and distortions, especially if experiences from the past have to be retrieved (Veenman, 2011). Additionally, validity issues occur when questions about the relative frequency of certain activities ("How often do/did you...?") are asked. In contrast to off-line measures, on-line measures for measuring self-regulation gained substantial interest. These types of measurements are obtained during task performance, that is, they are based on actual behaviour of the learner. Typical online measures include observational methods, the analysis of thinking-aloud protocols, eye-movement registration, or log file analysis. The unobtrusiveness of some of these methods (i.e., log-file analysis) enables researchers to track learning events in a learning environment and "re-play" learners' self-regulatory behaviour. Tracing methods such as log-file analysis provide us with a fuller understanding of how learning, cognition, motivation, and metacognition intersect and vary throughout the process of self-regulation.

Measuring self-regulation online

The measurement of self-regulation as a series of events, is based on the dynamic nature of the phenomenon and so relies on continuous measurements to determine the quality of self-regulation. In this study we will focus on online measures, more specifically, log file analyses. These types of measurements appear to be better suited to finding relations between specific aspects of real-time self-regulatory behaviour in authentic contexts (Zimmerman, 2008) and may be more accurate than retrospective self-reports that require recall of actions and thoughts. The idea that self-regulation unfolds in the four main phases, described in the Hadwin and Winne model, suggests a cyclical relation among the components. Cleary et al. (2012) proposed the term 'sequential phases of regulation' to describe this cycle, which involves transitions from one event to the next. Several researchers have expressed the need to explore time and order in self-regulatory processes (Greene & Azevedo, 2010; Molenaar & Järvelä, 2014; Morris et al., 2010).

Event sequences

In this study, we use the term “event sequence” to describe patterns of learners’ self-regulatory behaviour. In many fields of research the terms “event” and “sequence” are used to describe different sorts of patterns (e.g., Abbott, 1995; Suthers & Verbert, 2013), so some clarification is in order. The first distinction relates to whether patterns contain information related to a state or an event. An example of a state in the context of log file analysis is being on a discussion forum page, while clicking on an exercise link would be an event, which changes the state to being on the exercise page. Thus, each change of state is an event, and events imply that the state has changed (Müller et al., 2010). The next distinction to be drawn is whether the order of events or states is logged and preserved. If this is the case, the data is sequenced; if not – for example, if the focus is on the frequency or diversity of the events rather than their order – then the data is perceived as an item set (e.g., Schraw, 2007). In the current study, the data (subject ID, event, and time stamp) is treated as event sequence data. This is because (1) the events revealed by the log files fall between unknown states and (2) the data is ordered by time stamps.

Investigations of event sequence data can be divided into three main types: pattern mining, pattern pruning and interactive visualization design (Liu, Dev, et al., 2016). In the current study, the focus is on pattern mining, the first type, which involves identifying meaningful event sequences (patterns). Mining these patterns involves two key elements: the order of the events (when the order is maintained, we refer to ‘sequential’ patterns) and the containment of sub-sequences, which are sections of a sequence that also appear in other sequences. Thus, sub-sequences are unique sets of events carried out in the same order by a threshold number of learners. They can be identified by applying the minimum edit distance (Levenshtein distance) between two sequences. The minimum distance between sequences is calculated based on the minimum number of editing operations: (a) insertion, (b) deletion, and (c) substitution of an event needed to transform the sequence into another sequence (Levenshtein, 1965). Containment relates to support for a sub-sequence in the sample. Support for a sub-sequence is the number (or percentage) of sub-sequences matching other learners’ sub-sequences. A frequent sub-sequence is a sub-sequence that is present in at least the threshold number of times among learners (see Figure 3). Following the identification of such sub-sequences, statistical trials (e.g., chi-square tests) can be carried out in an attempt to relate significant differences in the occurrence of sub-sequences to specific learner characteristics.

Learner characteristics and learners' self-regulatory behaviour sequences

Although the investigation of the relation between learner characteristics and learners' self-regulatory behaviour using (event) sequence analysis is new in educational research extensive research has been done , in recent years on differences in learners' course performance based on differences in learners' self-regulation (e.g., Bannert et al., 2015; Cho & Yoo, 2017; Pardo, Han, & Ellis, 2016; Romero, Ventura, & García, 2008; You, 2016). This work is valuable, but it often fails to uncover how the differences observed in self-regulation can be attributed to differences within learners (internal conditions) and how they can be influenced by the designs of interventions or learning environments (external conditions). In-depth insights seem to be needed into how self-regulatory behaviour is influenced by learner characteristics and how this (in a later stage) can be stimulated by targeted interventions towards better course performance (e.g., Greene & Azevedo, 2010; Hwang, Shadiev, Wang, & Huang, 2012; Molenaar & Järvelä, 2014; Morris et al., 2010).

The literature includes a number of studies related to the role of learners' prior domain knowledge, expectancy value, and metacognitive awareness in learners' self-regulatory behaviour. Liu, Lee, Kang, and Liu (2016) for example, used two cases to describe the behavioural differences between experts and novices and concluded that learners with different learning characteristics exhibited different learning behaviours. Jang et al. (2017) applied person-oriented analytic methods to multimodal data including verbal protocols, questionnaires, and computer logs from 78 task solutions and found that learners' clinical diagnosis abilities were positively correlated with advanced self-regulated learning behaviours, such as increased cognitive strategy use, critical attention to experts' feedback, and their responses to feedback. Finally, Blikstein (2011) used learning analytics to assess learners' behaviour in open-ended programming tasks. He concluded that a better understanding of each learner's coding style and behaviour provides us with an additional window into learners' cognition. In sum, the literature review on the relation of prior domain knowledge, motivation (expectancy value), and metacognition (metacognitive awareness) to learners' self-regulatory behaviour patterns (event sequences) shows that only a limited amount of research is available with this specific aim. However, identifying patterns and examining the relationship between this behaviour and learner characteristics is essential to creating the necessary scaffolding for facilitating increased course performance (Liu, Lee, et al., 2016).

Problem statement

In the search for guidelines for designing blended learning environments that support learners' self-regulation, it remains unclear how learners' self-regulatory behaviour is affected by the learner characteristics. This information will help us determine how interventions may affect different types of learners and so at a later point their learning outcomes. The ultimate goal is to identify learners' characteristics based on their behaviour and to provide targeted guidelines for designing learning environments to suit different types of learners. In this study, we treat self-regulation as an event rather than an aptitude. Based on the assumptions related to this conceptualization of self-regulation, and because little research has connected learner characteristics (internal conditions) to learners' self-regulatory behaviour, we analyse ecologically valid blended learning environment log files, using an event analysis approach to answer the research question: How do learner characteristics relate to learners' self-regulatory behaviour in blended learning environments?

Method

Three steps to answer the research question were taken. First, to safeguard the comparability of the external conditions, the course was analysed using a framework for the description of blended learning environments that support self-regulation (Van Laer and Elen (2016b). Secondly, based on the learner characteristics identified (a) a prior domain knowledge test, (b) the Motivated Strategies of Learning Questionnaire (Pintrich, 1991), and (c) the Metacognitive Awareness Inventory (Schraw & Dennison, 1994) were administered. Finally, event sequence data of the log files from the virtual learning environment (Moodle) were extracted for the analysis of the learners' self-regulatory behaviour.

Population and context

In this study, learners (n=25) from a Philippine university participated. The learners were freshmen enrolled in an eight-week Business Communication course. They all had a similar age (*M* = 18.12, *SD*= 0.23) and the majority of them were female (87%).

Design of the blended learning environment

The study took place in an ecologically valid blended learning environment. No adaptations to the course were made by the researchers in order to keep the context as authentic as possible. The course entailed six different topics, all of which had a similar structure (see 2.3.1). The six topics covered business communication in general, business writing, business letters, employment communication, and finally oral communication. The course consisted of 75% (6 sessions) online instruction and 25% (2 sessions) offline instruction. It was started online (see Figure 1 for the landing page of the online component of the course) and ran for four weeks, until the first offline session (see Figure 2 for an impression of the offline component). Following this session, there were another three weeks of online sessions. The course ended after eight weeks, at which point the instructor set the learners a classroom-based paper and pencil exam.

Online component of the course

At the start of the course, the instructor sent an e-mail to the learners including the deadlines for task-submission, information about the offline component of the course, and how to progress through the online component of the course. From then on, all communication about the course occurred via the online platform. The platform was a Moodle-based learning management system, running on the institute's server. After logging into the course, learners saw the landing page (see Figure 1). This page included a welcome message from the instructor, links (via icons) to two support topics ((1) How to study? and (2) Where to find help?), the different topics addressed in the course, and two discussion forums ((1) content issues and (2) practical issues). The learners were able to consult each part of the course at any time.

As indicated above, the structure of each of the topics was similar. Each topic started with a short introduction (examples, often a short video), followed by course content information (PowerPoint presentation in pdf), and exercises accompanied by scoring rubrics. Completed exercises would be uploaded via the platform. Finally, each of the topic pages contained a link to the discussion forum in case learners felt the need to discuss things as well as links to additional resources such as extra examples or non-compulsory content. The instructor was on hand to correct exercises, to moderate and answer questions when needed, and to emphasize the importance of sending in tasks on time in order not to miss deadlines. After four weeks, the instructor placed an announcement about the offline component of the course. This announcement stated that each learner had to be able to talk about and discuss each topic covered so far. After the first offline component of the course, the learners and the instructor continued their routine. In the run-up to the exam, the instructor posted a notification about the procedure for the exam on the platform. After the exam, the students' grades were also communicated via the platform.

Figure 1. Course landing page – online component.

Offline component of the course

The offline components of the course consisted of an interactive problem-based session and the formal exam. The interactive session involved the instructor questioning the learners about the different topics plenary-style. Following this, small-group discussions were organized on the different topics presented in the online component of the course. With regard to the final offline session, the exam was a 90-minute (10 questions) sit-in exam consisting of cases that the learners had to address. Examples of such cases were for example “write a complaint letter” or “Discuss the steps of oral collaboration”.

Figure 2. Course in progress – offline component.

Instruments

The instruments used assessed (a) the description of the external conditions, (b) the description of learners' internal conditions (cognitive, motivational, and metacognitive), and (c) learners' self-regulatory behaviour.

Description of external conditions

To ensure that differences in learners' self-regulatory behaviour did not relate to changes in the blended learning environment the stability of the design throughout the runtime of the course was investigated. During the course the offline components of the course was video-recorded. After the runtime (8 weeks) of the course the online component was copied to a server for research purposes, this to ensure its sustainability over time. The different topics addressed during the course were investigated using a framework (Van Laer & Elen, 2016b) containing the seven attributes that support self-regulation. The unit of analysis chosen was a topic, this because a topic was representative for an inclusive cycle of instruction. Based on the coding of the entire course by the raters, following rater training (including (a) the discussion of the rater manual, (b) agreement over the scoring, and (c) unit of analysis used) the inter-rater reliability was calculated. Inter-rater reliability here is defined as the extent to which different raters, each describing the same content, come to the same decisions (Rourke et al., 2001). Among other coefficients the Kendall's W (also known as Kendall's coefficient of concordance) is used to investigate inter-rater reliability. This coefficient is of particular interest for the purpose of the method presented. It is a normalization of the statistic of the Friedman test, and can be used for assessing agreement of ordinal variables (Likert-type scale) among multiple raters. Kendall's W ranges from 0 (no agreement) to 1 (complete agreement) and is reported with a significance score. According to Cicchetti (1994) a Kendall's W score of .63, $p = .033$ indicates good reliability. It became clear that all six topics addressed in the course were rated equally for all seven attributes (minimum: 1 and maximum: 5) (authenticity: 3, personalization: 2, learner control: 3, scaffolding: 3, Interaction: 4, cues for reflection: 2, and cues for calibration: 2) and could be regarded as stable throughout the course.

Description of internal conditions

To assess learner characteristics three actions were undertaken. First, a performance based prior domain knowledge test was administered to investigate learners' prior domain knowledge. This test was a trial exam that represented the content of the entire course consisting of 5 questions. The trial exam consisted of exercises on each of the topics. The learners were asked to write a complaint letter, elaborate on the different steps of oral communication, and so on. The complete trial exam took 90 minutes and was administered in a traditional classroom set-up. After completion of the test, the exercises were scored by another instructor who was not participating in the study. Based on the score of the learners on the test they were divided into three percentile scores (i.e., 33.33, 66.66 and 100.00) and were labelled low, moderate or high. Secondly, regarding the motivational conditions of the learners the motivation part of the Motivated Strategies of Learning Questionnaire (MSLQ) was administered (Pintrich, 1991). The MSLQ is a self-report instrument designed to assess college learners' motivational orientations and their use of different learning strategies for a course. The MSLQ is based on a general cognitive view of motivation and learning strategies. This 81-item questionnaire is composed of two major sections: learning strategies and motivation. On the one hand, there is the learning strategies section. This section is divided into a cognitive, metacognitive and resource management section. Because the aim of the current study is to uncover learners’ behaviour this part of the MSLQ was not used. Prior research (e.g., Muis, Winne, & Jamieson-Noel, 2007) also showed the misfit of this section with learners’ behaviour. The motivation section on the other hand is shown (e.g., McClendon, 1996) to be highly effective for investigating learners’ motivational conditions influencing self-regulation. This section involves scales that involve value (intrinsic and extrinsic goal orientation and task value), expectancy (self-efficacy and control of learning), and affect (test anxiety). In the MSLQ, learners respond to questions on a Likert-type scale that ranges from ‘not at all true for me’ to ‘very true for me’. Third and final for metacognition, the knowledge about cognition part of the Metacognitive Awareness Inventory (MAI) was administered (Schraw & Dennison, 1994). The MAI targets the two major components of metacognition: knowledge about cognition and regulation of cognition. The latter in this study is seen as self-regulation and therefore not included. The knowledge about cognition component includes beliefs about declarative, procedural, and conditional knowledge. This instrument was chosen for its focus on the influence of metacognition on self-regulation (e.g., Sperling, Howard, Miller, & Murphy, 2002). Each of the instruments, with their scales was piloted and investigated for reliability (Cronbach’s Alpha). Table 1 show the reliability scores for each variable investigated.

Table 1.

Reliability scores per construct measured.

Latent variable	Construct	Cronbach's Alpha
Cognition		
	Prior domain knowledge (PDK) (5 items)	.78
Motivation		
Value	Intrinsic goal orientation (IGO) (4 items)	.66
	Extrinsic goal orientation (EGO) (4 items)	.65
	Task value (TV) (6 items)	.87
Expectancy	Control of Learning Beliefs (CoLB) (4 items)	.73
	Self-efficacy of learning and performance (SEoLaP) (8 items)	.83
Affective	Test anxiety (TA) (5 items)	.88
Metacognition		
Knowledge of cognition	Beliefs about declarative knowledge (DK) (8 items)	.85
	Beliefs about procedural knowledge (PK) (4 items)	.83
	Beliefs about conditional knowledge (CK) (5 items)	.73

Description of self-regulatory behaviour

To describe learners' self-regulatory behaviour, log files from the online learning environment were extracted. These log files contain ecologically valid traces related to the different actions learners did. The Moodle environment tracked variables related to assignments, calendars, discussions, forums, notes, pages, URLs and user profile. Each of these variables was elaborated with components such as submit, view, or delete. Combined these variables described 52 unique events tracked by the environment. Each of these unique events included an action (view, submit, modify, etc.) and could be categorized into nine unique categories of variables used by the learners: (1) the course's landing page (course), (2) a content-related page (page), (3) an obligatory assignment (assign), (4) a discussion forum (forum) and (5) post on the forum (post), (6) a user page containing personal information (user), (7) a note page where learners could collect notes (note) and finally (8) non-obligatory extra resources (resources) and (9) URLs (url). Not each event was used by all learners. Each of the events was related to the learner-ID and timestamped. This resulted in an event sequence dataset that included more than 10,000 events recorded over the 25 learners.

Procedure

At the start of the course each of the learners' filled in an informed consent and was asked to complete the prior domain knowledge test, the questionnaire targeting their motivation (MSLQ) and metacognition (MAI). During the course, the offline components of the course were recorded using a video camera. All the events in the online course were tracked. After the 8-week runtime of the course, a back-up of the course was taken and the data secured on a separate server. Based on these data sources, analyses including statistical trials were done. All the learners agreed to participate in the study, so all the data collected could be used.

Analysis

Following the data collection, the data was cleared from events prior to the start and after the end of the course. Only the learners who participated in the prior domain knowledge test and the motivation and metacognition questionnaire were withheld. The data was imported in R-statistics and analysed using the TraMineR package (Gabadinho et al., 2011). Below the event sequence analysis will be discussed.

Event sequence analysis

The event sequence analysis consisted of two major steps. First, an exploratory sequence analysis was done by the identification of frequent event sub-sequences. Secondly, an explanatory approach was taken by the identification of discriminant frequent event sub-sequences by considering learners' internal conditions (cognition, motivation, and metacognition).

Frequent event sub-sequences: exploratory sequence analysis

Three parameters are of importance when identifying frequent event sub-sequences. The first one is the maximum length (k) of a sub-sequence. Due to the limitations of the R-package used, k was set on three. The second one is the minimal relative support (pMinSupport) of a sub-sequence among the different learners. In this study, this parameter was set on .05. The last parameter is the Levenshtein distance. This to be able to distinguish when a sub-sequence can be seen as unique. To be able to calculate this distance, the following is needed: (a) an event sequence object (seqe), (b) the insertion/deletion cost (idcost) of the different type of event (amount of events observed), here nine, and (c) the cost of moving an event one time unit (vparam). For the cost of moving (vparam) the value was kept on the default of .1. The calculation of the distance measure is fully described in Studer et al. (2010). Figure 3 gives a visual representation of the procedure described.

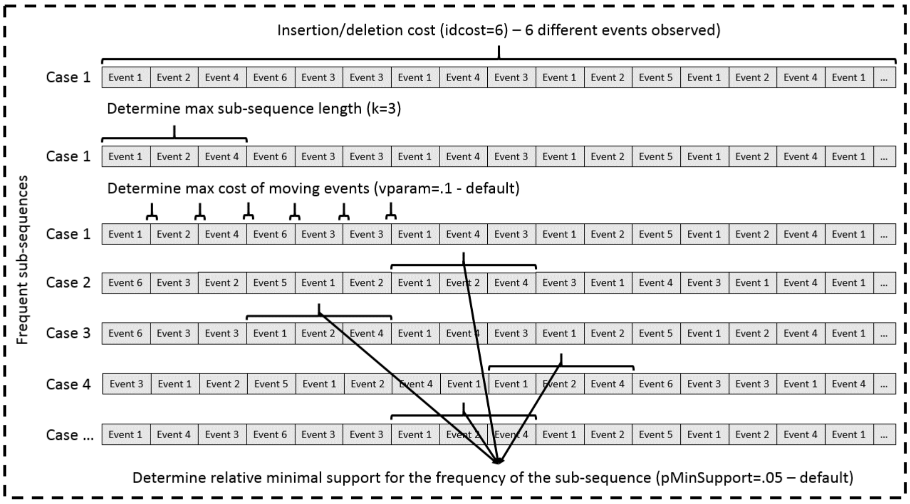

Figure 3. Visual representation of the determination of a frequent sub-sequence.

Discriminant frequent event sub-sequences per learner characteristic

The significant discriminating ability of the sub-sequences was based on differences between groups (e.g., cognition, motivation, or metacognitive conditions) by using the chi-square test. To be able to calculate the discriminating abilities of a frequent sub-sequence two arguments are needed (a) a sub-sequence (subseq) object containing the sub-sequences considered for discriminating the groups and (b) the variable that defines the groups (groups). The use of the chi-square test is appropriate as it investigates the significance of the relation between the observed and expected occurrence of a frequent sub-sequence for each value of the measured variables. Finally, the effect sizes are calculated using Cohen's d. The Cohen's d was calculated to express the relation between a certain discriminating frequent sub-sequence and the learners' characteristics. This analysis is based on the mean frequency of the occurrence of the frequent sub-sequence per score for each learner condition. Figure 4 gives a visual representation of the procedure described.

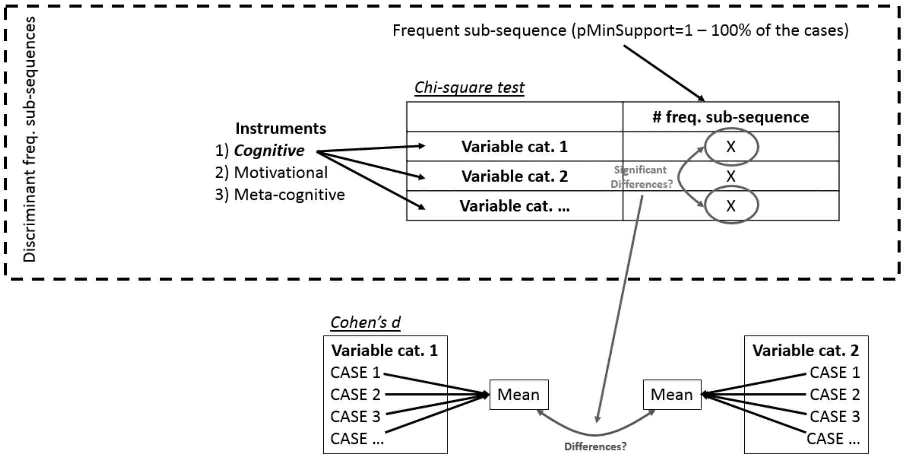

Figure 4. Visual representation of the determination of a discriminant frequent sub-sequence and the calculation of the Chi² -measure and the effect.

Results

Learner characteristics

Of the 25 learners, 22 were included in the analysis (exclusion based on missing values). Descriptive statistics showed that for the prior domain-knowledge test, eight learners scored below the 33.33rd percentile (i.e., low or below 32.00 out of 100.00), eight learners scored between the 33.33rd and 66.66th percentile (i.e., average or between 32.00 and 43.33 out of 100.00) and six learners scored above the 66.66th percentile (i.e., high or between 43.33 and the maximum score achieved of 60.00 out of 100.00). Regarding the Likert-type scales (1 for totally disagree and 5 for totally agree) for (1) motivation and (2) metacognitive awareness the mean score, standard deviations and variance statistics was calculated. Table 2 gives an overview of these calculations.

Table 2.

Descriptive statistics learner characteristics.

Latent variable	construct	Mean	Std. Deviation	Coefficient of Variation
Motivation				
Value component	IGO	4.45	.671	.151
	EGO	4.68	.568	.121
	TV	4.82	.395	.082
Expectancy component	CoLB	4.41	.590	.134
	SEoLaP	4.23	.685	.162
Affective component	TA	3.55	.912	.257
Metacognition				
Metacognitive awareness	DK	4.45	.596	.134
	PK	4.55	.800	.176
	CK	4.59	.666	.145

In a first step, 703 frequent sub-sequences were identified. The sub-sequences contained maximum three events (k=3), nine unique categories (idcost=9) of variables were used by the learners: (1) the course's landing page (course), (2) a content related page (page), (3) an obligatory assignment (assign), (4) a discussion forum (forum) and (5) post on the forum (post), (6) a user page containing personal information (user), (7) a note page where learners could collect notes (note) and finally (8) non-obligatory extra resources (resources) and (9) URLs (url). Table 3 gives an example of the interpretation of such an event sub-sequence.

Table 3.

Example of the description and interpretation of event sub-sequences.

Sequence	Interpretation
(course)-(page)-(forum)	The learner first entered the course landing page, progressed via a content-related page (including information and exercises) to a discussion forum topic.
(assign)-(forum)-(course)	The learner made an assignment followed by a visit to the discussion forum and finished by visiting the course's landing page.
(user)-(forum)-(page)	The learner visited a colleague's user page followed by a visit to the discussion forum and a visit to some content related course material.

Secondly, the influence of the learner characteristics on learners' behaviour throughout the course was investigated. To investigate the relationship of learners' cognitive, motivational, and metacognitive levels and the occurrence of frequent sub-sequences (703) chi-square tests were done followed by the calculation of the effect sizes. Based on this analysis it was possible to extract discriminant frequent sub-sequences that occur significantly more (and their frequency effect size) per score on each variable. The idea was explicitly, first to use this data-driven approach and to later relate the findings to the theory.

Cognitive conditions influencing learner's self-regulatory behaviour

Related to the relationship of learners' level of prior domain knowledge (PDK) and the occurrence of certain frequent sub-sequences, the results showed both a significant negative correlation (high score, low occurrence) between the level of PDK and sequences containing pages related to content (χ^2 (2) = 11.41, p < .05, *d* = -1.37) and a positive correlation (high score, high occurrence) between the score for PDK and frequent sub-sequences containing the use of the discussion forum (χ^2 (2) = 16.38, p < .05, *d* = .60) and the consultation of other users' personal page (χ^2 (2) = 7.84, p < .05, *d* = 1.22). These results indicate that when learners have a high score for prior domain knowledge, they use significant fewer sequences containing content page visits and significantly more sequences containing interactions with the discussion form or other learners' personal page.

Motivational conditions influencing learner's self-regulatory behaviour

Related to the value component of motivation, for intrinsic goal orientation (IGO), results showed significant positive correlations between the level of IGO and sequences containing other learners' personal information page (χ^2 (2) = 5.10, *p* < .05, *d* = .56) and visits to the course discussion forum (χ^2 (2) = 5.10, *p* < .05, *d* = .56). A significant negative correlation was found between IGO and sequences containing assignments (χ^2 (2) = 6.70, *p* < .05, *d* = -.48).

For extrinsic goal orientation (EGO) results showed significant positive correlations between the level of EGO and sequences containing content related pages (χ^2 (2) = 6.88, *p* < .05, *d* = .76) and visits to assignment pages (χ^2 (2) = 6.88, *p* < .05, *d* = 1.44).

Finally chi-square tests between learners' perceived task value (TV) and the occurrence of frequent sub-sequences showed significant positive correlations with regard to sequences containing external web links (χ^2 (2) = 3.87, *p* < .05, *d* = .50) and additional sources related to the content (χ^2 (2) = 3.87, *p* < .05, *d* = .33).

Related to the expectancy and affective component, for control of learning beliefs, self-efficacy of learning and performance and test anxiety no significant differences among the learners' behaviour could be determined. The results show significant positive correlations between IGO and sequenced related to the discussion forum and other learners' pages, and a significant negative correlation related to sequences containing assignment pages. The higher learners' scored on extrinsic goal orientation (EGO), the more they were involved in sequences related to assignments and content pages.

Metacognitive conditions influencing learner's self-regulatory behaviour

For the investigation of the effect of knowledge of cognition on learners' self-regulatory behaviour, first learners' beliefs about declarative knowledge (DK) was investigated. The results of the chi-square test showed significant correlations between learners' beliefs about DK and frequently used sequences. Significant positive correlations were found between beliefs of DK and sequences containing additional resources (χ^2 (2) = 8.92, $p < .05$, d = .58), other users' personal information page (χ^2 (2) = 6.89, $p < .05$, $d = .52$), urls (χ^2 (2) = 7.68, $p < .05$, $d = 1.04$) and posts on discussion forum (χ^2 (2) = 6.89, $p < .05$, $d = .52$).

Also for learners' beliefs about conditional knowledge (CK) and the occurrence of frequent sub-sequences the results showed significant positive correlations when learners reported higher beliefs of CK and sequences containing the submission of assignments (χ^2 (2) = 8.69, $p < .05$, $d = 1.60$) and visiting content related information pages (χ^2 (2) = 7.27, $p < .05$, $d = .79$).

Finally, for learners' beliefs about procedural knowledge (PK) and the occurrence of frequent sub-sequences the analysis showed significant negative correlations between learners who reported higher beliefs about PK and sequences containing the course homepage (χ^2 (2) = 14.13, $p < .05$, $d = -.73$), visiting content related information pages (χ^2 (2) = 9.37, $p < .05$, $d = -1.19$) and visits to the forum (χ^2 (2) = 8.48, $p < .05$, $d = -.71$).

The results indicate that learners scoring higher on beliefs about declarative knowledge used sequences that include significantly more additional resources, other learners' personal pages, and posts on the discussion forum. Learners' scoring higher on conditional knowledge applied significantly more sequences that included assignments and content related pages. Finally, learners who scored higher on beliefs about procedural knowledge applied significantly fewer sequences that included visits to the course homepage, content pages, and the forum.

Discussion

Findings

Influence of cognition on learners' self-regulatory behaviour

With regard to cognition, it became clear that a higher score on prior domain knowledge (PDK) leads to the occurrence of "fewer sub-sequences that include content pages" and "more sub-sequences that include other users' personal profiles and the discussion forum". Although no prior research seems to be available using event sequence analysis to investigate the relation between learners' internal conditions and learners' self-regulatory behaviour, there is comparable research in the tool-use literature. In the light of this research the findings are comparable with those of Renkl (2002), who found that PDK mainly affects the amount of tool use (negatively correlated). In relation to this, Chapelle and Mizuno (1989) emphasized that this is only the case for content-related pages and not for discussion forums or assignment pages. A more recent study of Taub et al. (2014) investigated the sequences presented by learners differing in prior domain knowledge. The results from this study demonstrated how low and high prior knowledge learners might have used cognitive and metacognitive self-regulation strategies as they learned about the human circulatory system. Results indicated that prior domain knowledge groups significantly differed in their use of total cognitive and metacognitive self-regulation processes; and more specifically, learners with high prior domain knowledge engaged in metacognitive strategies before cognitive strategies because they were more focused on monitoring what they knew from what they did not know, and this requires metacognitive knowledge and skills; they also had more working memory capacity to allocate to metacognitive monitoring processes. Learners with low prior domain knowledge engaged in cognitive strategies before metacognitive strategies because they were focused on learning the material, therefore using more cognitive strategies. Similar results were found by Trevors, Duffy, and Azevedo (2014). An explanation for the differences in sequences and number of occurrences of content pages from a self-regulation perspective was formulated by Moos and Azevedo (2008), who concluded that unlike high prior domain knowledge learners, low prior domain knowledge learners are engaged in what is called 'knowledge acquisition'. Given their lack of a well-established knowledge base of the topic, they regulate their learning by frequently using content-related pages (or sequences) to learn as much as possible about the topic to accomplish the overall learning goal within the time imposed time restrictions. In sum, the results presented in our study support Moos and Azevedo (2008) second conclusion that learners with high prior domain knowledge seem to use different self-regulation strategies. A possible explanation for this may be that these types of learners no longer need to focus on the content as much as learners with lower levels of prior domain knowledge. These results lead us to hypothesize that learners with high prior knowledge engage more in self-regulation processes (e.g., monitoring) than learners with low prior knowledge, who focus more on cognitive processes.

Influence of motivation on learners' self-regulatory behaviour

With regard to motivation, our results showed that (1) learners with higher intrinsic goal orientation use more sequences that include external (additional) resources, forums, and URLs compared to learners with low intrinsic goal orientation; (2) learners with high extrinsic goal orientation focus more on sequences that include the formal requirements of the course; and (3) when learners perceive the value of a task to be higher, they use more resources to supplement the course material. The finding that learners who score high on intrinsic goal orientation use more resources outside the formal course structure is in line with Lust (2012), who found that these type of learners made more use of elaborate information tools compared to learners with lower scores for intrinsic goal orientation. Secondly, we found that learners with higher scores for extrinsic goal orientation seem to focus more on sequences related to testable course elements that yield a performance output (Elliot & Church, 1997). This finding could be explained as the operationalization of intrinsic goal orientation, which comprises exploration, spontaneity, and interest in the surroundings (Piaget, 1971; White, 1959).

The findings about task value are comparable with those of Neuville, Frenay, and Bourgeois (2007), who found that learners who scored high on the MSLQ construct for task value (TV) used more elaborate and deeper processing strategies characterized by the use of elaborate information tools (e.g., extra resources, URLs and forums). Thirdly, it was observed that neither the expectancy nor affective constructs produced significant discriminant sequences. These findings echo Lust (2012); however, they challenge self-efficacy theory's assertion that learners' self-efficacy beliefs have an important influence on learners' behaviour (e.g., Pajares, 1996; Pintrich & De Groot, 1990) and they also contradict prior findings that highly test-anxious learners have difficulties encoding and organizing the material in the learning stages (e.g., Birenbaum, 2007). This observation may have two causes. On the one hand, it is possible that there is no relation between either of the two concepts and learners' self-regulatory behaviour. This seems unlikely given the findings of prior research (Schunk & Ertmer, 2000). A more plausible explanation is that the scales used were unable to capture the nature of self-efficacy in relation to learners' self-regulatory behaviour (Muis et al., 2007). This should be explored in future investigations.

Overall the results presented are comparable to the findings of Moos (2014), Duffy and Azevedo (2015), Nelson et al. (2015) and Conley (2012). Although no significant relations were found for expectancy and affect, the findings presented above lead us to the hypothesis that learners who are intrinsically motivated and value the task at hand high will show more elaborated use of tactics and strategies. In contrast, learners who are extrinsically motivated and value the task at hand low will show less elaborated use of tactics and strategies, but will monitor the external goals set more closely.

Influence of metacognition on learners' self-regulatory behaviour

Finally, our findings on the knowledge of cognition component indicate that learners who score higher on beliefs about declarative knowledge used significantly more sequences that include additional resources, other learners' personal pages, and posts on the discussion forum. Learners who scored higher on conditional knowledge went through significantly more sequences that include assignments and content-related pages. Finally, learners who scored higher on beliefs about procedural knowledge applied sequences that included significantly fewer visits to the course homepage, content pages, and the forum. These findings are supported by a large body of literature investigating the relation between learners' metacognitive awareness and their use of metacognitive tactics and strategies. Bannert et al. (2015) and Bannert et al. (2015) carried out an experimental study to explore whether learners with different levels of metacognitive awareness would exhibit different navigation behaviours, finding that the navigation behaviour of learners who configured and used their own metacognitive prompts differed significantly in a subsequent learning session from that of learners in the control condition. Azevedo et al. (2016) observed similar results. Pintrich (2002) explained these findings by stating that, if learners are not aware of the approaches they can use to solve problems, they will probably not be able to use them (Bransford et al., 2000). If learners know about a range of approaches, they are more likely to use them than when they have only a limited repertoire (Schneider & Pressley, 1997). If learners know about general approaches, they are more likely to use them in different situations (Weinstein, Mayer, & Wittrock, 1986). These results lead us to the hypothesis that learners with high levels of beliefs on the three types of knowledge (declarative, procedural, and conditional) leading to high metacognitive awareness (or knowledge about cognition) engage more in a diversity of self-regulation processes than learners with low levels of metacognitive awareness.

Implications for research

A first implication for research is a methodological one. More specifically the presentation of a study administered in an ecologically valid online environment, using an as data-driven approach as possible, which is able to generate comparable results as studies administered in strict experimental settings using deductive approaches. Whereas other studies rely on the use of visualisations (e.g., process-mining) or inferences straight from object-level to meta-level self-regulation via the recoding of raw data, this study presents a data-driven approach using statistical key-figures identifying meaningful and discriminating sub-sequences. Although this approach is far from perfect, it allows research to transfer from a pure deductive approach towards a more data-driven and ecological approach. To be able to further develop the methodology proposed in this study, it would be interesting in future research to recode the overt, object-level variables using non-self-regulation related object-level categories. Such categories provide a theoretical sound categorization (Lust, 2012) and could be based on for example tool classification schemes. This would allow the identification of meaningful sub-sequences (generalizable to broader contexts), which could be tested and triangulated against other online measures.

Secondly, there are some theoretical implications. On the one hand, our study validates prior research on the relation between prior-domain knowledge (e.g., Kramarski, Weiss, & Sharon, 2013; Song et al., 2016; Taub et al., 2014), expectancy-value (e.g., Ali, Hatala, Gašević, & Winne, 2014; Karabenick & Zusho, 2015; Mega et al., 2014), and metacognitive awareness (de Fátima Goulão & Menéndez, 2015; Duffy et al., 2015; Feyzi-Behnagh et al., 2014) and learners' self-regulatory behaviour in technology-rich environments. On the other hand, it highlights that learners not always perceive (based on differences in their cognition, motivation, and metacognition) designs of learning environments (prompts and cues) as intended by the instructor. This raises the question: "what accounts for the differences between learners?". This question calls for a more thorough investigation of the relation between (1) learners' internal conditions, (2) characteristics of the task conditions as provided by the learning environment, (3) the behaviour learners engage in in these environments and (4) the relation of the latter with learners' learning outcomes. By conduction experimental studies including learners with differences in learner characteristics (in both experimental and control condition), describing the design of the learning environments in both conditions, and comparing their outcomes and self-regulatory behaviour (in both experimental and control condition) insights might be gained about which interventions work best for what learners.

Implications for practice

Although several studies (e.g., Lopez, Nandagopal, Shavelson, Szu, & Penn, 2013) have shown unique differences between high- and low-achieving learners in the specific strategies they engage in to achieve academically (Zimmerman & Martinez-Pons, 1990), the awareness that learners not always perceive prompts and cues as intended by the instructor (Winne & Hadwin, 1998) seems not to be disseminated thoroughly into practice. As the aim of this study was not to investigate under what internal (learners' characteristics) and external (design of the learning environment) which learner behaviour (event sequences) led to increased learning outcomes (course performance), no concrete guidelines on how to design effective learning environments are provided. Instead, the findings of the study underscore the importance of being aware that learners react differently to one-size-fits-all designs. In combination with prior research on the role of external conditions, our findings confirm the theoretical model for self-regulation used in this study, which states that both internal and external conditions influence learners' self-regulatory behaviour.

With regard to the impact of external conditions more specific the design of learning environments, ample evidence is provided in current research by Gašević, Dawson, Rogers, and Gašević (2016), who have investigated the extent to which instructional (external) conditions predict course performance. These authors conclude that differences in technology use, especially those related to whether and how learners use the learning environment, require consideration before a generalized model for predicting course performance can be created. A lack of attention to instructional (external) conditions can lead to over- or underestimation of the effects of environments' features on learners' course performance.

With regard to the impact of internal conditions and in line with prior research mainly focussing on tool-use, this study demonstrated that when the design of the learning environment is controlled and identical (one-size-fits-all) for all learners, differences in behaviour can still be observed. Keeping this in mind, we can conclude that a lack of attention to conditions within (internal to) the learner may also lead to over- or underestimation of the effects of environments' features on learners' course performance. Although only a few studies have used a behavioural sequence approach, this finding is in line with a large body of tool-use research that emphasizes the importance of design in learners' individual differences. Nakic, Granic, and Glavinic (2015) and Thalmann (2008) found in their reviews that interventions in learning environments were highly successful when they were adapted to learners' cognitive, motivational and metacognitive variables. Only by taking into account both internal and external conditions will we be able to investigate the full effect of interventions on both self-regulatory behaviour and course performance.

Limitations and conclusions

Limitations

To enable further research to build upon the theoretical and methodological approach presented in this study, some issues need to be addressed. The first consideration relates to the balance between inductive (data-driven) and deductive (theory-driven) approaches. This study differed from the traditional approach to investigating self-regulation as an event (e.g., Azevedo, 2002; Taub et al., 2014;

Winne, 2011; Zhou et al., 2010) in that it took an inductive, learning analytics approach to gathering and analysing data. Clow (2013) points out that, “as a field, learning analytics is data driven and is often atheoretical, or more precisely, is not explicit about its theoretical basis”, so such an approach might have certain benefits for theory-building. A data-driven approach could be used to identify and operationalize specific behaviours that are believed to reflect self-regulation (Winne & Baker, 2013). Based on the outcomes of data-driven trials, theoretical models can be developed through prediction modelling. This type of modelling involves obtaining specific learners’ behavioural profiles using a data-driven approach and developing a model, which can match the profiles to new data, and it may prove more promising than, for example, practises which attempt to validate a theory by recoding variables using the same theory. Nonetheless, in further research it might be useful to integrate a theory-driven approach in a subtler way (i.e., in the analysis phase). This could be achieved for example by recoding the events or sequences based on a theoretical framework unrelated to self-regulation theory. This would reduce the number of events in the analysis drastically and potentially make them more meaningful. In contrast to this, the data would not speak so well for itself and be more of a representation of the theoretical model imposed on it.

Another limitation, although related, relates to the format of the data and the analysis techniques used. Questions regarding the optimal grainsize for uncovering self-regulatory behaviour remain unaddressed. Likewise, the level of some parameters included in the analysis (length of sequences (k=3), cut-off score for categorization as frequently occurring, etc.) is somewhat arbitrary. Although the parameter setting used to define the length of event sequences (k=3) was set based on technical limitations, in our opinion and for validation purposes this nevertheless remains a transparent means of investigating the relation between overt behaviour and the covert nature of self-regulatory behaviour. Other relevant studies with similar focusses (e.g., Taub et al., 2014; Zhou et al., 2010) preferred to recode the object-level variables into meta-level self-regulatory behavioural inferences. Taking this deductive approach would have minimized the computational power needed for the sequential analysis, as it would have limited the number of meta-level constructs depending on the theoretical basis of the framework used. Nonetheless, we did not take such an approach because of our data-driven focus (see: inductive vs deductive approaches). Other data-driven researchers (e.g., Kovanović, Gašević, Joksimović, Hatala, & Adesope, 2015; Siadaty et al., 2016b) used the methodological approach presented in our study, but treated self-regulation as a state. Leaving aside the appropriateness of such an approach (see: state vs event), it does not require the same amount of computational power as it does not cross-tabulate all data to identify frequent sub-sequences. Finally, with regard to the use of the TraMineR package for the event sequence analysis of self-regulatory behaviour, we are the first authors to use it in this fashion. However, to be able to develop the methodology proposed in this study further, it would be interesting in future research to recode the overt, object-level variables using non-self-regulation-related object-level categories. Such categories could be based on, for example, tool classification schemes. This would allow for the identification of meaningful sub-sequences, which could be tested and triangulated against other online measures.

The statistical background of the data also needs to be investigated further. The algorithms used often limit the analysis (chi-square) to checking the significance of the discriminant occurrence of certain sequences based on the more frequent occurrence. Although the approach uses sequences, it is still based on frequencies rather than on patterns. It would be useful to be able to investigate the order and temporality of sub-sequences to uncover patterns of events. Furthermore, triangulation of the data (events) would help uncover their relation to learners' self-regulatory states. Finally, due to the limitations of the analysis techniques, it was not possible to test the multicollinearity of the different learner characteristics investigated. The development of standards for conducting event sequence analyses would be a desirable next step in future research. In summary, to reap the full potential of log-file data there is a need for (a) a careful balance between data-driven and theory-driven approaches and (b) standards for conducting event sequence analyses. Although this study has its limitations, it reports a number of sound and validated findings related to learners' characteristics and their relation to self-regulatory behaviour.

Conclusions

The results of this study demonstrate the impact of learners' cognitive, motivational, and metacognitive characteristics on learners' self-regulatory behaviour. Additionally, they lend support to the notion of investigating log files using sequences in events extracted from ecologically valid learning environments. Most of the cognitive, motivational, and metacognitive conditions investigated in this study were associated with differences in learners' self-regulatory behaviour throughout the course. These findings are similar to previous research and thus contribute to evidence of the influence of learners' characteristics in their learning processes. This finding has both theoretical and practical implications.

The study contributes to two research fields. On the one hand, it contributes to the field of learning analytics by shifting away from a descriptive perspective (data visualization) towards an approach that combines data with theory. On the other hand, it also contributes to the field of self-regulation. It critically reviews the theoretical assumptions and empirical findings of self-regulation as well as its mechanisms of external control. Second, it integrates learner characteristics such as motivation, metacognition, and prior domain knowledge into the overall model of self-regulation. Third, it empirically investigates the potential of event sequences gathered unobtrusively through log files from an ecologically valid online learning environment (Moodle). Finally, it suggests theoretical and practical implications for the design of online and blended learning environments.

SECTION THREE

Empirical investigation of the conceptual framework

Chapter Six

The effect of cues for reflection on self-regulated learning

The text of this chapter is under review for publication in *The Internet and Higher Education*. [Van Laer, S., Jiang, L., & Elen, J. (2018). The Effect of Cues for Reflection on Learners' Self-Regulated Learning through Changes in Learners' Learning Behaviour and Outcomes. *The Internet and Higher Education*, **under review**.]

Introduction

The current literature on technology-enhanced learning emphasizes the importance of self-regulation in blended learning (e.g., Boekaerts, 1999; Greene & Azevedo, 2007; Vohs & Baumeister, 2016) and the role of learners' self-reflection in self-regulated learning (e.g., Lin, Coburn, et al., 2016; Pajares & Schunk, 2001). This is based on the assumption that learners in blended learning environments need to be able to deal with varying degrees of autonomy and to judge and adapt their learning to the learning outcomes imposed on them. Although instructional interventions fostering self-regulated learning have been investigated widely in different educational settings (e.g., Arrastia-Chisholm, Torres, & Tackett, 2017; Bannert et al., 2015), evidence remains inconclusive regarding what effect support for reflection actually has on learners' self-regulated learning (Roessger, 2014). Results indicate positive effects (e.g., Bannert, 2006), no effects (e.g., van den Boom et al., 2007) as well as negative effects (e.g., Furberg, 2009). Moreover, the literature provides little insight into why the findings are inconclusive, or how to overcome this. In order to establish a more accurate picture of the effect of support for reflection on self-regulated learning, this study aims to enrich current insights. The effects of cues for reflection that are designed in line with the literature on designing such cues on self-regulated learning – and through self-reflection – are investigated in a blended learning environment. We operationalize self-regulated learning as changes in learners' learning behaviour and outcomes. Investigating learning behaviour and outcomes provides insights into learners' self-regulated learning, and also into the nature of cues' effects (Gašević, Dawson, & Siemens, 2015). In the next part of the introduction, we elaborate on blended learning and the conceptualization of self-regulated learning and present a theoretical basis for designing reflection cues intended to evoke self-regulated learning. In the final part of the introduction, we focus on the significance of relationships between self-regulated learning, learning behaviour, and outcomes for investigating changes in self-regulated learning.

Blended learning

Blended learning is an increasingly popular approach in contemporary education. Often defined as a mix of online and face-to-face learning, it is assumed that blended learning combines the advantages of both modes of delivery (Graham et al., 2014; McCutcheon, Lohan, Traynor, & Martin, 2015). In line with this, blended learning is defined as learning in an instructional context which is characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning (Boelens et al., 2015). Blended learning as a notion is widely used in higher and adult education (Allen et al., 2007); K-12 education (Picciano et al., 2012); and corporate training (Bonk, 2017; Spring & Graham, 2017). Over the years, blended learning has been the focus of many research studies (Drysdale, Graham, Spring, & Halverson, 2013). The majority of studies on blended learning have focused either on comparing blended and face-to-face learning (Halverson et al., 2014) or on the characteristics learners need to thrive in such environments (Deschacht & Goeman, 2015). With regard to the latter, research for example has identified that learners with high amounts of verbal ability and self-efficacy (Lynch & Dembo, 2004) and learners with high self-regulatory capabilities (e.g., Kizilcec et al., 2017; Kuo et al., 2014) often perform better in blended learning environments compared to learners who lack these capabilities. Despite the importance of these types of research, hardly any research propels the quest for empirical evidence to support the design of such environments in which less 'capable' learners can also find success (Van Laer & Elen, 2018).

Self-regulated learning

If we consider learning (including blended learning) to be something that learners undertake rather than something which happens to them as result of instruction (e.g., Bandura, 1989; Oliver & Trigwell, 2005), then it can also be viewed as a process in which learners regulate their behaviour in order to respond to instructional demands (Zimmerman & Schunk, 2001). Numerous studies have shown that scores on performance-related variables exhibit strong positive correlation and have a causal relationship with scores on self-regulated-learning-related variables (e.g., Daniela, 2015; Lin, Coburn, et al., 2016). Several self-regulated learning theories have been proposed in the last three decades (see: Puustinen & Pulkkinen, 2001), yet each describes a cyclical process of self-regulatory phases, namely (a) forethought, (b) enaction, and (c) evaluation. It is not yet possible to observe the metacognitive processes inherent to each of these phases directly, though they are revealed in cognitive behaviours (i.e., learners' learning behaviour) and behavioural consequences (i.e., learners' learning outcomes) (Veenman & Alexander, 2011). For instance, when a learner retakes a self-test after failing it the first time, it is assumed that this action is based on the learner's self-reflection and evaluation of the outcome of the previous attempt, preceding the overt cognitive activity of retaking the self-test. Several variables are believed to influence learners' self-regulated learning. Recent theories posit that self-regulated learning as a concept is superordinate to metacognition, and thus influences learners' cognitive, motivational and metacognitive characteristics, and in turn, their future self-regulated learning (Veenman et al., 2006). The influence of the instructional context is also seen as having a major influence on the development of self-regulated learning (Zimmerman, 2013). If we take the influence of variables that are internal and external to the learner into account, self-regulated learning inevitably becomes dynamic in nature and therefore changes over time. Because of this, and because of the inferential characteristics of self-regulated learning, continuous measurements and inferences derived from learners' learning behaviour and outcomes are required to obtain a full picture of learners' self-regulated learning.

Self-reflection and self-regulated learning

Borkowski et al. (1990) define learners' self-reflection as a strategy or skill that operates on other strategies. For example, when learners recognize that a particular cognitive strategy (e.g., making a concept map) not seems to lead to retention, they might or might not switch to another strategy (e.g., self-questioning). By reflecting on their own learning, learners become aware of their learning processes and possible alternative strategies. This example illustrates that self-regulated learning includes a self-reflective phase in which performance measured in terms of internal or external feedback is evaluated (Winters et al., 2008). Ample evidence is provided on the role of self-reflection in self-regulated learning, this by the creation of perceptions of choice and awareness of the need for alternatives, which are both critical elements for self-regulated learning (e.g., Järvelä et al., 2016; Nicol & Macfarlane-Dick, 2006).

Supporting self-reflection for self-regulated learning

Based on the relationship between self-reflection and self-regulated learning and in accordance with Butler (1998) and Winters et al. (2008) we assume that cues for reflection used to provoke learners' reflections are well suited to evoke learners' self-regulated learning. Additionally, there is no theoretical reason why self-regulated learning would not be at stake in blended learning environments (e.g., Lehmann, Hähnlein, & Ifenthaler, 2014; Lord, Chen, Cheng, Tai, & Pan, 2017). Nonetheless, empirical studies seem not to demonstrate conclusive results when it comes to the effect of cues for reflection on learners' reflection and so learners' self-regulated learning. In their extensive reviews, Roessger (2014) and Kori, Pedaste, Leijen, and Mäeots (2014) reported inconclusive results and provided no conclusions on what kind of cues under what configuration supports self-reflection most. Moreover, hardly any explanations are given for the mixed effects of cues for reflection. Only few studies claim causality or correlation, revealing a positive relationship between cues for reflection and learners' self-regulated learning, and elaborate on the possible nature of these findings (e.g., Pannese & Morosini, 2014; Renner et al., 2014). Without insights in the nature of the effects of cues for reflection on learners' reflection and self-regulated learning, teachers and instructional designers remain dependent on inconsistent conceptual claims that cueing self-reflection may improve self-regulated learning (e.g., Burke, Scheuer, & Meredith, 2007; Mezirow, 2000; Van Woerkom, 2004).

Literature focusses on two types of support when it comes to cues for self-reflection (e.g., Pannese & Morosini, 2014; Renner et al., 2014). On the one hand, there are cues for reflection for cognitive support and on the other hand, there are those for metacognitive support. Cognitive support refers to cues to evoke learners' reflection on the understanding of content (Reiser et al., 2001). Metacognitive support refers to cues for reflection evoking learners to reflect on their use of (meta)cognitive strategies (Kori et al., 2014). Current research reporting positive effects of cues for reflection on learners' self-regulated learning indicates cues for reflection focussing on jointly cognitive and metacognitive support seem more successful than cues solely allowing learners to engage either with cognitive or metacognitive support (e.g., Bannert et al., 2015; Chen, Wei, Wu, & Uden, 2009; Davis, 2003; van den Boom, Paas, van Merriënboer, & van Gog, 2004). Combining cognitive and metacognitive cues for reflection may help learners identify support tools, information, and monitor task engagement potentially enhancing learners' self-regulated learning (Butler & Winne, 1995).

Although it is of vital importance to target cues for reflection so learners will be directed to the right types of information, cue-use research shows that this is only one part of the challenge. Studies evidence that not all learners equally use and benefit from cues provided (e.g., Lust et al., 2011; Rashid & Asghar, 2016; Winne & Hadwin, 1998). In general, three characteristics of cues for reflection can be extracted from literature: (1) timing, (2) focus, and (3) integration. In relation to the timing of cues for reflection, literature indicates that cues for reflection can occur at three different moments centred around the task at hand (e.g., Farrall, 2007; Mann, Gordon, & MacLeod, 2009): before the task, during the task, and after the task. Cues for reflection provided before the task aim to trigger learners' proactive reflection (e.g., Lehmann et al., 2014). Cues presented during the task aim to trigger learners' reflection while learners are performing a task and encourage learners to reflect upon the need to alter, amend, or change what they are doing in order to adjust to changing circumstances (e.g., Lavoué, Molinari, Prié, & Khezami, 2015). Finally cues for reflection after the task aim to encourage learners to reflect on what they have done to discover what metacognitive strategies they used and perceived as successful (e.g., Embo, Driessen, Valcke, & Van Der Vleuten, 2014; Hatton & Smith, 1995)

Regarding the focus of the cues, as we aim to impact learners' self-regulated learning it is important to identify which part of the self-regulated learning process should be targeted to trigger learners' to use their most effective metacognitive strategies. Winne and Hadwin (1998) suggested that the first two phases of self-regulation, namely task identification and goal-setting and planning are most prone (e.g., Feyzi-Behnagh et al., 2014; Rubenstein, Callan, & Ridgley, 2017) to changes by interventions as they seem to be most directional for change in learning (Wehmeyer & Shogren, 2017). With regard to task identification learners need to identify the task at hand, the information supporting the execution of the task, and the strategies needed to solve the task. In relation to goal-setting and planning learners need to identify the steps needed to complete the task at hand, how to plan for successful completion of the task, and which cognitive and metacognitive strategies to use. Keeping this in mind, combining on the one hand cognitive and metacognitive information and on the other hand task identification and goal-setting and planning seem to make up the most optimal content of cues for reflection to foster self-regulated learning (e.g., Bannert, 2006; Bannert & Mengelkamp, 2013; Bannert et al., 2015; Chen et al., 2009; Davis, 2003; Davis & Linn, 2000; van den Boom et al., 2004).

Finally with regard to integration, different authors in the past (e.g., Aleven, Stahl, Schworm, Fischer, & Wallace, 2003) recognized the problem of suboptimal use of cues. Greene and Azevedo (2007) and Winne and Jamieson-Noel (2002) indicated that the lack or inadequate use of cues might be related to the considerations learners need to make when deciding on the use of a cue. If learners are not able to make functional decisions about the use of cues for reflection, they should benefit from a learning environment that provides embedded cues. Embedded cues are defined as unavoidable by the learner. However, embedding cues may not necessarily solve all problems (Clarebout & Elen, 2009). It cannot be guaranteed that learners make use of the support and use the cues as intended (Land & Greene, 2000).

Investigating learners' self-regulated learning

Due to self-regulated learning's dynamic nature and its inferential characteristics, continuous measurements and inferences based on learners' learning behaviour and outcomes are needed to capture learners' self-regulated learning. Investigating both learners' learning behaviour and outcomes does not only provide insights in learners' self-regulated learning, but also in the nature of cues' effects (e.g., Bannert et al., 2017).

Learning behaviour and self-regulated learning

The various behavioural traces observed in learners during instructional processes can be categorized as 'learning behaviour' (Entwistle & Peterson, 2004). Continuous, online, measurements of learning behaviour have grown in popularity recently as the dynamic nature of self-regulated learning has received more recognition. These continuous measurements record real learners' learning behaviour and may include observational methods, thinking-aloud protocols, eye-movement tracking and log-file registration. The fact that some of these methods (i.e., log-file registration) are unobtrusive enables researchers to track learning events with high ecological validity. Such tracking methods also make it possible to trace learning events in nonlinear environments and "re-play" learners' behaviour, providing a more complete picture of how learning outcomes take shape.

The idea that self-regulation unfolds in different phases suggests that there is a cyclical relationship among the components of self-regulated learning. Research by Cleary et al. (2012) explored what they refer to as the 'sequential phases of regulation'. Recognition of this cyclical process combined with the use of log file data has given rise to the term 'event sequence', which describes patterns of learners' behaviour. The words 'event' and 'sequence' are used in various fields of research to describe an array of ordered events structured into patterns (e.g., Abbott, 1995; Suthers & Verbert, 2013), but when it comes to self-regulated learning, 'event sequences' indicate specific theoretical assumptions and methodological approaches. One key methodological distinction, for example, relates to whether the basic information contained in the data is about a state or an event. A change in state is considered an event, so an event signals that a change in state has taken place (Müller et al., 2010). In log files, being on a page might represent a state, while clicking on the calendar tool in the online learning environment would be an event that changes the state to being on a different page. Log files can only capture events, since we cannot establish what learners do between two consecutive events (e.g., taking a break, reading something) without triangulation.

Another distinction is whether the order of events or states is logged. If so, we say that the data is sequenced; if not, it is an item set. Event sequence data analysis falls into three main types: pattern mining, pattern pruning and interactive visualization design (Liu, Dev, et al., 2016). Studies investigating differences in learner behaviour focus on pattern mining, defined as the identification of meaningful event sequences (patterns) (e.g., Azevedo et al., 2016; Bannert et al., 2017; Bannert et al., 2015; Siadaty et al., 2016b). Pattern mining consists of two dimensions: the order of the events (ordered events are called sequential patterns) and the containment of sub-sequences. When the events' original order is preserved, the pattern is known as a sequential pattern. Sub-sequences, then, are parts of a sequence whose elements also appear in the same order elsewhere. In other words, they are unique sets of events carried out in the same order by a threshold number of learners. Containment indicates the level of support in the sample for a particular sub-sequence to be identified as such – it is the number (or percentage) of sub-sequences that match other learners' sub-sequences. A frequent sub-sequence is one that recurs at least the threshold number of times among learners. Once the sub-sequences have been identified, statistics can be used to link significant differences in their occurrence to internal (learner) or external (environmental) conditions.

Learning outcomes and self-regulated learning

Learners' learning outcomes can be conceived as the outcomes of instruction (e.g., Endedijk et al., 2014). To operationalize learning outcomes the Winne and Hadwin model (1998) for self-regulated learning was used. This model proposes beliefs, dispositions, and styles; motivational factors and orientation; domain knowledge; knowledge of task; and knowledge of study tactics and strategies as variables influencing or influenced by learners' self-regulated learning. In this study, we focus on three main learning outcomes (1) domain knowledge; (2) goal orientation; and (3) academic self-concept. These learning outcomes were chosen as they have each been investigated widely in terms of their relationship to self-regulated learning. In what follows, we relate each of them to research on self-regulated learning.

The first outcome, domain knowledge, relates to learners' knowledge about a task (Greene & Azevedo, 2007). The literature on expertise has established that when learners have a higher degree of domain knowledge, they are less likely to need to search for, use, and regulate metacognitive strategies when tackling complex tasks or learning new information in the same domain (e.g., Lesgold et al., 1988; Song et al., 2016).

With regard to the second outcome, goal orientation, Pintrich (2000b) and Eccles and Wigfield (2002) operationalized it as mastery and performance goals, along with their approach and avoidance forms. Most research on mastery goal orientation has focused on the approach form and has almost universally found more use of cognitive elaboration and organization strategies, and more frequent help-seeking behaviour (e.g., Duffy & Azevedo, 2015; Kitsantas et al., 2017; Midgley, 2014). Few studies have explored the mastery-avoidance orientation. Wolters, Pintrich, and Karabenick (2005) and Elliot and McGregor (2001) did find an association between the mastery-avoidance orientation and test anxiety, which ties in with the evidence that mastery-avoidant learners are perfectionists. With regard to the performance approach, some authors argue that it can lead to some productive strategy behaviour (e.g., Harackiewicz et al., 2002; Kitsantas et al., 2017; Mega et al., 2014), whereas others claim that the effects of this form have not yet been proven decisively (e.g., Dompnier et al., 2013; Midgley et al., 2001; Senko et al., 2013). The results are also ambiguous with regard to performance avoidance. Some research has associated this orientation with negative outcomes, such as the use of fewer cognitive strategies (Pintrich, 2000b). Yet, there is also evidence that these learners use more cognitive strategies to test their own abilities and compare themselves to others (e.g., Collazo et al., 2015; Crippen et al., 2009).

Finally, (Elliot & Dweck, 2013) define academic self-concept as an individual's perception of self within academia. It encompasses two components, namely competence and effort. The academic competence component relates to how easy learners perceive academic subjects to be and the extent to which they believe themselves to be good at them. Academic effort, on the other hand, describes learners' enjoyment of going to school and studying different subjects (Liu & Wang, 2005). The literature has established a strong positive correlation between academic self-concept and the number and types of metacognitive strategies used: learners with a stronger academic self-concept engage more vigorously with the learning environment, whereas learners with lower self-concepts tend to retreat and concentrate on simple cognitive strategies (e.g., Kuo et al., 2014).

Problem statement and hypotheses

Literature emphasizes the importance of self-regulation for learning in blended learning environments and the role of learners' self-reflection for self-regulated learning. Nonetheless, evidence is inconclusive on the use of cues for reflection and their effect on self-regulated learning. Given the inconclusiveness guidelines for interventions are difficult to outline, hence new approaches are needed to better understand the underlying mechanisms that may explain the inconclusive results. To get more profound insights in the effect of cues for reflection, this study investigates if cues for reflection in blended learning environments designed in line with the timing, focus, and integration principles on the design of cues for reflection foster self-regulated learning. This when learners' self-regulated learning is investigated through changes in learners' learning behaviour (operationalized through event sequences) and learning outcomes (operationalized through prior domain knowledge and domain knowledge, goal orientation, and academic self-concept). This leads us to three hypotheses:

- Hypothesis 1: "Cues for reflection will evoke more goal-directed behaviour in learners' learning behaviour (operationalized through event sequences) when they are designed in line with current insights on the design and implementation for cues for reflection."
- Hypothesis 2: "Cues for reflection in blended learning environments will positively affect learners' learning outcomes (operationalized in domain knowledge, goal orientation, and academic self-concept) when they are designed in line with current insights on the design and implementation for cues for reflection."
- Hypothesis 3: "Relating learners' learning outcomes to changes in learners' learning behaviour provides a more complete account of cues for reflection's effect on learners' self-regulated learning."

Method

Participants

The participants in this study were 41 adults from a centre 'second-chance' adult education in Flanders, the northern region of Belgium. There were 25 women (61.00%) and 16 men (39.00%). In total, 14.60%

of the participants were younger than 20 years of age; 39.00% were between 20 and 30; 31.70% were between 31 and 40; and 14.60% were between 41 and 50 years of age. They were familiar with the domain of mathematics to some extent, but before the experiment, they had not acquired the basic principles of statistics, which was the subject of the study task in the experiment. The subject matter was expected to be entirely new to them. This was controlled for in a prior domain knowledge test dealing with basic knowledge as presented in the study task. None of the participants was able to achieve the maximum score on the test’s questions. It was concluded that the students could be divided over the experimental groups at random. All 41 adults voluntarily participated in the study; nonetheless, some (different numbers for different analyses) were excluded along the way because of incomplete records.

Content and course description

Content

In second chance education, ‘module two - mathematics: basic statistics’ is one of the three modules of the obligatory ‘mathematics cluster’ in the ‘basis education’ track. The course is both theoretical (statistics concepts) and practical (calculating the different key figures). The course content consists of eight topics: (1) quantitative and qualitative characteristics, (2) representative surveys, (3) descriptive tables, (4) presentation of statistical data using ICT, (5) using grouped data, (6) centred measures, (7) variance measures, and (8) standard deviation. The course content was provided through Moodle.

Course description

The course ‘Module two - mathematics: basic statistics’ was organized in the second semester of the 2016-2017 school year. The course consisted of 62.50% (5 sessions) online instruction and 37.50% (3 sessions) of face-to-face instruction. It was started face-to-face with an introductory lesson containing general information with regard to the course and a short introduction to each of the topics. Next, the course ran for three weeks online, until the first face-to-face session (week 5). After this session, there was another two weeks of online sessions. The course ended after eight weeks, at which point the instructor administered a classroom-based online exam.

The blended learning environment

Experimental and control environment

Using a descriptive framework consisting of seven design elements defined by Van Laer and Elen (2018), the experimental and control environments were considered identical (except for the cues for reflection) as they had the same design. The environments did not differ in degree of authenticity, personalization, learner control, scaffolding, interaction, or cues for calibration. With regard to authenticity, both environments used the same authentic examples and exercises. As regards personalization, neither of the environments included any adaptation to learners' personal or cognitive preferences. The amount of control learners had in the environments was the same, as they were free to select which content to consult when. With regard to scaffolding, learners in both conditions were scaffolded equally, through decreasing amounts of instruction over time. The interaction possibilities were also identical for learners in both environments. Learners could navigate and do exercises. Finally, no cues for calibration were provided in either the control or experimental environments, ensuring comparability. As the intervention focused on cues for reflection, this element was different in the two environments. Observed differences in outcomes can thus be assigned to the difference in cues for reflection. With regard to the online component of the blended learning environment, a Moodle course was developed in a co-design fashion between instructor and researcher. For each topic, an identical structure was used. This outline consisted of following elements: the goals of the topic, an introduction (examples from practice), the course content (theory), followed by exercises, tasks, and assessments. In the experimental condition, cues for reflection were added to each of the topics. For each of these elements learners interactions' was tracked. The structure of the face-to-face contact moment of week 5 was similar to the online ones. It also included the mentioning of the goal of the lesson at the start, used an example as introduction, provided the learners with theory, and concluded the lesson with exercises and a formative test. The differences with the online component for this lesson was that week 5 was more focussing on all the topics addressed during the first three online weeks.

Cues for reflection design

The cues for reflection as integrated in the experimental learning environment were provided in two different formats, one for the online learning environment (Moodle) and one for the face-to-face contact moments. Although the formats (online of face-to-face) were different, the principles used for the design were the same (see Appendix 1). Cues for reflection were provided at three different moments for each of the topics. The first cue was provided before the introduction of the theory. The second cue appeared before the learners started the exercise related to the topic. The final cue was given at the end of the topic after the completion of the assessment. The cues for reflection focused on the first two phases of self-regulation namely (1) task identification and (2) goal-setting and planning. With regard to task identification learners were asked to reflect on the content and task at hand, the information supporting the execution of the task, and the strategies needed to solve the task. In relation to goal-setting and planning learners were asked to reflect on the steps needed to complete the task at hand, how to plan for successful completion of the task, and which metacognitive strategies to use. Finally, each of the cues was embedded in the environment at the same level of the other content items. Learners were signalled that the content hidden under the link of the cue for reflection might help their learning. The operationalization of this design in the online learning environment was done by using feedback forms, including the 'megaphone' icon in Moodle. Each page looked similar. In the face-to-face contact moment, cues for reflection were presented through whole classroom interactions between the learners and the instructor. During the co-design phase, reflection cues were selected and integrated in both the online learning environment and the design of the face-to-face contact moments. This was done based on a list of reflection cues provided by the researcher, based on current literature (see Appendix 1).

Data structure of the log files

To investigate the suitability of using event sequence analysis the data structure of the log file data needs to be understood. Each action made by a learner within the online course was registered resulting in a time stamped event (TSE) database with as column headers the time stamp of the action, personal identifier of the user, and event name. To keep the gathered data as ecologically valid as possible a data-driven approach was chosen. In line with this approach, the raw data was used to perform the event sequence analysis, no recoding or transformations took place. Both environments (experimental and control) were identical and included eight standard event names (see Table 1). Each of these event names refers to an attribute of the environment; data reported on the attributes hence refer to specific (series of) events. In the experimental condition, a ninth attribute was available because of the integration of the cues for reflection, Feedback. As in the investigation of the relationship between cues for reflection and learners' behaviour the aim was to identify which sub-sequences occurred significantly more in which condition, sub-sequences including the Feedback attribute were exclude from the analysis as they only occur in the experimental condition. The feedback attribute itself was only used for the investigation of learners' cue-for-reflection use.

Table 1.

Actions traced in the online learning environment.

Attribute	Description
Course	Landing page of the course. On this page learner found an overview of the entire course, links to each of the topics addressed, and links to the discussion forum.
File	Downloadable content pages elaborating on the topic addressed. These attributes were glossary sheets for making calculations.
Folder	Collection of extra, not mandatory materials related to the content, consisting of alternative software, examples, etc.
Forum	Discussion forum including the viewing of the forum, posting of information, and all other interactions related to the forum.
Link	External resources, related to the course and not mandatory. Containing extra examples or exercises.
Page	Organizational information about the course. Contains information about the goals, study help, etc.
Task	Exercises learners needed to perform on the different topics. Each of these tasks was obligatory and contributes to the grades learners could obtain for participation.
Test	Assessment in the different topics or at the end of the course. Obligatory and contributes to learners grades obtained for the course.
Feedback	Cues for reflection and posed as an open ended question to the learner (which were free to either answer or don't answer)

Finally, for the face-to-face contact moments trace data with regard to the learners was also collected via the online learning environment as the learners did use it as the main and only source for information during the face-to-face contact moment. Additionally, each of the contact moments was video and audio recorded to assure the rigor of the intervention. Each of the recordings was confronted with the accompanying (and agreed upon) lesson plan. If deviations would occur, the data of that lesson would be discarded. No deviations were observed, so no data needed to be discarded.

Instruments

Prior domain knowledge and domain knowledge

During the pre-test phase a performance based prior domain knowledge test was administered to investigate learners' prior domain knowledge. This prior domain knowledge test represented the content of the entire course consisting of fifteen questions (multiple choice and open questions). The test consisted of questions related to each of the eight topics. The test was scored on fifteen points and recalculated to a score out of 100. The same test was used as post-test to measure learners' domain knowledge.

Goal orientation

Learners' goal orientation was measured by using the merged version of two questionnaires of Elliot and Church (1997) and Elliot and McGregor (2001) for measuring learners' goal orientation as constructed by Lust (2012). Whereas the initial questionnaire of Elliot and Church (1997) measured solely three dimensions of goal orientation (mastery approach, performance avoidance, and performance approach), the revised questionnaire Elliot and McGregor (2001) incorporated the fourth dimension of mastery avoidance as well. These two questionnaires were merged into one that consisted out of 21 items (Mastery goal approach (MGA) (6 items), Mastery avoidance approach (MAA) (4 items), Performance goal approach (PGA) (5 items), Performance avoidance approach (PAA) (6 items)). Answers for the items were given on a 5-point Likert type scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Academic self-concept

The Academic self-concept (ASC) scale comprised two 10-item subscales: learning confidence and learning effort. The learning confidence subscale assessed learners' feelings and perceptions about their academic competence (Liu, Wang, & Parkins, 2005). Example items included 'I am good in most of my course subjects' and 'most of my classmates are smarter than I am' (negatively worded). The learning effort subscale assessed learners' commitment to, involvement, and interest in schoolwork. Example items included 'I study hard for my tests' and 'I often feel like quitting my courses' (negatively worded). Answers for the items were given on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The quality of the instruments

Traditional reliability analysis was used to investigate the quality of the measurement instruments. The reliabilities of the different measurement instruments were measured through Cronbach's alpha. The measurement instruments are reliable when the Cronbach' s alpha is above the threshold of .70 (Cortina, 1993). Table 2 depicts the Cronbach's alpha values of the different scales. The values are all above .70, hence the measurements seem reliable.

Table 2.

Pre and post reliability analysis per construct.

Latent variable	Construct	α pre	α post
Cognition	Prior domain knowledge (PDK) (15 items)	.76	.83
Goal orientation	Mastery goal approach (MGA) (6 items)	.80	.73
	Mastery avoidance approach (MAA) (4 items)	.87	.85
	Performance goal approach (PGA) (5 items)	.88	.83
	Performance avoidance approach (PAA) (6 items)	.80	.80
Academic self-concept	Learning effort (LE) (10 items)	.85	.71
	Learning confidence (LC) (10 items)	.82	.75

Procedure

Learners' were randomly assigned to two separate but identical learning environments, either the control or the experimental condition. All (n=41) learners attending the course were invited to complete the online pre-test questionnaire and prior domain knowledge test before starting the module. The learners got 60 minutes to complete the questionnaire and prior domain knowledge test during the first face to face and introductory contact moment of the course. The subsequent weeks (eight in total), the learners in the experimental condition received cues for reflection (as described earlier) in the online and face-to-face learning environment. After the completion of the intervention, in the last face to face contact session the learners of both groups completed the online post-test questionnaire and domain knowledge test, in their classroom. The learners were given 60 minutes to complete them. The learners did not receive any other form of instruction on the course topic during the time period between the pre-test and the post-test. For the matching of the pre-test and post-test questionnaire, prior domain knowledge test and domain knowledge test, and behavioural traces learners' anonymized student IDs were used.

Analysis

Comparison of pre-test scores

With regard to the pre-test comparison of the experimental and control group as to prior domain knowledge, goal-orientation and academic self-concept assumptions were tested using one-way analysis of variance (ANOVA) and one-way multivariate analysis of variance (MANOVA) measures.

Cue-for-reflection use

For the investigation of the cue-for-reflection use, we first applied descriptive statistics to identify the overall and mean use of the cues. Secondly, a one-way multivariate analysis of variance (MANOVA) was used to investigate differences in cue use among learners' with different pre-test scores. As third, a repeated Measures ANOVA was administered to investigate differences in timing of cue use (prior, during, or after a task) among learners' with different pre-test scores. Fourth and final an ANOVA build from the Trend Line Model was used to investigate a decrease in cue use over time.

Investigation of learning behaviour

The event sequence analysis consisted of two major steps (e.g., Cicchinelli et al., 2018; Zhou, 2016). First, an exploratory sequence analysis was done by the identification of frequent event sub-sequences. Secondly, an explanatory approach was taken by the identification of discriminant frequent event sub-sequences. The latter analysis was based on the condition learners were in. This to identify what sub-sequences occurred significantly more in which condition. The same analysis was done using the learning outcome impacted by the intervention (see: Results). Here it was done to distinguish if the same differences in sub-sequences observed among conditions also could be observed within the significant impacted learning outcome (Hypothesis 3). The data was imported in R-statistics and analysed using the TraMineR package (Gabadinho et al., 2011).*Frequent event sub-sequences: exploratory sequence analysis*

An identical approach to identify frequent event sub-sequences was used as Jovanović et al. (2017) and Van Laer and Elen (2016a). Both studies emphasize the importance of two parameters when identifying frequent event sub-sequences. The first one is the time constraint (Studer et al., 2010). As we followed a data-driven approach while investigating the ecological order of events, we chose to set this parameter on one. This indicates that only events that actually occurred following each other will be included instead of events further apart in time. The second one is the relative threshold number of times (pMinSupport) a sub-sequence occurs among the different learners (Müller et al., 2010). In this study this parameter was arbitrarily set on .25 (25%) to assure frequent sub-sequences occurred at least in 25% of the participants.

Discriminant frequent event sub-sequences per condition and outcome

The identification of discriminant frequent event sub-sequence happened in line with Kim and Shute (2015) and with Grover et al. (2017). The significant discriminating ability of the sub-sequences was first based on differences between conditions learners were in and secondly on the impacted learning outcome. For these analysis chi-square tests were used (Studer et al., 2010). To be able to calculate the discriminating abilities of a frequent sub-sequence two arguments are needed (a) a sub-sequence (subseq) object containing the sub-sequences considered for discriminating the groups and (b) the variable that defines the groups (groups) (Garza, 2016). The former was defined using the method described in the previous paragraph and the latter based first on the condition and secondly on the outcomes of the statistical trials on significant changes in learning outcomes. A chi-square test is used to investigate the significance of the relationship between the observed and expected occurrence of a frequent sub-sequence for each value of the measured variables. Finally, the effect sizes are calculated based on the Cramer's V. The Cramer's V expresses the relationship between a certain discriminating frequent sub-sequence and the learners' characteristics and is reported in a value between zero and one. The closer to one the higher the relation. Cohen (1988) refers to small (≤.30), medium (≥.30 and ≤50), and large (≥.50) effect sizes.

Investigation of learning outcomes

In order to examine the effect of the instructional intervention on learners' learning outcomes, a 2 (groups: experimental and control) × 2 (testing time: pre-test and post-test) mixed design ANOVA was conducted. Before conducting this test the variables were tested for normality (Shapiro–Wilks' test), sphericity (Mauchly's Test of Sphericity), and homogeneity of variances (Levene's test). The main advantage of a mixed ANOVA design in this ecologically valid study is that unlike the traditional repeated measures approaches that discard all results on any subject with even a single missing measurement, mixed versions allow other data of such subjects to be used as long as the missing data meets the so-called missing-at-random definition (Seltman, 2012).

Results

Pre-test comparison of the experimental and control group

Based on initial comparison of pre-test measurements for each variable, no significant differences between the pre-test scores of the experimental and control group could be found (see Table 3) (respectively prior domain knowledge test (ANOVA) (F (1, 23) = 2.881, p = .10), goal orientation and academic self-concept questionnaire (MANOVA) (F (6, 29) = 1.272, p = .30). Of the 41 learners, 23 learners (control (n=13) and experimental (n=10)) completed the prior domain knowledge test. The goal orientation and academic self-concept questionnaire was completed by 36 participants (control (n=18) and experimental (n=18)).

Table 3.
Pre-test comparison experimental and control group.

Latent variables	Construct	df	F	Sig.	Ctrl. M	Ctrl. SD	Exp. M	Exp. SD
Cognition	*PDK*	1, 23	2.88	.10	12.73	6.42	17.26	7.32
Goal orientation	*MGA*	1, 36	2.28	.41	4.07	.14	4.23	.14
	MAA	1, 36	.47	.83	3.26	.24	3.33	.24
	PGA	1, 36	.01	.92	2.75	.31	2.80	.31
	PAA	1, 36	.60	.45	3.32	.24	3.06	.24
Academic self-concept	*LE*	1, 36	1.13	.30	1.85	.18	2.11	.18
	LC	1, 36	.01	.92	2.58	.20	2.61	.20

Use of cues for reflection

To be able to assign changes to either learners' learning outcomes or learning behaviour we need to be sure that learners were actually exposed to the cues for reflection. Descriptive statistics showed that on average learners consulted sixteen of twenty-four cues for reflection. Individual learners consulted on average each cue three times. Repeated Measures ANOVA did indicate there was no significant difference among learners with regard to timing of individual cue use (prior, during, or after a task) ($F(2, 8) = 2.168$, $p = .19$). Nor were significant differences found through an ANOVA build from the Trend Line Model for a decreased use of the cues over time ($F(2, 16) = 1.76$, $p = .14$) or based on a one-way MANOVA based on differences in learners' characteristics ($F(2, 16) = .51$, $p = .81$).

Hypothesis 1: Cues for reflection affect learners' learning behaviour

Frequency of event occurrence

With regard to the frequency of use of the attributes available in the online learning environment statistically significant differences ($F(9, 20) = 6.130$, $p < .001$, $\Lambda = .450$, $\eta_p^2 = .73$) were found between the control and the experimental condition as determined by a one-way multivariate analysis of variance (MANOVA) (see Table 4). Of the 41 learners overall, only 28 logged in to the online learning environment and so were included for further analysis (control (n=14) and experimental (n=14)). Only for the Folder attribute no significant differences were retrieved ($p = .73$).

Table 4.

Frequency and significance of attribute occurrence for the experimental and control condition.

Attribute	Ctrl. M	Ctrl. SD	Exp. M	Exp. SD	df	F	Sig.	η_p^2
Course	65.00	65.73	180.00	152.34	1, 28	8.485	.007	.23
File	35.95	42.86	124.80	125.11	1, 28	8.385	.007	.23
Folder	-	-	-	-	-	-	.730	-
Forum	30.65	50.76	93.70	103.32	1, 28	5.116	.032	.15
Link	01.50	01.79	04.50	03.03	1, 28	11.707	.002	.30
Page	03.80	04.81	23.20	25.37	1, 28	11.272	.002	.29
Task	10.70	12.47	28.60	21.31	1, 28	9.493	.007	.23
Test	52.10	51.48	108.30	69.96	1, 28	6.245	.019	.18
Overall	201.20	214.94	564.30	470.142	1, 28	8.584	.007	.24

Frequency of significant discriminant sub-sequence occurrence (between conditions)

The learners (n=28) included in the event sequence analysis generated 10163 events over the timespan of eight weeks. A total of 688 frequent sub-sequences were extracted. First, we will describe the nature of the discriminant sub-sequences; next, we will discuss the differences between the experimental and the control condition. Based on the assignment of the learners to either the control or the experimental condition (independent variable) 80 significant discriminant sub-sequences were identified (see Appendix 2). The analysis of the 80 significant discriminant sub-sequences showed that a sub-sequence contained between two and thirteen events. The occurrence of each of the attributes in the 80 significant discriminant sub-sequences was: Course (83%), File (53%), Test (49%), Forum (18%), Task (15%), Page (6%), and Link (4%). No Folder attributes occurred. Course events were mostly followed by Task (33%) and File (32%) events, whereas Task and File events were often preceded by Forum events (18%) or the consultation of other Task (15%), or File (18%) events. Finally, with regard to Test events, these were most often proceeded by the consultation of other Test (39%) and followed by Course (23%) events. Based on this analysis we categorized the significant discriminant sub-sequences in three main categories.

The first category relates to significant discriminant sub-sequences involving File and Task events, which in many cases (see description online learning environment) consisted of assignments and tasks. Results show that the sub-sequence containing File events occurred significantly (between $\chi(1) = 3.906$, $p = .048$, $V = .36$ and $\chi(1) = 11.271$, $p < .001$, $V = .61$) more (standardized residuals between 1.13 and 2.65) in the experimental, compared to the control condition. Examination of the Cramer's V scores indicate according to Cohen (1988) effects from medium (≥.30 and ≤50) to large (≥.50). Similar findings were found in relation to Task events with Chi squared test (between $\chi(1) = 3.906$, $p = .048$, $V = .36$ and

$\chi(1) = 8.750$, $p = .003$, $V = .54$), effect size (≥.30 and ≤50), and standardized residuals (between 1.23 and 2.31).

The second category relates to Forum events, focussing on communication. Results show that the sub-sequence containing Forum events occurred significantly (between $\chi(1) = 3.906$, $p = .048$, $V = .36$ and $\chi(1) = 6.158$, $p < .013$, $V = .45$) more (standardized residuals between 1.50 and 2.04) in the experimental, compared to the control condition. Examination of the Cramer's V score indicate medium (≥.30 and ≤50) effects (Cohen, 1988).

The third and final category relates to Test events, focussing on formal assessment. Results show that sub-sequences containing Test events occurred significantly (between $\chi(1) = 3.906$, $p = .048$, $V = .36$ and $\chi(1) = 8.856$, $p < .003$, $V = .54$) more (standardized residuals between 1.23 and 2.01) in the experimental, compared to the control condition. Examination of the Cramer's V score indicate medium (≥.30 and ≤50) effects (Cohen, 1988).

Hypothesis 2: Cues for reflection positively affect learners' learning outcomes.

Effect of time on learners' learning outcomes

The results of the mixed design ANOVA revealed that both the control group and the experimental group demonstrated a statistically significant increase (*MD* = 41.29; *SE* = 6.04, $p < .001$) in mean domain-knowledge (DK) scores across the two time points ($F(1, 8) = 46.716$, $p < .001$, $\eta_p^2 = .85$). The effect size value suggested a large practical significance (Cohen, 1988). Also the mean score for goal orientation and more specifically performance goal approach (PGA), was significantly impacted over time ($F(1, 8) = 6.564$, $p = .034$, $\eta_p^2 = .45$). A significant decrease (*MD* = -.64; *SE* = .25, $p = .034$) in mean score was found. Finally, the mean score for learning confidence (LC) within learners' academic self-concept was impacted significantly ($F(1, 8) = 7.498$, $p = .026$, $\eta_p^2 = .48$). A significant increase (*MD* = 1.06; *SE* = .39, $p = .026$) in mean score on confidence was found. No other significant effects of time were found.

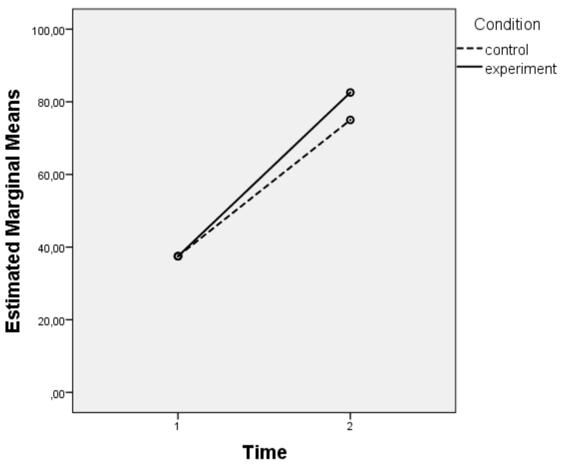

Figure 1. Differences in means of domain knowledge.

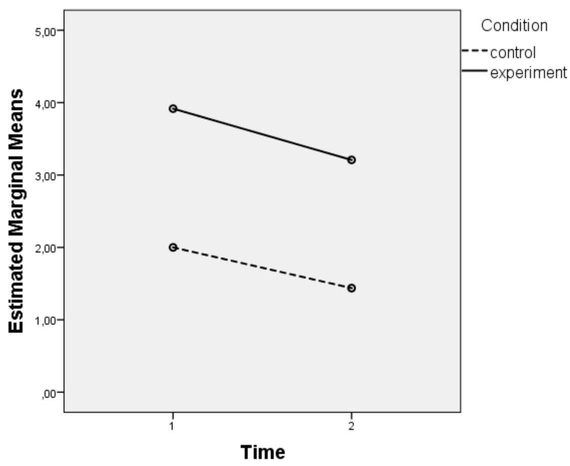

Figure 2. Differences in means of performance goal approach.

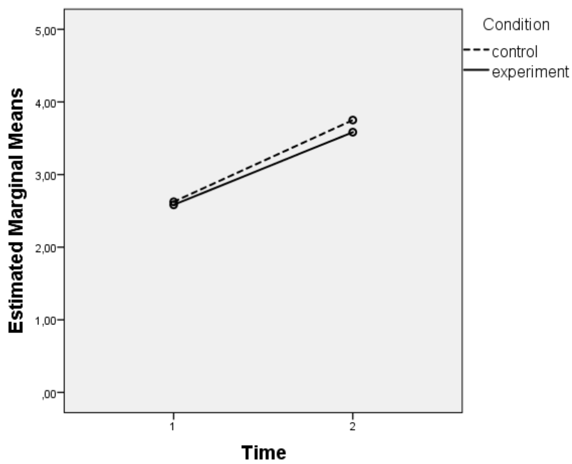

Figure 3. Differences in means of learning confidence.

Effect of condition on learners' learning outcomes

The results of the mixed design ANOVA also revealed that for the between subject analysis the experimental group had only a statistically significant different ($F (1, 8) = 26.396$, $p < .001$, $\eta_p^2 = .77$) mean score (higher) for performance goal approach (PGA) ($MD = 1.84$; $SE = .36$, $p < .001$).

Figure 4. Differences in means of performance goal approach.

Effect of time and condition on learners' learning outcomes

With regard to the interaction effect of time and condition on learners' learning outcomes there was only one significant interaction effect between the intervention type (experimental - control) and the testing time (pre-test - post-test) found for learners' performance avoidance approach (PAA), $F(1, 8) = 7.374$, $p = .026$, $\eta_p^2 = .48$. The effect size value suggested a large practical significance (Cohen, 1988). Where the control group (*MD* = -.68) decreased, the experimental group (*MD* = .50) increased.

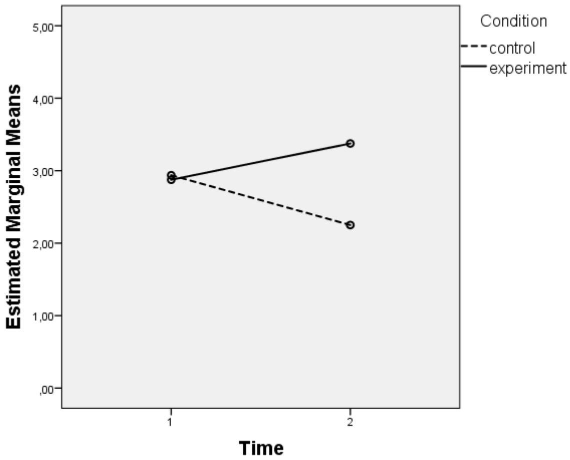

Figure 5. Differences in means of performance avoidance approach.

Hypothesis 3: There is a relationship between learning behaviour and learning outcomes.

To investigate if the differences in significant discriminant sub-sequences between conditions are related to differences in performance avoidance approach (PAA) (low (1) – high (5)), the same analysis was done as when addressing Hypothesis 1. Here, too, we describe the nature of the discriminant sub-sequences followed by a discussion on the differences between learners with different performance avoidance approach scores. A total of 30 significant discriminant sub-sequences were identified (see Appendix 3). The analysis of the 30 significant discriminant sub-sequences showed that sub-sequences contained between two and seventeen events. The occurrence of each of the attributes in the 80 significant discriminant sub-sequences was: Course (73%), File (73%), Test (67%), Forum (7%), Task (27%), Page (13%), and Link (13%). No Folder attributes occurred. Also here Course events were most often followed by Task (28%) and File (28%) events, whereas Task and File events were often preceded by Forum events (22%) or the consultation of other Task (28%), or File (61%) events. Finally, with regard to Test events, these were most often proceeded by the consultation of other Test (33%) and followed by Course (72%) events. The same three categories as when analysing the impact of the condition was used. Below, Table 5 provides a detailed account of the key figures for each category.

Table 5.

Frequency of significant discriminant sub-sequence occurrence (PAA).

Attribute	**Summary**
File	Occurred significantly (between $\chi(4) = 9.574$, $p = .048$, $V = .73$ and $\chi(4) = 13.846$, $p < .008$, $V = .88$) more when the score of PAA increased from low (1) (standardized residuals = -0.52) to high (5) (standardized residuals = -1.37). Cramer's V score indicate large (≥.50) effects.
Task	Chi squared test (between $\chi(4) = 9.574$, $p = .048$, $V = .72$ and $\chi(4) = 13.041$, $p = .011$, $V = .76$), effect size (between ≥.50) and standardized residuals (between -0.52 and 2.37).
Forum	Occurred significantly ($\chi(4) = 10.286$, $p = .036$, $V = .76$) more when the score of PAA increased from low (1) (standardized residuals = -0.47) to high (4) (standardized residuals = -2.31). Cramer's V score indicate large (≥.50) effects.
Test	Occurred significantly (between $\chi(4) = 10.393$, $p = .034$, $V = .76$ and $\chi(4) = 15.195$, $p < .004$, $V = .92$) more when the score of PAA increased from low (1) (standardized residuals = -0.58) to high (4) (standardized residuals = -1.15). Cramer's V score indicate large (≥.50) effects.

Discussion

In this section, we first summarize the results obtained. After analysing the data, it became clear that learners in the experimental and control conditions did not differ significantly from each other at the start of the eight-week intervention, that all learners in the experimental condition were exposed to the cues for reflection, and that no significant differences in use among these learners could be observed.

With regard to Hypothesis 1, the results showed that learners in the experimental condition made significantly more use of sub-sequences consisting of File and Task attributes related to assignments and tasks, Forum attributes related to communication, and Test attributes referring to assessment. In relation to Hypothesis 2, the results of post-tests for both conditions showed a significant increase in domain knowledge and learning confidence and a decrease in performance goal approach. Learners in the experimental condition who received cues for reflection scored significantly higher on performance goal approach compared to the learners in the control condition. As for the interaction effect between time and condition, learners in the experimental condition scored significantly higher on performance avoidance approach (PAA) compared to the controls. Finally, as regards Hypothesis 3, the results showed that when differences in learners' behaviour per condition were compared to differences in learners' behaviour per PAA score, the same differences in behaviour were found. This suggests that a change in learning behaviour might be linked to learning outcomes.

Findings

A change in learners' self-regulated learning was only observed through learners' behaviour related to self-testing and monitoring others via the use of Forum attributes and via performance avoidance approach (PAA) goal orientation. This appears to be in line with Crippen et al. (2009), whose results indicate that cues for reflection prompted learners to test their own performance against others and thus attempt to reduce the anxiety associated with a potential failure (perhaps triggered by the question to reflect upon their own behaviour). As a result, learners might seek (1) information on others' performance through the consultation of discussion forums and (2) to demonstrate that they are not doing worse than others by using tests (Collazo et al., 2015). In line with this, our findings seem to indicate that changes in learners' learning behaviour can be linked to changes in learners' learning outcomes. Subsequently, this study shows that cues for reflection designed according to the timing, focus, and integration guidelines extracted from current literature affected learners' self-regulated learning in an unexpected manner.

Exploration of unexpected findings

Despite the wide range of studies that have indicated the importance of reflection for self-regulated learning and increased learning outcomes (e.g., Johnson, Azevedo, & D'Mello, 2011; Kramarski & Gutman, 2006), only a limited number of empirical studies seem to be able to demonstrate positive results. This is especially true when it comes to cues intended to evoke self-regulated learning through self-reflection. The findings of the study presented here add to the inconclusive nature of the investigation of the effect of cues for reflection on learners' self-regulated learning. Although the reason for these unexpected findings is unclear, the literature suggests two sets of possible explanations: firstly, the influence of learners' characteristics (e.g., Bannert & Reimann, 2012) and the design of the cues for reflection (e.g., Bannert, 2009), and secondly, the additional cognitive and metacognitive capacities needed to act upon the cues presented (Veenman, 1993).

Learners' characteristics and the design of cues for reflection

In the introduction to this study we addressed cues' timing (e.g., Farrall, 2007; Mann et al., 2009), focus (e.g., Bannert et al., 2015; Winne & Hadwin, 1998), and integration (e.g., Aleven et al., 2003; Greene & Azevedo, 2007) as potential mechanisms to overcome issues related to no or sub-optimal cue use. Yet, there is no guarantee that learners (1) make use of the support and/or (2) use the cues as intended (Land & Greene, 2000). With regard to the former, the results of the study presented show that a mismatch between learners' characteristics and the design of the cues for reflection seems highly unlikely, as the results of the description of learners' cue use indicated that learners (with different learner characteristics) in the experimental condition did not differ significantly in their frequency or temporal use of the cues for reflection. With regard to the use of cues as intended, the results show that the intervention evoked self-regulated learning observed through changes in learners' learning behaviour and learning outcomes. The combination of these findings strengthens our hypothesis that in the study presented cues for reflection were sufficiently well designed to evoke self-regulated learning, but that they also triggered unintended behaviour and outcomes.

Additional cognitive and metacognitive capacities needed

In line with our findings, van den Boom et al. (2004) found no effect of metacognitive strategy use when only cues for reflection were provided to learners with low self-regulated learning capabilities. However, in conditions where cues for reflection were combined with different forms of feedback, a significant increase in metacognitive strategy use was observed. Similar findings were presented by Krause and Stark (2010), who demonstrated that feedback interventions alone clearly enhanced learning outcomes, whereas conditions including cues for reflection had no significant effect on learning. The meta-analysis of Ardasheva, Wang, Adesope, and Valentine (2017) reveals that the overall effects of cues with regard to the use of specific cognitive and metacognitive strategies were large (.87) and that this is specifically the case when interventions adopt a reflection-oriented model targeting metacognitive strategies (Dabarera, Renandya, & Zhang, 2014; Takallou, 2011; Vandergrift & Tafaghodtari, 2010). In the light of self-regulated learning theory (see: Puustinen & Pulkkinen, 2001) the observations described above might be explained as follows. Even when learners can reflect on cognitive (Reiser et al., 2001) and metacognitive (Kori et al., 2014) strategies, they might not possess or be able to recall the metacognitive strategies needed to act in a way that will produce successful learning outcomes (e.g., Pintrich, 2002; Veenman, 1993). This will result in sub-optimal self-regulated learning. Based on this notion, we hypothesize that when cues for reflection are supported by cues directing learners towards appropriate metacognitive strategies, learners are more likely to evolve towards the behaviour needed to affect learning outcomes positively than when they only receive cues for reflection.

Further directions and conclusions

In our view, the merit of the study presented lies in its fine-grained insights into the relationship between learners' self-regulated learning and cues for reflection. To obtain these insights, we first investigated learners' reflection-cue use based on learners' individual differences. Secondly, we operationalized self-regulated learning through learners' learning behaviour and outcomes. Although the use of online event measurements are nothing new, the link to learners' learning outcomes is not often made, neglecting the essence of self-regulation in an educational context. Investigating both learning behaviour and outcomes provides insights not only into learners' self-regulated learning, but also into the nature of cues' effects. In the study presented, we found that unexpected learning outcomes were related to behavioural indications, thus establishing a link between learners' self-regulated learning and cues for reflection. Finally, in the discussion of the results, we unravelled the effect of the design and content of the cues for reflection provided and hypothesized that when differences in learners' characteristics are taken into account when designing cues for reflection, learners' self-reflection will be evoked and self-regulated learning will take place. For this self-reflection and self-regulated learning to be effective, however, learners subsequently need to be guided towards metacognitive strategies that will help them perform the task successfully.

Further directions

To enable us to build further on the theoretical and methodological insights of this study, some challenges need to be addressed. A first challenge to overcome is the sample-size fluctuation in our ecologically valid setting. A total of 41 learners were involved in the study – 20 in the control group and 21 in the experimental condition, which according to Field (2013) is an appropriate rule of thumb for testing the effect of a single condition. Nonetheless, there was a substantial amount of random missing data related to both the pre- and post-tests. Although the mixed analysis of variance did not include case-wise deletion, meaning the effect of missing values was minimized, the power of some of the statistics might be debatable. The lack of power might result in false negatives (Mapstone, 1995). Such false negatives lead to the underappreciation of the interventions' impact and leave important significant results unobserved. To overcome this issue, in further research we recommend performing power analysis up front and involving a larger sample of learners, although the latter might be challenging because of limited access to particular target groups in ecologically valid settings (e.g., vulnerable learners in blended learning environments). A second challenge relates to the use of a data-driven approach to analyse learners' learning behaviour and its arbitrary parameter setting. As theoretical insights can be derived from the results of data-driven trials, contributing to such an approach may prove more promising than, for example, recoding events as (covert) metacognitive strategies or activities. In further research, this data-driven approach might be explored by experimenting with different parameter settings or using a combination of data-driven and theory-driven approaches. With regard to the latter, this could be achieved for example by recoding events or sequences based on a theoretical framework unrelated to self-regulation theory (for example a tool-use scheme), which would make the sub-sequences identified more meaningful.

Conclusions

The current lack of certainty regarding the effects of cues for reflection on learners' self-regulated learning means teachers and instructional designers remain dependent on inconsistent conceptual claims that cues for reflection may improve self-regulated learning. Studies such as the one presented here could help both researchers and practitioners distinguish between the effect of cues for reflection, how different learners use them, and how learners react to them, resulting in particular behaviours and outcomes. Establishing more fine-grained links between learners' cue use, learning behaviour, and learning outcomes could help us propel the investigation of intervention research.

Chapter Seven

The effect of cues for calibration on self-regulated learning

The text of this chapter is under review for publication in *Computers and Education*. [Van Laer, S., & Elen, J. (2018). The Effect of Cues for Calibration on Learners' Self-Regulated Learning through Changes in Learners' Learning Behaviour and Outcomes. *Computers and Education*, **under review**.]

Introduction

Learners in blended learning environments need to be able to deal with varying degrees of autonomy and to judge and adapt their learning to the learning outcomes imposed. Based on this assumption, current literature on technology-enhanced learning emphasizes the importance of self-regulation in blended learning (e.g., Boekaerts, 1999; Greene & Azevedo, 2007; Vohs & Baumeister, 2016) and more specifically the role of learners' calibration in the monitoring phase of self-regulated learning (e.g., Lin, Coburn, et al., 2016; Pajares & Schunk, 2001). Although instructional interventions fostering self-regulated learning have been investigated widely in different educational settings (e.g., Arrastia-Chisholm et al., 2017; Bannert et al., 2015), the actual effect of support for calibration on learners' self-regulated learning remains unclear (Panadero, Klug, et al., 2016). In general, literature investigating learners' calibration hypothesizes that learners are well calibrated if they perceive links between their learning behaviour, cues provided, information presented, and the task at hand, and when their perceptions reflect reality (Butler & Winne, 1995; Nelson, Narens, & Bower, 1990). In that case learners are equipped to effectively monitor their learning (DiFrancesca, Nietfeld, & Cao, 2016; Zimmerman et al., 2015). However, even when learners can calibrate external and internal feedback, they might not possess or be able to recall the cognitive and/or metacognitive strategies needed to act in a way that will produce increased learning outcomes (e.g., Pintrich, 2002; Veenman, 1993). This would result in sub-optimal self-regulated learning.

Although literature on calibration is clear on its importance for self-regulated learning, it provides insufficient insight into how to support learners' calibration and so self-regulated learning (Stone, 2000; Yang, Potts, & Shanks, 2017). In order to establish a more accurate picture of the effect of cues for calibration on learners' self-regulated learning, this study investigates whether cues for calibration do actually affect self-regulated learning in a blended learning environment, and whether this effect is different for learners with different metacognitive abilities. We operationalize self-regulated learning as changes in learners' learning behaviour and outcomes. Investigating learning behaviour and outcomes provides insights on learners' self-regulated learning, as well as on the nature of cues' effects (Gašević et al., 2015). In the next part of the introduction, we elaborate on blended learning and the conceptualization of self-regulated learning and present a theoretical basis for designing cues for calibration intended to evoke learners' self-regulated learning through monitoring. In the final part of the introduction, we discuss the relationship between self-regulated learning, learning behaviour, and learning outcomes.

Blended learning

Blended learning is a well-established approach that is applied in various educational contexts (e.g., Bonk, 2017; Spring & Graham, 2017). A frequently recurring aspect among definitions of blended learning is its combination of online and classroom-based learning. Current conceptualizations of blended learning assume that blended learning environments combine the advantages of both modes of delivery (e.g., Graham et al., 2014; McCutcheon et al., 2015). In line with this assumption, the current study defines blended learning as learning in an instructional context which is characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning (Boelens et al., 2015). Many researchers have investigated different aspects of blended learning (Drysdale et al., 2013), with the lion's share of studies focusing either on comparing different modes of delivery (Halverson et al., 2014) or on learners' compliance with blended learning environments (Deschacht & Goeman, 2015). With regard to the latter, research has identified for example that learners who have a high degree of control over their learning and intrinsic goal orientation (e.g., Kassab et al., 2015) and learners with high cognitive and metacognitive capabilities (e.g., Kizilcec et al., 2017) often perform better in blended learning environments compared to learners who do not have these characteristics.

Self-regulated learning

Blended learning environments do not themselves result in learning, as all learning requires activity on the part of learners (Oliver & Trigwell, 2005). More precisely, blended learning is a self-regulated process in which learners regulate their behaviour according to the instructional demands (Zimmerman & Schunk, 2001). Literature shows that performance strongly positively correlates with self-regulated learning variables (e.g., Daniela, 2015; Lin, Coburn, et al., 2016). Self-regulated learning has been widely investigated and various theories have been proposed (see: Puustinen & Pulkkinen, 2001). Each of these theories describes self-regulated learning as cyclical, influenceable, and covert in nature. With regard to its cyclical nature, self-regulated learning roughly consists of three phases, namely (a) a forethought phase, (b) an enacting phase, and (c) an evaluation phase. Each theory also draws attention to the key role of internal (learner characteristics) and external factors (design of the learning environment) in the development of self-regulated learning (Zimmerman, 2013). This cyclical and influenceable nature of self-regulated learning means that continuous measurements are needed to capture learners' self-regulated learning. Finally, regarding the covert nature of self-regulated learning, the metacognitive processes that occur in the different phases of self-regulated learning cannot be observed directly. If a learner reviews her exercises after completing an online test, for example, it might be assumed that an evaluation or monitoring process must have preceded this overt cognitive reviewing activity. This example shows how self-regulated learning is manifested through overt cognitive behaviours (i.e., learners' learning behaviour) and behavioural consequences (i.e., learners' learning outcomes) (Veenman & Alexander, 2011). Given the dynamic nature of self-regulated learning, investigations would benefit from using continuous measurements and inferences that draw on learners learning' behaviour and learning outcomes.

Monitoring, calibration, and self-regulated learning

Learners working on a task need to monitor their actions to be sure their enactment leads to achieving the targeted learning outcomes. Monitoring is the cognitive operation influencing whether an action is taken or not (Muis, Winne, & Ranellucci, 2016; Winne & Jamieson-Noel, 2002). When learners interact with different tasks, information about changes in learning outcomes is monitored relative to learners' perceived changes. When discrepancies exceed an idiosyncratic threshold, self-regulating learners adjust their behaviour to eliminate the discrepancies (Winne & Hadwin, 1998). So for this adjustment to be effective, good calibration between perceptions of and actual changes in learning outcomes is needed. The better learners' calibration is, the more accurate monitoring will be (Stolp & Zabrucky, 2017). This accuracy is often referred to as judgement of learning (JOL) (Schraw, 2009). The information available to learners to calibrate and hence to monitor changes in learning outcomes has two main sources. Either changes in learning outcomes in reality (external feedback), or cognitive representations (internal feedback) by the learners of changes in learning outcomes (e.g., Ariel & Karpicke, 2018; Broadbent & Poon, 2015). For learners to be able to accurately calibrate, they have to process the external feedback along with the internal feedback (Winne & Hadwin, 1998). More precisely, learners have to compare (a) the internal feedback with the desired level of change in learning outcomes, (b) the external feedback with the desired level of change in learning outcomes, and (c) the internal feedback with the external feedback. Based on the results of this process, learners monitor their learning and select cognitive and metacognitive strategies (e.g., error correction strategies, revision activities, etc.) which may help to proceed them in the direction of the desired level of learning outcomes (Narciss, 2017).

Supporting learners' calibration for self-regulated learning

One reason for interest in learners' calibration is that learners do use the result of the comparison of internal and external feedback to make decisions about how to monitor and self-regulate learning. Thus, low levels of calibration can undermine effective regulation (e.g., Dunlosky & Rawson, 2012; Thiede et al., 2003). Despite its importance, a substantial body of literature suggests learners are generally not especially good at accurately judging themselves (Bol & Hacker, 2001; Klassen, 2002). And even when they are, extensive reviews by Dunlosky and Thiede (2013) and Alexander (2013) show that this does not mean that learners have any particular insight into this aspect of cognition.

To be able to provide support to learners' calibration attempts and evoke monitoring, literature on cues for calibration proposes two approaches, outcome feedback and cognitive feedback. The simplest and most common type of feedback is outcome feedback (e.g., Delgadillo et al., 2017; Earley, Northcraft, Lee, & Lituchy, 1990; Paulson Gjerde, Padgett, & Skinner, 2017). This type of feedback is binary information describing whether or not results are correct. It contains no additional information (e.g., about task, tools provided, or support offered) other than the state of the current learning outcomes (Butler & Winne, 1995). Hence, outcome feedback provides minimal external support for learners about how to self-regulate their learning (Kluger & DeNisi, 1996). Alternatively, feedback can be elaborated to supply several different types of information. Cognitive feedback can provide learners with information that links the task, tools or support provided, and changes in learning outcomes (Butler & Winne, 1995). In line with this, research showed feedback providing validity-related information (i.e., cognitive feedback) was judged more effective than outcome feedback (e.g., Balzer & Doherty, 1989; Nadolski & Hummel, 2017; Ridder, McGaghie, Stokking, & Cate, 2015).

Cognitive feedback comes in two forms, namely functional validity feedback and cognitive validity feedback (e.g., Besser, 2016; Butler & Winne, 1995; Ernst & Steinhauser, 2017; Sedrakyan & Snoeck, 2016). Functional validity feedback, describes the relation between learners' estimate of change in learning outcomes and the actual change in learning outcomes (e.g., Bui & Loebbecke, 1996; Frysak, 2017; Popelka, 2015). For example, in an adaptive learning environment, learners might be asked to estimate their scores on a to-come test (in the form a JOL-cue). Then, after learners' estimates were compared to the actual score, functional validity feedback suggest to the learners, "You overestimated yourself, your score is 60% not 80%" (e.g., Mory, 2004). Cognitive validity feedback aims to evoke monitoring through the activation of learners' perceptions about the relationship between the different course components, information offered, cues provided, and potential change in learning outcomes (e.g., Chyung, 1996; Ellis, 2012). For example, in an adaptive learning environment, a learner who studies texts might be shown a cue: "You aren't using the advance organizer to guide your studying." (Butler & Winne, 1995). Cognitive validity feedback conveys the information that directs learners' further actions based on their estimate and actual performance.

Research investigating the use of functional and cognitive validity feedback does not lend uniform support to the effectiveness of these types of cues for calibration in practice. On the one hand it is reported that cognitive validity feedback helps learners distinguish those pieces of information most important to increase their learning outcomes (Popelka, 2015). Or when outcome or functional feedback is provided, learners tend to devote time and energy to compare themselves with others, rather than to develop ways to revise and make improvements to their learning (e.g., Nicol & Macfarlane-Dick, 2006; Van Popta, Kral, Camp, Martens, & Simons, 2017). Even a score accompanied by suggestions for improvement seemed to distract learners from addressing how they might improve their work (Wiliam & Thompson, 2007). On the other hand, cognitive validity information alone seems insufficient to support learners' monitoring, as without information on learners' change in learning outcomes, behaviour will not be goal-directed (Butler & Winne, 1995; Ellis, Carette, Anseel, & Lievens, 2014). In line with this inconclusive view, Gielen, Peeters, Dochy, Onghena, and Struyven (2010) showed that functional validity feedback was as effective as cognitive validity feedback.

Metacognitive skilfulness as influencing variable of calibration-cue use

Unarguably it is of vital importance to target cues for calibration so learners will eventually be directed to the right types of information. Nonetheless, cue-use research shows that this is only one part of the challenge. It evidences that not all learners equally use and benefit from cues provided (e.g., Lust et al., 2011; Rashid & Asghar, 2016; Winne & Hadwin, 1998). Learners often do not utilize well-developed cues (Cleary et al., 2012). These learners typically make ineffective, suboptimal learning choices (Segedy, 2014). One of the possible explanations of sub-optimal cue use provided by the self-regulated learning literature is that learners might lack the skills needed or the ability to activate the targeted cognitive or metacognitive strategies. Even when learners can calibrate external and internal feedback, they might not possess or be able to recall the cognitive and/or metacognitive strategies needed to act in a way that will produce increased learning outcomes (e.g., Pintrich, 2002; Veenman, 1993). This would result in sub-optimal self-regulated learning. A way to investigate this issue and partly explain differences in the effect of the cues provided might be the investigation of learners' metacognitive abilities in relation to the instructional interventions provided (e.g., Ardasheva et al., 2017). Metacognitive skilfulness or the ability to regulate and control cognitive and metacognitive strategies is a combination of general cognitive and metacognitive strategies. By mapping learners' metacognitive skilfulness differences in the use of cues provided can be investigated (Veenman et al., 1997). Doing so will provide us with a more fine-grained picture of the effect of cues for calibration.

Investigating learners' self-regulated learning

Due to self-regulated learning's dynamic nature and its covert nature, continuous measurements and inferences through learners' learning behaviour and learning outcomes are needed to capture learners' self-regulated learning. Investigating both learners' learning behaviour and outcomes provides insights not only into learners' self-regulated learning, but also into the nature of cues' effects (e.g., Bannert et al., 2017).

Learning behaviour and self-regulated learning

Behavioural traces gathered from learners during instructional processes can be categorized as learners' learning behaviour (Entwistle & Peterson, 2004). As support grows for the conception of self-regulated learning as a continuous process, so does interest in online measures such as thinking-aloud protocols, eye-movement tracking and log-file registration, which account for the dynamic nature of learners' learning behaviour. Some of these methods (i.e., log file registration) involve no direct interaction with the learner, and this unobtrusiveness enables researchers to trace learning events in ecologically valid settings. Thus, we can "re-play" learners' learning behaviour and obtain a better understanding of what leads to certain learning outcomes.

Cleary et al. (2012) describe the cyclical relationship among the components of self-regulated learning as 'sequential phases of regulation'. In relation to log file data, this cyclical nature is reflected in the term 'event sequence', which describes patterns of learners' learning behaviour. Both 'event' and 'sequence' are common terms for describing all sorts of patterns in different fields of research (e.g., Abbott, 1995; Suthers & Verbert, 2013). When it comes to self-regulation, a first distinction made between trace data types is whether the basic information they contain relates to a state or an event. An example of a state might be being on a content page, while clicking on a self-test link might be an event that changes the state to being on a self-test page. This means that each change of state is an event, and each event indicates a change in state (Müller et al., 2010). Log files only capture events, as we assume in this study that we cannot determine what learners are doing between two events. Another distinction is whether the order of events or states is logged. If the original order is logged by, for example, the inclusion of timestamps, the data is considered to be sequenced; otherwise, it is perceived as an item set.

Event sequence data analysis generally takes one of three forms: pattern mining, pattern pruning, and interactive visualization design (Liu, Dev, et al., 2016). The current study focusses on investigating differences in learners' learner behaviour, so our focus lies on pattern mining defined as the identification of meaningful event sequences (patterns) (e.g., Azevedo et al., 2016; Bannert et al., 2015; Siadaty et al., 2016b). Pattern mining has two main concerns – the order of the events and the containment of sub-sequences. A sequential pattern implies the order of events has been preserved. A sub-sequence is a part of a larger sequence, which also appears elsewhere. Containment relates to the amount of support there is for a particular sub-sequence in the sample; in other words, the number (or percentage) of sub-sequences matching other learners' sub-sequences. A sub-sequence is considered frequent if it occurs in at least the threshold number of learners' sequences. Following sub-sequence identification, links between significant differences in subsequence occurrence and conditions either internal or external to the learner can be investigated in statistical trials.

Learning outcomes and self-regulated learning

Instruction may result in a variety of learning outcomes (e.g., Endedijk et al., 2014). In this study, we focus on four main learning outcomes: (1) domain knowledge; (2) goal orientation; (3) academic self-concept; and (4) judgement of learning. We selected these learning outcomes as their relationship to self-regulated learning has already been investigated extensively.

Domain knowledge, firstly, relates to learners' knowledge of the content involved in a particular task (Greene & Azevedo, 2007). It has been widely demonstrated in the literature on expertise that when learners have more extensive domain knowledge, they are less reliant on the need to identify, use, and regulate metacognitive strategies during complex tasks or the acquisition of new information in the domain (e.g., Lesgold et al., 1988; Song et al., 2016).

Goal orientation was operationalized by Pintrich (2000b) and Eccles and Wigfield (2002) in mastery and performance goals, along with their approach and avoidance forms. Most research on mastery goal orientation has focused on the approach form, often finding increased use of cognitive elaboration and organization strategies and more frequent help-seeking behaviour (e.g., Duffy & Azevedo, 2015; Kitsantas et al., 2017; Midgley, 2014). The mastery-avoidance orientation remains underexplored, though Wolters et al. (2005) and Elliot and McGregor (2001) did observe a correlation between this orientation and test anxiety, tying in with the characterization of mastery-avoidant learners as perfectionists. The performance approach has been linked by some authors to certain productive strategy behaviours (e.g., Harackiewicz et al., 2002; Kitsantas et al., 2017; Mega et al., 2014), whereas others have claimed that its effects remain unclear (e.g., Dompnier et al., 2013; Midgley et al., 2001; Senko et al., 2013). Results on performance avoidance are also ambiguous, with some research associating it with negative outcomes, such as the use of fewer cognitive strategies (Pintrich, 2000b), and others producing evidence for learners' increased use of cognitive strategies to test their own abilities and compare themselves to other learners (e.g., Collazo et al., 2015; Crippen et al., 2009).

Academic self-concept, the third outcome, can be defined as an individual's perception of self within academia (Elliot & Dweck, 2013) and incorporates the two distinct concepts of competence and effort. It measures the degree to which learners feel that academic subjects are easy and that they are good at them (competence), and the degree to which learners like or dislike going to school and studying different subjects (effort) (Liu & Wang, 2005). Previous studies have revealed that academic self-concept has a strong and positive influence on the variety of metacognitive strategies that learners use. A stronger academic self-concept leads to a deeper engagement with the learning environment, while a less well-developed self-concept is associated with retreat and concentration on simpler cognitive strategies (e.g., Kuo et al., 2014).

Finally, learners' judgement was operationalized in line with Schraw (2009), focussing on learners' precision of estimation of future performance compared to actual performance (Maki, Shields, Wheeler, & Zacchilli, 2005). When learners are able to accurately estimate their performance, they are more likely to take appropriate action and so regulate their learning (Butler & Winne, 1995). Learners who have a poor judgement of learning tend to make ineffective, suboptimal learning choices (Segedy, 2014).

Problem statement and hypotheses

While the literature emphasizes the importance of self-regulation for learning in blended learning environments on the one hand and the role of learners' monitoring through calibration for self-regulated learning on the other, evidence is inconclusive on the use of cues for calibration and their effect on self-regulated learning. Given this inconclusiveness, guidelines for interventions are difficult to outline. Hence, new approaches are needed to better understand the underlying mechanisms that may help to understand the inconclusive results. To get more profound insights in the effect of cues for calibration, this study investigates whether cues for calibration in blended learning environments foster self-regulated learning through changes in learners' learning behaviour and outcomes, and if this effect is different for learners with different metacognitive abilities. This leads us to four hypotheses:

- Hypothesis 1: "Cues for calibration affect learners' learning behaviour."
- Hypothesis 2: "Cues for calibration affect learners' learning behaviour differently for learners with different levels of metacognitive skilfulness."
- Hypothesis 3: "Cues for calibration positively affect learners' learning outcomes."
- Hypothesis 4: "Cues for calibration positively affect learners' learning outcomes most when learners have high levels of metacognitive skilfulness."

Method

Participants

The participants in this study were 151 learners taking a course on instructional psychology and technology as part of a Bachelor's degree in Educational Sciences from a large Belgian university. There were 134 women (88.74%) and 17 men (11.26%), which is a representative sample of the entire student population within the Faculty of Psychology and Educational Sciences. The learners were between 19 and 58 years of age (*M*=21.87, *SD*= 6.84). They were familiar with the domain of instructional psychology and technology to some extent, but before the experiment they had not acquired insight in the texts of Anderson (2005) and Mayer (2004), which were the subject of the study task in the experiment. The subject matter was expected to be entirely new to them. This was controlled for in a prior domain knowledge test. None of the participants was able to achieve the maximum score on the test's questions, the average score was 4.5/10. It was concluded that the students could be divided over the experimental groups at random. All voluntarily participated in the study, some (different numbers for different analyses) were excluded along the way because of incomplete records.

Content and module description

Content

In the course 'instructional psychology and technology', the module dealing with 'educational practice' was targeted. In this module, two texts are discussed. Through the first text written by Anderson (2005) the instructors introduce the 'revised taxonomy of Bloom' and aim to provide learners with insights about: (1) the importance of learning objectives, (2) the difficulties with regard to the formulation of such objectives, (3) the differences between the initial and the revised taxonomy of Bloom, (4) the link of assessment and instruction with the taxonomy, and (5) the revised taxonomy's potential application. The second text written by Mayer (2004) is used by the instructors to evoke learners' reflection on (1) the difference between 'pure discovery learning' and 'guided discovery learning', (2) research on both, and (3) the implications for education.

Module description

The module 'educational practice' was organized in the second semester of the 2017-2018 academic year. The module was provided in a blended learning format and consisted firstly of an online learning module in Moodle. Between two face-to-face contact sessions, learners had 28 days to progress through the environment and study the texts. In addition, learners were invited to participate in a two hour-long contact sessions dealing with the content of the online learning module after having studied in Moodle.

The blended learning format

<u>**Experimental and control environments**</u>

The experimental and control environments were considered identical (except for the cues for calibration) as they had the same design. According to the descriptive framework of Van Laer and Elen (2018) containing seven design elements, the three environments did not differ in degree of authenticity as in each environment the same authentic tasks were used. The level of personalization was also the same in each environment as no differentiation or cognitively based adaptive exercises were provided. The amount of learner control was equal in all the environments, as each of the learners had to be exposed to all of the content. Learners were scaffolded in each of the environments in the same way, namely by decreasing the amount of instruction they received with each exercise over time. In addition, the types of interaction learners were exposed to were identical in each environment. Finally, all environments had cues for reflection in them in the form of content-related exercises; besides these, no additional cues for reflection were provided. Naturally, as the intervention focused on cues for calibration, this element was different in each of the three environments. Observed differences in outcomes can thus be assigned to the difference in cues for calibration. With regard to the online component of the blended learning environment, a Moodle course was developed in a co-design fashion between instructors and researcher. For each text, the outline was identical and consisted of the following elements: (1) goals of the text, (2) introduction (examples from practice), (3) text, (4) exercises, and (5) self-tests. With regard to the exercises and self-tests, each section of the texts was supported by practice exercises (not obligatory), preparing the learners for a self-test about the section addressed. Following each practice exercise an obligatory self-test was provided. After this test was submitted, learners could progress to the next section. Learners were allowed to choose a text to start with. During the studying of the texts learner control was limited, but after having finished the entire online learning module, learners could navigate freely through it. Also a (6) discussion forum was provided for course related discussions. In the experimental conditions cues for calibration were added to each section of the texts, to be more precisely before (in the form of a JOL- cue) and after (in the form of validity feedback) each self-test. With regard to the latter only functional validity feedback was given to learners in the functional validity feedback condition (F-condition), whereas learners in the functional and cognitive validity condition (FC-condition) received both functional and cognitive validity feedback. Figure 1 shows the design of each condition.

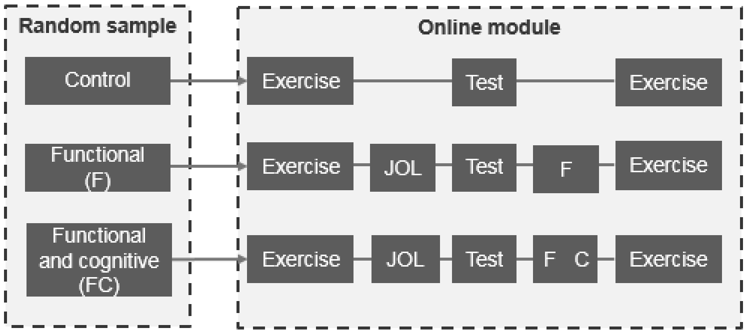

Figure 1. Visual representation of the intervention for each condition.

For each of the elements in the online learning module learners' interactions were tracked. The structure of the face-to-face contact moment (after the 28 days of independent study) was identical for all learners. Learners were divided in groups of 5 to 6 and were instructed to make (1) a concept map of both texts, (2) elaborate a multimedia knowledge clip explaining the elements of the concept map and their link with practice, and finally they were asked to come up with (3) exam questions targeting the different levels of the 'revised taxonomy of Bloom' and focussing on the content of the two texts. The results of these exercises were discussed in the entire group and after the sessions, all materials were made available to all learners for further study.

Cues for calibration

Judgement of learning cues

Both experimental conditions contained judgement of learning cues to generate input for the automatization of the validity feedback. In line with Schraw (2009) these cues provided the learners with a question about their expected performance on the upcoming self-test, potentially based on the practise exercises. The cues were embedded and so implemented in line with guidelines on cue-use as formulated by Clarebout and Elen (2009). Each of the cues was embedded in the environment at the same level of the other content items and presented prior to each self-test. Learners in the experimental conditions were obliged to estimate their score. The operationalization of this design in the online learning module was done by using tests, including the 'test' icon in Moodle. Each page looked similar. In the face-to-face contact moment, no cues were provided.

Functional and cognitive validity feedback cues

As mentioned before, both experimental conditions differed in the type of validity feedback cues learners received. Only functional validity feedback was given to learners in the F-condition, whereas learners in the FC-condition received both functional and cognitive validity feedback. Both the functional and cognitive validity feedback cues were developed in line with Balzer and Doherty (1989) and Butler and Winne (1995). The functional validly feedback cues focused on the relationship between learners' judgement of learning (absolute accuracy index) obtained via the JOL-cues and their actual performance (obtained via self-test scores). The accuracy of learners' judgement of learning was calculated using the absolute accuracy index formula proposed by Schraw (2009). This index was used as an indicator for assigning the appropriate functional validity feedback cue. This feedback contains any of the following labels: 'underestimate', 'estimate accurate', or 'overestimate' to the accuracy of prediction. Additionally learners were informed about their score on each self-test. A comparison of a learner's score was compared with the maximal score possible on the different self-tests. This was done by assigning either the label 'below 50% correct' or '50% or above 50% correct'. Combined this resulted in a personalized message for the learners stating: "You seem to [judgement of learning label] your ability and your score is [score label].".

The cognitive validity feedback cues pertained to learners' perceptions about the relationship between the instructional components and performance. Learners received information on the link between (1) the instructional components, (2) the cognitive and metacognitive strategies needed to use these components, and (3) on the potential impact of both on their performance. Both the functional and cognitive validity feedback cues were embedded in the environment at the same level of the other content items and provided after the completion of each self-test. Additionally, through a popup learners were informed that the content under the link of the cue might significantly help their learning. The operationalization of this design in the online learning module was done by using feedback forms, including the 'megaphone' icon in Moodle. Each page looked similar. In the face-to-face contact moment, no cues were provided.

Data structure of the log files

To investigate the suitability of using event sequence analysis, insight is needed in the data structure of the log file data. Each action made by learners within the online course was registered resulting in a time stamped event (TSE) database with as column headers the time stamp of the action, personal identifier of the user, and event name. A data-driven approach was chosen. Prior to the event analysis, no recoding or transformations took place. The three conditions (F-condition, FC-condition, and control condition) were identical and included six standard event names (see Table 1). Each of these event names refers to an attribute of the environment. Data reported on the attributes hence refer to specific (series of) events. In the F-condition two additional attributes were available, namely 'judgement of learning (JOL)' and 'functional validity feedback (F-feedback)'. In the FC-condition both were available too and a ninth one was available, 'cognitive validity feedback (C-feedback)'. As in the investigation of the relationship between cues for calibration and learners' behaviour the aim was to identify which sub-sequences occurred significantly more in which condition, sub-sequences including judgement of learning, functional validity, and cognitive validity feedback cues were excluded from the analysis as they only occur in the experimental conditions.

Table 1.

Actions traced in the online learning environment.

Attribute	***Description***
Course	Landing page of the course. On this page, learners found an overview of the entire course, links to each of the texts addressed, and links to the discussion forum.
Objective	Pages elaborating on the learning objectives aimed for by the different texts.
Text	Downloadable version of both texts addressed during the online learning module.
Forum	Discussion forum including the viewing of the forum, posting of information, and all other interactions related to the forum.
Exercise	Practise exercise for the support of learning prior to the self-test.
Self-test	Formative test on each section of the different texts under investigation. Obligatory to be able to progress to the next part of the online learning module.
JOL-cue	Formative test to estimate performance on the self-test for each section addressed in the different texts. Obligatory to be to progress to the next part of the online learning module.
F-feedback	Feedback page containing a functional validity feedback cue providing information and an open question (free to answer or not) aiming to evoke learners' calibration.
C-feedback	Feedback page containing a cognitive validity feedback cue providing information and an open question (free to answer or not) aiming to evoke learners' calibration.

Finally, in the face-to-face contact moments no trace data were gathered as all learners received the same instruction and did not interact with the Moodle environment.

Instruments

Prior domain knowledge and domain knowledge

During the pre-test phase a performance based prior domain knowledge test was administered to investigate learners' prior domain knowledge. This prior domain knowledge test containing ten multiple-choice questions (including an "I don't know option") represented the content of the module. The test consisted of questions related to both texts (five per text). The test was scored on ten points. The same test was used as post-test to measure learners' domain knowledge.

Goal orientation

Learners’ goal orientation was measured by using the merged version of two questionnaires of Elliot and Church (1997) and Elliot and McGregor (2001) for measuring learners’ goal orientation as constructed by Lust (2012). Whereas the initial questionnaire of Elliot and Church (1997) measured solely three dimensions of goal orientation (mastery approach, performance avoidance, and performance approach), the revised questionnaire Elliot and McGregor (2001) incorporated the fourth dimension of mastery avoidance as well. These two questionnaires were merged into one that contained 21 items (Mastery goal approach (MGA) (6 items), Mastery avoidance approach (MAA) (4 items), Performance goal approach (PGA) (5 items), Performance avoidance approach (PAA) (6 items)). Answers for the items were given on a 5-point Likert type scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Academic self-concept

The Academic self-concept (ASC) scale comprised two 10-item subscales: learning confidence and learning effort. The learning confidence subscale assessed learners' feelings and perceptions about their academic competence (Liu et al., 2005). Example items are 'I am good in most of my course subjects' and 'most of my classmates are smarter than I am' (negatively worded). The learning effort subscale assessed learners' commitment to and involvement and interest in schoolwork (Liu et al., 2005).

Judgement of learning

Learners’ judgement of learning was used in two ways. On the one hand as a dependent variable, on the other hand as the input for the adaptive feedback in the experimental conditions. For both purposes learners’ judgement of learning was calculated in accordance with Schraw (2009). Learners’ absolute accuracy was measured, indicating the precision of a single estimation of future score compared to performance on a single test (Maki, Shields, Wheeler, & Zacchilli, 2005).

With regard to judgement of learning as a dependent variable, right before the pre-test and post-test for domain knowledge all learners were asked to estimate their score on both domain knowledge tests. Based on the comparison with their performance on the domain knowledge, a pre-test and post-test judgement of learning score was calculated.

In view of generating automated functional validity feedback (for both experimental conditions - see: Cues for calibration), learners’ estimation of their future score was gathered through the judgement of learning cues proceeding each self-test. For both purposes, learners were asked to score their estimation of future score on an ordinal scale with ten point interval that range from 0/10 (0%) to 10/10 (100%). Their actual score was measured through a single test. Scores were recalculated to an identical ten point interval also ranging from 0/10 (0%) to 10/10 (100%). Following this measurement, the absolute accuracy index was calculated. The formula of this index can be found below:

$$\text{Absolute Accuracy Index} = \frac{1}{N}\sum_{i=1}^{N}(c_i - p_i)^2$$

In this formula, c_i corresponds to the estimation of future score and p_i corresponds to the actual score. Each deviation score between learners' estimation of future score and actual score is squared so it ranges from zero to one, where a score of zero corresponds to perfect calibration accuracy and a score of one corresponds to no accuracy. Smaller deviations correspond to better accuracy.

Metacognitive skilfulness

In line with the literature on cues for calibration, we investigated learners' metacognitive skilfulness to get more profound insights in the cues' effect on learners' self-regulated learning. This was done by using an online aptitude measurement developed by Veenman (e.g., Veenman et al., 2014; Veenman et al., 2004), called "The otter task". This measurement is a computerized learning-by-discovery task in Authorware. The otter-task requires learners to experiment with five independent variables in order to discover their (combined) effects on the growth of the otter population. The five variables were habitat, environmental pollution, public entrance, setting out new otter couples, and feeding fish in wintertime. Independent variables could have no effect on the otter population (public entrance), a main effect (habitat; pollution), and interact with another variable (habitat x setting out otter couples; pollution x feeding fish). For each experiment, participants could choose a value for the five variables by clicking on the pictograms on the left, and then order the computer to calculate the growth of the otter population. Results of experiments done were transferred to a storehouse where learners could scroll up and down to consult earlier results. After a minimum of fifteen experiments, an exit button occurs which allows the learners to leave "The otter task", nonetheless they are free to continue. All actions done by the learners are logged in a text file. This log file is scored for metacognitive skilfulness through ten log file indicators, namely: (1) number of experiments, (2) think time, (3) scroll down, (4) scroll up, (5) transition with one altered variable, (6) mean number of changes, (7) number of unique experiments, (8) variation of variables, (9) systematic changes, and (10) complete variation of variables. All learners' values per log file indicator were standardized into z-scores. Finally, mean z-scores were calculated over the ten log file indicators as an overall measure of metacognitive skilfulness (for a full account of the methodology, see: Veenman et al. (2014)). This calculation resulted in an individual metacognitive skilfulness score per learner, comparing learners' individual score with the sample score.

The quality of the instruments

Traditional reliability analysis (Cronbach's alpha) was used in order to investigate the quality of the measurement instruments. Table 2 depicts the Cronbach's alpha values of the different scales. Given the threshold of .70 as proposed by Nunnally and Bernstein (1994), all instruments seem to be in reach of this threshold.

Table 2.

Pre and post reliability analysis per construct.

Latent variable	***Construct***	***α pre***	***α post***
Cognition	Domain knowledge (DK) (10 items)	.65	.66
Goal orientation	Mastery goal approach (MGA) (6 items)	.79	.75
	Mastery avoidance approach (MAA) (4 items)	.73	.80
	Performance goal approach (PGA) (5 items)	.86	.86
	Performance avoidance approach (PAA) (6 items)	.74	.77
Academic self-concept	Learning effort (LE) (10 items)	.79	.80
	Learning confidence (LC) (7 items)	.74	.72
Metacognition	Metacognitive skilfulness (MS) (10 log file indicators)	.84	

Procedure

Learners' were randomly assigned to three separate but identical learning environments, either the control group, the functional validity feedback experimental condition (F-condition), or the functional and cognitive validity feedback experimental condition (FC-condition). All (n=151) learners attending the module were invited to complete the otter task (during four available timeslots) prior to their first login in the online learning module. The learners got 60 minutes to complete this task. The online pre-test questionnaire, the pre-test judgement of learning question, and prior domain knowledge test were administered at the start of the online learning module and obligatory to activate the content of the online learning module. Learners got 28 days' time to complete the online learning module, learners in the experimental conditions received cues for calibration (as described earlier) during that time; learners in the control condition did not. After the completion of the intervention, learners in the three conditions completed the online post-test questionnaire, the post-test judgement of learning question, and the domain knowledge test. The learners did not receive any other form of instruction on the module content during the time period between the pre-test and the post-test. For the matching of the different datasets anonymized student IDs were used.

Analysis

First, to be able to determine the effect of learners' metacognitive skilfulness as an independent variable, we quartered the learners based on their metacognitive skilfulness score. This was by done by ordering all learners' scores from the lowest to the highest, followed by dividing them in 4 groups. Each group represented 25% of the sample. Learners were assigned a quartile number indication in which quartile their score was situated (1 = low to 4 = high). In this way, a new categorical variable metacognitive skilfulness quartile membership (PMSQ) was created and will be used as an independent variable throughout the analyses.

Second, descriptive statistics were calculated presenting the number of subjects involved (*N*), the minimum (*Min*) and maximum (*Max*) scores, the mean scores (*M*), the standard error (*SE*), the standard deviation (*SD*), and the variance (σ^2). This was done for learners' metacognitive skilfulness quartile membership (PMSQ) and each of the pre-test variables (domain knowledge (DK), mastery goal approach (MGA), mastery avoidance approach (MAA), performance goal approach (PGA), performance avoidance approach (PAA), learning effort (LE), learning confidence (LC), and judgement of learning (JOL)). Also the post-test variables were investigated for correlations, to identify the need for multivariate or univariate tests.

Third and final, through a one-way multivariate analysis of variance (MANOVA) with condition as independent variable, followed by univariate analyses of variance (ANOVAs) the three conditions' comparability among each other was checked for learners' prior domain knowledge, goal-orientation, academic self-concept, and metacognitive skilfulness quartile membership.

Investigation of learning behaviour

The event sequence analysis consisted of two major steps (e.g., Cicchinelli et al., 2018; Zhou, 2016). First frequent event sub-sequences were identified using exploratory sequence analysis. Secondly, discriminant frequent event sub-sequences were identified by using an explanatory approach as well. The latter analysis was based on the condition learners were in. This to identify what sub-sequences (dependent variable) occurred significantly more in which condition (independent variable). A similar approach was adopted for metacognitive skilfulness (PMSQ) and for the interaction between condition and metacognitive skilfulness. The learners' behavioural data was imported in R-statistics and analysed using the TraMineR package (Gabadinho et al., 2011).A similar approach to identify frequent event sub-sequences was used as Jovanović et al. (2017) and Van Laer and Elen (2016a). Both studies emphasize the importance of two parameters when identifying frequent event sub-sequences. The first one is the time constraint (Studer et al., 2010). As we followed a data-driven approach while investigating the ecological order of events, we chose to set this parameter on one. This indicates that only events that actually occurred following each other are included. Events further apart in time are not considered. The second one is the relative threshold number of times (pMinSupport) a sub-sequence occurs among the different learners (Müller et al., 2010). In this study, this parameter was arbitrarily set on .25 to assure frequent sub-sequences occurred at least in 25% of the learners.

Discriminant frequent event sub-sequence were identified in line with Kim and Shute (2015) and with Grover et al. (2017). The significant discriminating ability of the sub-sequences was first based on differences between conditions learners were in, secondly on metacognitive skilfulness, and finally on the interaction of the condition learners were in and learners' metacognitive skilfulness quartile membership (PMSQ). To be able to calculate the discriminating abilities of a frequent sub-sequence two arguments are needed (a) a sub-sequence (subseq) object containing the sub-sequences considered for discriminating the groups and (b) the variable that defines the groups (groups) (Garza, 2016). A chi-square test is used to investigate the significance of the relationship between the observed and expected occurrence of a frequent sub-sequence for each value of the measured variables (Studer et al., 2010). Finally, the effect sizes are calculated using the Cramer's V. The Cramer's V expresses the relationship between a certain discriminating frequent sub-sequence and the learners' characteristics and is reported in a value between zero and one. The closer to one the higher the relation. Cohen (1988) refers to small (≤.30), medium (≥.30 and ≤50), and large (≥.50) effect sizes.

Investigation of learning outcomes

In order to (1) examine the effect of the instructional intervention on learners' learning outcomes and (2) examine the interaction effect of instructional intervention and learners' metacognitive skilfulness on learners' learning outcomes, a two-way multivariate analysis of covariance (MANCOVA) test with pre-test and post-test data will be used. The MANCOVA can be seen as an extension of the multivariate analysis of variance (MANOVA) incorporating pre-test covariates. These covariates are related to the dependent post-test variables under investigation and reduce the error variance between pre-test and post-test results (Dimitrov & Rumrill, 2003). A MANCOVA is used to determine whether there are any statistically significant differences between the adjusted means of three or more independent (unrelated) groups, having controlled for the pre-test covariates.

In this study a MANCOVA will be done with as dependent variables learners' post-test scores on: domain knowledge (DK), mastery goal approach (MGA), mastery avoidance approach (MAA), performance goal approach (PGA), performance avoidance approach (PAA), learning effort (LE) learning confidence (LC), and judgement of learning (JOL) . Condition and learners' metacognitive skilfulness (PMSQ) will be used as independent variables. Learners' pre-test scores on domain knowledge (DK), mastery goal approach (MGA), mastery avoidance approach (MAA), performance goal approach (PGA), performance avoidance approach (PAA), learning effort (LE), learning confidence (LC), and judgement of learning (JOL) are used as covariates. The main effects, followed by the interaction effects, and univariate tests will be reported. Additionally, pairwise comparison with a Bonferroni correction will further investigate the found effects. Nonetheless, before conducting the MANCOVA test, the variables were tested for normality (Shapiro–Wilks' test), sphericity (Mauchly's Test of Sphericity), and homogeneity of variances (Levene's test). Figure 2, visualizes the MANCOVA.

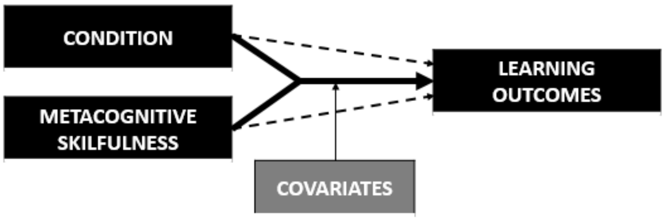

Figure 2. Visual representation of the MANCOVA analysis.

Results

Descriptive statistics

151 learners were included in the analysis. There were 134 women (88.74%) and 17 men (11.26%) aged between 19 and 58 years (*M*=21.87, *SD*= 6.84). Learners were assigned to a quartile, based on their score on metacognitive skilfulness. The first quartile (n = 38) represented Z-scores between -1.26 and -.61 (*M* = -.91, *SD* = .208), the second quartile (n = 38) between -.60 and -.15 (*M* = -.39, *SD* = .157), the third quartile (n = 39) between -.14 and .36 (*M* = .11, *SD* = .160), and the fourth quartile (n = 37) between .39 and 5.38 (*M* = 1.36, *SD* = 1.121). Descriptive statistics of learners' pre-test scores of the dependent variables can be found in table 3.

Table 3.

Descriptive statistics of the pre-test scores.

Pre-test variables	*N*	*Min*	*Max*	*M*	*S.E.*	*SD*	σ^2
Domain knowledge (PDK)	151	0.00	10.00	4.48	0.188	2.306	5.318
Mastery goal approach (MGA)	151	2.00	5.00	4.07	0.047	0.575	0.331
Mastery avoidance approach (MAA)	151	1.00	5.00	3.68	0.062	0.759	0.577
Performance goal approach (PGA)	151	1.00	4.20	2.37	0.060	0.751	0.564
Performance avoidance approach (PAA)	151	1.80	5.00	3.79	0.051	0.633	0.401
Learning confidence (LC)	151	1.57	4.43	3.02	0.040	0.498	0.249
Learning effort (LE)	151	1.90	4.90	3.45	0.041	0.510	0.261
Judgement of learning (JOL)	151	0.00	0.49	0.07	0.007	0.087	0.008

To identify if multivariate or univariate tests for further investigation would be most appropriate, relationships between the dependent variables were checked. Correlation analysis showed weak (.20-.39) to moderate (.40-.59) correlations (Evans, 1996) between the different post-test variables, namely between PGA and LC ($r(149) = .36$, $p < .001$), PAA and MGA ($r(149) = .16$, $p = .043$), PAA and MAA ($r(149) = .51$, $p < .001$), PAA and LC ($r(149) = -.16$, $p < .01$), and MAA and LE ($r(149) = .38$, $p < .001$). No other correlations were found.

Pre-test comparison of the experimental and control conditions

All 151 learners (control = 49, F-condition = 48, and FC-condition = 54) participated in the otter task, the prior judgement of learning question, the prior domain-knowledge test, and the pre-test questionnaire. The pre-test scores correlated weakly too moderately, so a multivariate analysis of variance (MANOVA) was applied to compare learners' pre-test scores (as dependent variables) for the three condition (independent variable). The MANOVA showed no significant differences (F (16, 282) = 1. 59, Wilk's Λ = .933, $p = .71$) for experimental and control condition. Nonetheless, the univariate tests showed a significant differences for domain knowledge (DK) (F (2, 151) = 3.42, $p = .035$) among the different conditions. Learners in the FC-condition seemed to score significantly ($p = .012$) higher (*MD* = 1.15) than learners' in the F-condition. No difference was found for the other variables.

The effect of condition and metacognitive skilfulness on learners' learning behaviour

Condition

The learners (n=149) included in the event sequence analysis generated 54434 events over the timespan of 28 days. A total of 249 frequent sub-sequences were extracted (TimeGap=1; pMinSupport=.25). 18 significant discriminant sub-sequences (pValueLimit=.05) were identified. Sub-sequences contained between two and seven events. Three conditions were compared (control condition, F-condition, and FC-condition) through chi-square tests.

Learners in the control condition made significantly the most use of sub-sequences consisting of Self-test events followed by other Self-test events (between $\chi(2) = 83.848$, $p < .001$, $V = .56$ and $\chi(1) = 98.706$, $p < .001$, $V = .66$). Whereas for the control condition the standardized residuals scores were between 6.50 and 7.00, for the F-condition they were between -2.97 and -3.35, and for the FC-condition between -3.37 and -3.51. Examination of the Cramer's V scores indicate, according to Cohen (1988), large effects (≥.50). Learners in the control condition also made significantly the most use of sub-sequences consisting of Self-test events followed by Exercises events. Here chi-square tests (between $\chi(2) = 11.964$, $p < .001$, $V = .08$ and $\chi(1) = 16.092$, $p < .001$, $V = .11$) showed smaller effect sizes (≤.30). The standardized residuals for the control condition were between 2.22 and 2.50, for the F-condition between -.04 and -.42, and for the FC-condition between -1.96 and -2.33. Learners in the F-condition (*SR* between .51 and 1.72) used significantly more sub-sequences related to Exercise events followed by other Exercise events (χ^2-tests between $\chi(2) = 6.004$, $p < .001$, $V = .04$ and $\chi(1) = 6.546$, $p < .001$, $V = .05$). The control condition's standardized residuals score were between -1.23 and .82 and the FC-condition's between -1.35 and -.15. Finally, learners in the FC-condition did never demonstrated significantly more sub-sequences to any types of events for all significant discriminant sub-sequences.

Metacognitive skilfulness

In line with the investigation of the effect of condition on learners' learning behaviour, the effect of metacognitive skilfulness (PMSQ) was also studied. Significant discriminant sub-sequences, based on learners' metacognitive skilfulness (PMSQ) (quartile 1 to quartile 4) were identified. The same analysis was applied as when addressing the effect of the condition on learners' learning behaviour. Only 3 significant discriminant sub-sequences (pValueLimit=.05) were identified. Sub-sequence contained between four and six events.

The three discrimant sub-sequences, all showed Text events (downloading of one of the two articles learners needed to read) followed by Forum events. Learners belonging to the lowest quartile (Q1) used these sub-sequences significantly more events (between $\chi(3) = 7.814$, $p = .050$, $V = .23$ and $\chi(3) = 8.069$, $p = .044$, $V = .82$) than learners belonging to quartile 2 (*SR* between .22 and .36), quartile 3 (*SR* between -.02 and -.07), or quartile 4 (*SR* between -1.89 and -1.99). Examination of the Cramer's V scores indicate according to Cohen (1988) small effects of learners' metacognitive skilfulness on learners' learning behaviour (≥.50).

Condition and metacognitive skilfulness

Finally, to investigate on the interaction of condition and metacognitive skilfulness (PMSQ) on learners' learning behaviour, significant discriminant sub-sequences based on condition and metacognitive skilfulness (PMSQ) (1 = low to 4 = high) were identified. 10 significant discriminant sub-sequences (pValueLimit=.05) were identified and compared among 12 groups (3 conditions x 4 quartiles). Sub-sequence contained between three and six events.

Learners in the control condition belonging to the lowest quartile (Q1) of metacognitive skilfulness made significantly the most use of sub-sequences consisting of Self-test events followed by other Self-test events (between $\chi(11) = 86.47$, $p < .001$, $V = .76$ and $\chi(11) = 101.280$, $p < .001$, $V = .82$). Examination of the Cramer's V scores indicate according to Cohen (1988) large effects based on condition and PMSQ (≥.50). Here standardized residuals score were between 4.41 and 4.68. Their counterpart belonging to different quartiles of PMSQ, but to the same condition, used fewer such sub-sequences. For learners belonging to the second quartile (Q2), standardized residuals score were between 2.50 and 3.75, for learners belonging to the third quartile (Q3), between 2.94 and 3.41, and for the highest quartile (Q4), between 2.36 and 2.64. The same observation could be made for learners belonging to the lowest quartile (Q1) in the F-condition (*SR* between -.97 and -1.64) and the FC-condition (*SR* between -1.75 and -1.88). Learners belonging to higher quartiles in the F-condition or the FC-condition made less use of sub-sequences consisting of Self-test events followed by other Self-test events. Learners in the FC-condition belonging to the second quartile (Q2) used the least of these sub-sequences (SR between -1.89 and -2.03).

Learners in the F condition belonging to highest quartile (Q4) made significantly more use of sub-sequences consisting of Self-test events followed by Exercises events. Here Chi squared tests (between $\chi(11) = 20.774$, $p = .036$, $V = .37$ and $\chi(11) = 23.431$, $p = .015$, $V = .40$) showed medium effect sizes (between .30 and .50). The standardized residuals were between .83 and 1.16, where they were for their counterparts belonging to the third quartile (Q3), between -.83 and -1.27, for learners belonging to the second quartile (Q2), between .38 and .75, and for the lowest quartile (Q1), between -.97 and -1.26. The same observation with regard to sub-sequences consisting of Self-test events followed by Exercises events could be made for learners belonging to highest quartile (Q4) of metacognitive skilfulness in the control condition (*SR* between 1.25 and 1.71), but not for learners belonging to this quartile in the FC-condition (*SR* between -1.75 and -1.99). Learners belonging to lower quartiles in the control condition or the FC-condition made less use of sub-sequences consisting of Self-test events followed by Exercise events. Learners in the FC-condition belonging to the highest quartile (Q4) used the least of these sub-sequences (SR between -1.75 and -1.99).

Finally, learners in the highest quartile (Q4) and the FC-condition did never demonstrated significantly more sub-sequences to any types of events for all significant discriminant sub-sequences.

The effect of condition and metacognitive skilfulness on learners' learning outcomes

For the multivariate tests, the main effect of condition (F (16, 150) = .908, p = .562, Wilk's Λ = .831, η_p^2 = .09) was not significant, indicating that condition had no direct effect on the dependent variables under investigation. In contrast to this, the main effect of learners' pre-test metacognitive skilfulness (PMSQ) was significant (F (24, 218.124) = 1.987, p = .005, Wilk's Λ = .564, η_p^2 = .17), indicating that a different degree of skilfulness affects the dependent variables. Here, univariate tests showed that only learners' judgement of learning (F (3, 138) = 6.025, p = .001, η_p^2 = .18) significantly differed depending on learners' degree of skilfulness. Pairwise comparisons using a Bonferroni correction showed that learners in the third quartile (Q3) (M = .105) scored significantly less accurate, than learners in the lowest quartile (Q1) (MD = -.03, SE = .025, p = .023), the second quartile (Q2) (MD = -.02, SE = .025, p = .022), or in the highest quartile (Q4) (MD = -.03, SE = .025, p = .011). Figure 3 shows the mean post-test scores for judgement of learning per metacognitive skilfulness quartile.

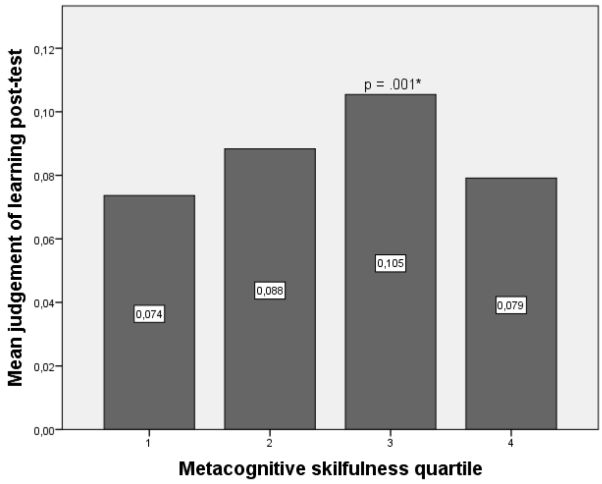

Figure 3. Mean judgement of learning post-test scores per metacognitive skilfulness quartile.

Results also reveal a significant interaction effect between condition and metacognitive skilfulness (F (48, 373.094) = 1.560, p = .025, Wilk's Λ = .591, η_p^2 = .09). The univariate tests showed learners' judgement of learning (F (6, 138) = 3.862, p = .002, η_p^2 = .13) and learning confidence (F (6, 138) = 1.474, p = .017, η_p^2 = .17) significantly differed depending on the condition learners were in and learners' degree of metacognitive skilfulness.

Post-hoc comparison using a Bonferroni correction showed that learners belonging to quartile 3 in the FC-condition (M = .25) scored significant less accurate than learners in the control condition (MD = -

.11, *SE* = .051, *p* = .103) or F-condition (*MD* = -.17, *SE* = .042, *p* < .001) belonging to the same quartile, indicating that they were less accurate. The opposite was found for learners belonging to the highest quartile (Q4) in the FC-condition (*M* = .04). Learners belonging to the control condition (*MD* =.10, *SE* = .048, *p* = .033) or the F-condition (*MD* = .01, *SE* = .042, *p* = .753) and the same quartile, scored less accurate. The other conditions and quartiles configurations did not show any significant differences with regard to learners' judgement of learning. Figure 4 shows the estimate marginal means for judgement of learning per condition and metacognitive skilfulness quartile.

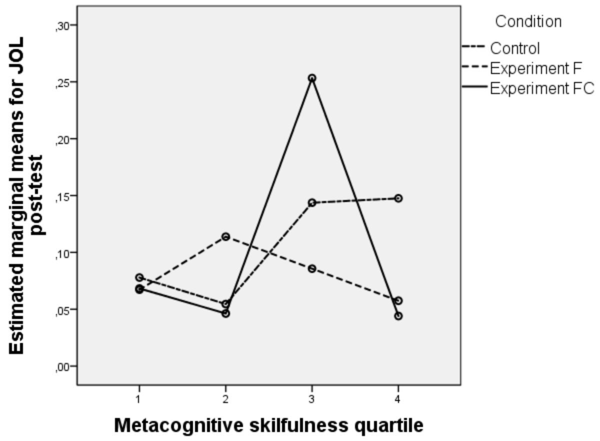

Figure 4. Estimate marginal means for judgement of learning per condition and metacognitive skilfulness quartile.

Finally, for learning confidence, post-hoc comparisons using a Bonferroni correction showed that learners with the lowest degree of metacognitive skilfulness (Q1) in the F-condition (*M* = 2.98) scored lowest on learning confidence. Learners belonging to the same quartile in the control condition (*MD* = .25, *SE* = .125, *p* = .050) or FC-condition (*MD* = .03, *SE* = .108, *p* = .804) scored higher on learning confidence. The opposite was found for learners belonging to the highest quartile (Q4) in the F-condition (*M* = 3.40) who scored highest on learning confidence. Learners belonging to the same quartile in the control condition (*MD* = -.37, *SE* = .137, *p* = .009) or FC-condition (*MD* = -.18, *SE* = .129, *p* = .178) scored lower on learning confidence. No other significances were found in the univariate tests for learning confidence. Figure 5 shows the estimate marginal means for learning confidence per condition and metacognitive skilfulness quartile.

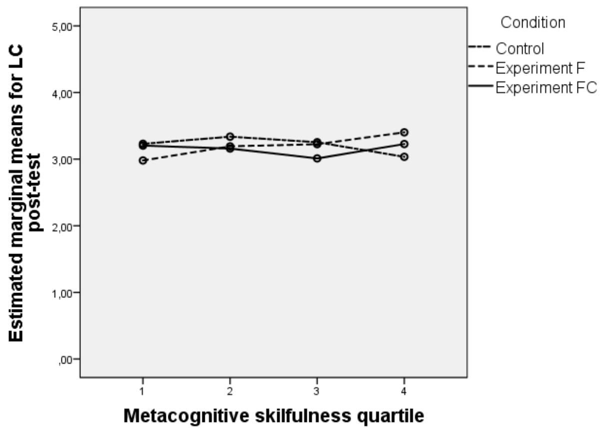

Figure 5. Mean judgement of learning post-test scores per condition and metacognitive skilfulness quartile.

Discussion

In what follows, first we relate the results to the hypotheses set in the introduction, secondly we explore the nature of the results and discuss them in terms of their theoretical and practical implications and provide recommendations for future research.

Findings

Hypothesis 1: "Cues for calibration affect learners' learning behaviour."

Cues for calibration clearly seem to affect learners' learning behaviour, so hypothesis one could be confirmed. Learners in the control condition made significantly more use of sub-sequences consisting of Self-test events followed by other Self-test events compared to the learners in the experimental conditions. Learners in the F-condition seemed to use such sub-sequences significantly less, and even less so by learners in the FC-condition. Similar findings were found in relation to sub-sequences consisting of Exercises events following Self-test events. Learners in the F-condition only used significantly more sub-sequences related to Exercise events following other Exercise events compared to the learners in the control condition, and learners in the FC-condition who used the sub-sequences the least. For all 18 significant discriminant sub-sequences learners in the FC-condition, never demonstrated significantly more use of sub-sequences compared to the other two conditions.

Additionally, independent from the condition also the effect of learners' metacognitive skilfulness was investigated. Here there seemed to be hardly any differences among learners. Learners with the lowest degree of metacognitive skilfulness (Q1) made significantly more use of sub-sequences related to Text events followed by Forum events. The higher learners' score was for metacognitive skilfulness, the fewer they used these sub-sequences.

<u>Hypothesis 2: "Cues for calibration affect learners' learning behaviour differently for learners with different levels of metacognitive skilfulness."</u>

Based on the following elements hypothesis 2 can be regarded to be confirmed. Learners in the control condition belonging to the lowest degree quartile (Q1) made the most use of sub-sequences consisting of Self-test events followed by other Self-test events compared to learners in the other groups. Learners in the same condition but with other degrees of skilfulness used these sub-sequences less frequently. Learners belonging to the same quartile in the F-condition and the FC-condition exhibited the same behaviour. Learners belonging to different quartiles made less use of sub-sequences consisting of Self-test events followed by other Self-test events. Learners in the FC-condition belonging to the second quartile (Q2) used these sub-sequences the least.

Learners in the F condition belonging to the highest quartile (Q4) of metacognitive skilfulness made significantly more use of sub-sequences consisting of Self-test events followed by Exercises events. Learners belonging to the highest quartile (Q4) in the control condition exhibited the same behaviour. Learners belonging to different quartiles in the control condition or the FC-condition made less use of sub-sequences consisting of Self-test events followed by Exercise events. Learners in the FC-condition belonging to quartile 4 used the least of these sub-sequences.

Finally, learners with the highest degree (Q4) of metacognitive skilfulness in the FC-condition did never demonstrated significantly more sub-sequences to any types of events for all significant discriminant sub-sequences.

<u>Hypothesis 3: "Cues for calibration positively affect learners' learning outcomes."</u>

No significant main effect of condition on learners' learning outcomes could be found. Therefore, hypothesis 3 is falsified. However, learners' metacognitive skilfulness significantly affected learners' learning outcomes. Further univariate analyses have revealed this only to be the case for learners' judgement of learning. Learners with metacognitive skilfulness degrees between -.14 and .36 (Q3) judged their learning significantly less accurate on the post-test than learners with other levels of metacognitive skilfulness. Explorative analysis showed indications of a curvilinear relationship between metacognitive skilfulness and judgement of learning. Figure 6 shows this relationship.

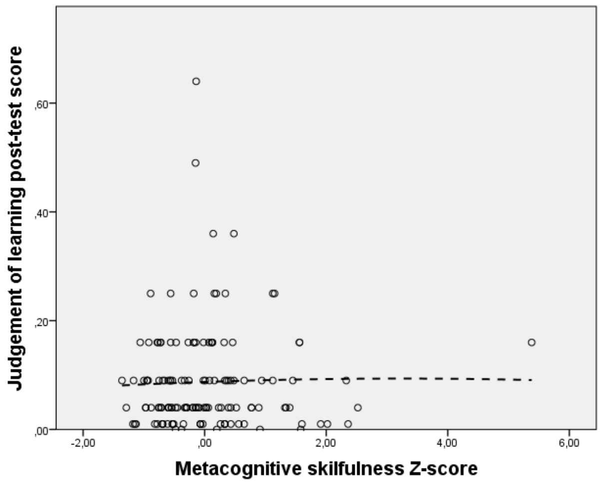

Figure 6. Curvilinear relationship between metacognitive skilfulness and judgement of learning.

Hypothesis 4: "Cues for calibration positively affect learners' learning outcomes most when learners have high levels of metacognitive skilfulness."

Finally, based on the following elements, hypothesis 4 can said to be confirmed although in an unexpected direction. Investigating the interaction effect of the cues for calibration (conditions) and learners' metacognitive skilfulness (PMSQ) on learners' learning behaviour, it became clear that certain constellations of condition and degrees of learners' metacognitive skilfulness significantly affected learners' learning outcomes. Nonetheless, this was the case only for two dependent variables. Univariate tests showed learners' judgement of learning and learning confidence to be affected by the interaction of both independent variables. With regard to judgement of learning, results showed that learners with metacognitive skilfulness degrees between -.14 and .36 (Q3) in the FC-condition scored less accurate, than learners in the control condition or F-condition belonging to the same quartile. For learners with high metacognitive skilfulness degrees between .39 and 5.38 (Q4) of the FC-condition, the results showed the opposite. These learners were more accurate than the others were.

In relation to learning confidence, results showed that learners with low degrees of metacognitive skilfulness between -1.26 and -.61 (Q1) in the F-condition scored lowest on learning confidences. Learners belonging to the same quartile in the control condition or FC-condition scored higher. The opposite result was found for learners with high degrees of metacognitive skilfulness between .39 and 5.38 (Q4) of the F-condition. These learners scored higher on learning confidence than learners in the same quartile for the other conditions.

Exploration of the unexpected findings

The current study yields three major findings. First, the more external feedback learners get and the higher their metacognitive skilfulness, the fewer sub-sequences learners use related to self-tests and exercises. Secondly, when learners have low degrees of metacognitive skilfulness and receive cues for calibration through functional validity feedback, they score significantly lower on learning confidence. The opposite is true in the F-condition for learners' with high degrees of metacognitive skilfulness. Learners are more confident. When both functional and cognitive validity feedback are provided, no differences are found for any learners. Third and final, learners with high degrees of metacognitive skilfulness who receive both functional and cognitive validity feedback are more accurate in judging their own learning than other learners. Nonetheless, this is not the case for learners with average degrees of metacognitive skilfulness. In conclusion, this study shows that cues for calibration, affected learners' learning behaviour and outcomes, and so self-regulated learning. However, the directions are unexpected. Below we provide a possible explanation.

Learners' cue use

In line with current research on the link between instructional interventions and learners' learning behaviour through log-file data (e.g., Rienties, Toetenel, & Bryan, 2015; Wolff, Zdrahal, Nikolov, & Pantucek, 2013), the type of calibration cue learners received influenced their learning behaviour. The observation that learners in the control condition made significantly more use of certain sub-sequences compared to the other conditions was rather striking as it contrasts with research reporting greater learner involvement with the learning environment and cues provided, when cues for calibration are provided (Szabo, Falkner, Knutas, & Dorodchi, 2018; Timmers, Walraven, & Veldkamp, 2015). However, from a self-regulated learning theory perspective a decrease in particular learning behaviour might be explained as follows. When learners are capable to identify the instructional requirements set, to comply with them, and so to be successful in achieving the learning outcomes targeted, they are self-regulated learners (e.g., Wolters, Won, & Hussain, 2017). In line with this reasoning the fewer actions needed to achieve the outcomes targeted the more effective one's self-regulated learning is (Winne & Hadwin, 1998). When cues for calibration are provided, including functional and cognitive validity feedback (FC-condition), self-regulated learners direct their behaviour towards the information that helps them to achieve the learning outcomes targeted (e.g., Butler & Winne, 1995; Dunlosky & Thiede, 2013; Geitz, Joosten-ten Brinke, & Kirschner, 2016; Rienties & Toetenel, 2016). When instead learners are only provided with indications about their calibration efforts (F-condition) they might act on this feedback and adapt their behaviour by for example making more exercises in an attempt to progress (e.g., Tempelaar, Rienties, & Giesbers, 2015). Finally, when in contrast learners are not provided with any information about their calibration efforts (control condition), it is solely up to them to gather this information, potentially resulting in feedback-seeking behaviour (e.g., Harrison, Könings, Schuwirth, Wass, & van der Vleuten, 2015). In conclusion, as a result of providing learners with functional and cognitive validity feedback, highly metacognitive skilful learners might be selective and only engage in specific goal-directed behaviour, whereas learners struggling with controlling their learning might rather perform a plenty-fold of undirected behaviours (e.g., Fonseca, Martí, Redondo, Navarro, & Sánchez, 2014; Van Laer & Elen, 2016a).

Learners' cue interpretation

As cues of calibration are inevitably interpreted through the lens of one's self-perceptions, it is important to understand how learners interpret the information provided to them (Eva et al., 2012). One way of doing this, is through the observation of changes in learners' learning outcomes. The findings of the study presented show that learners receiving functional validity feedback and having low degrees of metacognitive skilfulness, scored significantly lower for learning confidence in contrast to their counterparts in the control condition. According to research on the effect of cues for calibration on learners' learning confidence (e.g., Van der Kleij, Feskens, & Eggen, 2015), when learners are confronted with functional validity feedback, learners' might interpret the feedback for example as an indicator of personal failing or looming problem, rather than as a cue for them to re-calibrate (Hattie & Timperley, 2007). Especially when learners have low degrees of learning confidence this might be decisive for their further use of cues, as they might relate cues with negative experiences (Levine & Donitsa-Schmidt, 1998). In line with this reasoning, research points out that learners provided with functional and cognitive validity feedback do not have this problem, as cognitive validity feedback directs them to appropriate action to overcome this feeling (e.g., Ridder et al., 2015). Functional validity feedback did not only affect learners with low degrees of metacognitive skilfulness negatively, functional validity feedback also led to increased learning confidence for learners with high degrees of metacognitive skilfulness. Nonetheless, in the light of calibration, learning confidence without any performance related increase might lead to overestimation of one's own capabilities and further down the road to a decrease in performance (e.g., Dunlosky & Rawson, 2012).

Cue's effectiveness for increased performance

In line with our findings, Hellrung and Hartig (2013) present, in their systematic literature review, a substantial body of literature reporting increased learners' judgement of learning evoked by the use of functional and cognitive validity feedback. However, this was only the case for learners with high degrees of metacognitive skilfulness. One possible explanation for this is that learners with high degrees of metacognitive skilfulness are more aware of the different underlying strategies potentially supporting calibration and re-calibration (e.g., Hacker, Bol, & Bahbahani, 2008). This would result in more accurate estimations of one's performance (Callender, Franco-Watkins, & Roberts, 2016). So the information learners receive on the accuracy of their perceived level of performance in relation to their actual level, helps them to re-calibrate (e.g., Muis et al., 2016; Winne & Jamieson-Noel, 2002). Although for a change in accuracy to occur, learners need insight into the cognitive processes needed to calibrate their learning (e.g., Alexander, 2013; Dunlosky & Thiede, 2013). The combination of functional and cognitive validity feedback proved to provide calibration and showed increased judgement of learning. Based on the results of accurate calibration, learners monitor their learning and select cognitive and metacognitive strategies (e.g., error correction strategies, revision activities, etc.) which may help to proceed them in the direction of the desired level of performance (Narciss, 2017). The finding that certain learners increased in judgement of learning but not in performance might relate to the latter. Even when learners can calibrate external and internal feedback, they might not possess or be able to recall the cognitive and/or metacognitive strategies needed to act in a way that will produce increased performance (e.g., Pintrich, 2002; Veenman, 1993). This would evoke sub-optimal self-regulated learning and hamper increased performance. Although we investigated the effect of learners' metacognitive skilfulness based on learners' domain general ability to control and apply cognitive and metacognitive processes, the cues for calibration provided might have lacked the potential to evoke the transfer of these processes to a domain specific context (Butler & Winne, 1995). This finding has been supported by prior findings (e.g., Ardasheva et al., 2017; Dinsmore & Fryer, 2018) indicating that cues on the use of cognitive and/or metacognitive strategies should strongly align with the content provided (e.g., Alexander, 2018; Tricot & Sweller, 2014).

Further directions and conclusions

The present study documents fine-grained insights into the relationship between learners' self-regulated learning and cues for calibration. To obtain these insights, we first investigated learners' calibration-cue use based on learners' individual differences. Secondly, we operationalized self-regulated learning through learners' learning behaviour and outcomes. Investigating both learning behaviour and outcomes provides insights on learners' self-regulated learning, as well as on the nature of cues' effects. The current study reveals that differences in learner behaviour were related to condition and learners' metacognitive skilfulness, thus establishing a link between learners' self-regulated learning and cues for calibration. Finally, in the discussion of the results, we unravelled the effect of the design and content of the cues for calibration provided and hypothesized that when cues for calibration are provided through functional and cognitive validity feedback, learners' calibration capabilities will increase. Yet for this to result in goal-directed self-regulated learning and so increased achievement, learners not only need to be supported in identifying and recalling the cognitive and metacognitive strategies needed, but also directed to how to apply the cognitive and metacognitive strategies in their context.

Further directions

To further enrich our understanding, some challenges need to be addressed. A first challenge is the sample-size. A total of 151 learners were involved in the study – 48 in the control condition, 49 in the F-condition, and 54 in the FC-condition, which according to Field (2013) is an appropriate rule of thumb for testing the effect of three conditions (≥ 30 participants per condition). Nonetheless, to test the interaction between condition and metacognitive skilfulness, it might be advisable to include more learners per condition to overcome type II errors (Fraenkel, Wallen, & Hyun, 1993). By performing power analysis up front and involving more learners in the experiment, fewer false negatives might be observed, resulting in the uncovering of important significant effects of the intervention on the variables under investigation. A second challenge relates to the use of a data-driven approach to analyse learners' learning behaviour and its arbitrary parameter setting. As theoretical insights can be derived from the results of data-driven trials, contributing to such an approach may prove more promising than, for example, recoding events as (covert) metacognitive strategies or activities. In further research, this data-driven approach might be explored by experimenting with different parameter settings or a combination of data-driven and theory-driven approaches might be taken. With regard to the latter, this could be achieved for example by recoding events or sub-sequences based on a theoretical framework unrelated to self-regulation theory (for example a tool-use scheme). This would make the sub-sequences identified more meaningful and so interpretable. The third and final challenge relates to the relation between learners' self-regulated learning and the effect of cues. In this study the design of the cues and learners' metacognitive skilfulness were related to learners' learning behaviour. To be able to identify meaningful learning behaviour in the light of learning outcomes, future research might want to model the path of how different types of learners use the cues for calibration provide, leading them to certain learning outcomes for example through Hidden Markov Modelling.

Conclusions

Given the current lack of certainty regarding the effects of cues for calibration on learners' self-regulated learning, teachers and instructional designers remain dependent on inconsistent conceptual claims that cues for calibration may improve self-regulated learning. Studies such as the one presented here help both researchers and practitioners to distinguish between the effect of cues for calibration and how learners react to them. Establishing more fine-grained links between learners' characteristics, learning behaviour, and learning outcomes could help us propel the investigation of the effect of cues in intervention research.

DISCUSSION AND CONCLUSIONS

For decades, educational technology research assumed that the demonstration of an educational technology's potential affordance for learners' learning was enough to guarantee that instructors would be capable of using these technologies to instruct and support learners. Subsequently, educational technology research assumed that all learners would make use of technologies in the way intended by the instructor (e.g., Reiser & Dempsey, 2012; Spector, Merrill, Elen, & Bishop, 2014). The story is no different for blended learning environments, which have been applauded for their 'inherent' ability to support learning among all learners (e.g., Graham et al., 2005; Graham & Robison, 2007). Yet, in recent years, increasing studies have argued that blended learning environments themselves offer no guarantee of success (e.g., Graham et al., 2005; Liu, Peng, et al., 2016). On the contrary: (1) blended learning environments appear to challenge learners' self-regulated learning (e.g., Kuo et al., 2014; Lynch & Dembo, 2004), (2) there is a lack of design frameworks and guidelines for providing learners with optimum support (e.g., Oliver & Trigwell, 2005; Reigeluth, 2013), and (3) learners with different capabilities do not react in the same way to the support that is provided (e.g., Collazo et al., 2015; Lust et al., 2011; Winne & Hadwin, 1998). In response to this, current blended learning research has called for insights into how learners' self-regulated learning can best be fostered (e.g., Kassab et al., 2015; Lin, Lai, et al., 2016).

In answer to this call, the research project presented here aims to provide a framework for the investigation of the support of learners' self-regulated learning in blended learning environments. In the introduction to this thesis, the main concepts were defined and a hypothesized conceptual framework for the investigation of support for self-regulated learning in blended learning environments was proposed. First, blended learning was described as learning that happens in an instructional context characterized by a deliberate combination of online and classroom-based interventions to elicit and support learning (Boelens et al., 2015). Secondly, self-regulation was defined in accordance with Winne and Hadwin (1998) as the deliberate use of cognitive and metacognitive skills, in a particular context, to achieve goals set within or external to the learner. The key characteristics of self-regulation were identified as its cyclical, influenceable and covert nature. Third, whereas self-regulation refers to goals set within or external to the learner, self-regulated learning, in particular, reflects how learners respond to the instructional goals imposed on them by instructors or other educational actors. Finally, learners' behavioural reactions to changes in internal and/or external factors were designated as self-regulatory behaviour.

The hypothesized conceptual framework (see Figure 1) was operationalized (Section 1), validated (Section 2), and investigated empirically (Section 3) in the seven studies that make up the seven chapters of this thesis.

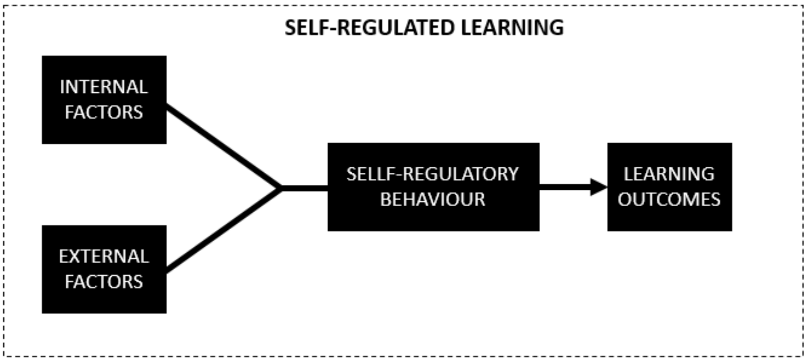

Figure 1. Visual representation of the conceptual framework under investigation.

Section One in brief

In the first section, three studies addressed the operationalization of a framework for investigating support for self-regulated learning in blended learning environments. In line with the conceptual framework hypothesized, both the investigation of factors influencing learners' self-regulated learning and their self-regulatory behaviour pose methodological challenges (e.g., Azevedo, 2005; Veenman et al., 2014; Veenman et al., 2006). In contrast to the long tradition of developing measurements for investigating internal factors (e.g., Marsh & Shavelson, 1985; Pintrich et al., 1993), measurements for investigating external factors influencing self-regulated learning are rather new (e.g., Reigeluth, 2013; van Merriënboer & Kirschner, 2017). The same goes for measurement methods that tie in with current conceptualizations of self-regulated learning, which only describe learners' self-regulated learning (e.g., Bannert et al., 2017; Veenman et al., 2014; Veenman et al., 2006; Winne & Baker, 2013) in relation to measurements of learners' learning outcomes. Following this observation, there was a clear need for (a) the identification of attributes that support learners' self-regulated learning in blended learning environments, (b) the operationalization of these attributes into an instrumentalized framework for the description of this support, and (c) a transparent and tangible approach to the investigation of self-regulated learning through learners' self-regulatory behaviour and learning outcomes.

To be able to describe blended learning environments (external factors) that influence learners' self-regulated learning, the first study examined the current literature for empirical evidence of instructional interventions that appear to affect learners' self-regulated learning in blended learning environments. Through a systematic literature review (n=95), seven attributes were identified, namely: authenticity, personalization, learner control, scaffolding, interaction, reflection cues, and calibration cues. The attributes identified were in line with the conceptualizations of Ley and Young (2001), Perry and Drummond (2002), and Perry et al. (2003) of support for self-regulated learning. Each attribute was related to self-regulated learning, learners' internal factors, and directions for design. The combination of these attributes comprises a support system for learners' self-regulated learning in blended learning environments. Once attributes supporting learners' self-regulated learning had been identified, a logical next step in the second study was to operationalize these attributes into an instrument and method. Through further investigation of the individual attributes, an instrument was developed providing questions relating to each of the attributes, followed by a method for using the instrument. This method consists of the establishment of a unit of analysis to overcome the dichotomy between online and classroom-based instruction, and a test for raters' interrater reliability. Finally, the instrument was piloted, modified, and further applied in practice. The instrument and method respond to the need for measurements and instruments to capture external factors influencing learners' self-regulated learning (e.g., Reigeluth, 2013; van Merriënboer & Kirschner, 2017). Together with the existing instruments for capturing internal factors affecting learners' self-regulated learning (e.g., Marsh & Shavelson, 1985; Pintrich et al., 1993) the establishment of such an instrumentalized framework enabled the description of factors influencing learners' self-regulated learning. According to Winne and Hadwin (1998), this step is necessary to enable the acquisition of insights into learners' self-regulated learning.

Self-regulated learning is not only observed through changes in learners' performance-related variables (e.g., Daniela, 2015; Lin, Coburn, et al., 2016). The shift from self-regulated learning as an aptitude to an event also affects the methods used to investigate learners' self-regulated learning. Alongside this shift, increased technological capability has introduced computer log files to the investigation of self-regulated learning, uncovering new research avenues. One such avenue investigates the time-related characteristics of self-regulated learning through learners' behavioural sequences. Ten years of investigating self-regulated learning through sequence analysis have produced a wide range of methodological approaches. While this variety of methods illustrates the diversity of opportunities, it also indicates the lack of consensus regarding the most appropriate approach. Since the introduction of sequence analysis in the field of self-regulated learning, researchers have repeatedly called for a methodological framework to guide its application. To help overcome this issue, a methodological framework for the use of sequence analysis in self-regulated learning research was proposed. First, a case was made for why such a framework is necessary. Second, we proposed a set of considerations that could serve as a starting point for the construction of a methodological framework. These considerations are centred on two key areas. The first area pertains to the alignment of the conceptualization with the different components of self-regulated learning, namely: the sequential and temporal characteristics of self-regulated learning, the development through time of self-regulated learning, the unit of analysis imposed by the factors influencing self-regulated learning, and the operationalization of the selected sequence analysis approach. The second area focusses on the enactment of the operationalization through the selected sequence analysis approach, namely: the systematic account of the operationalization and the transparent communication of parameter settings. These considerations directed the investigation of learners' self-regulated learning presented here. Moreover, the methodological framework serves as a response to the call for frameworks that tie in with current conceptualizations of self-regulated learning (e.g., Bannert et al., 2017; Veenman et al., 2014; Veenman et al., 2006; Winne & Baker, 2013).

Section Two in brief

Based on the insights obtained from the first three studies, the hypothesized conceptual framework for the support of learners' self-regulated learning in blended learning environments was operationalized in the second phase (see Section 2). Following this operationalization, assumptions relating to the influence of external and internal factors on learners' self-regulated learning were investigated. With regard to how self-regulated learning comes to be, recent theories regard self-regulated learning as being influenced by internal and external factors (e.g., Veenman et al., 2006; Winne & Hadwin, 1998). To investigate if this also holds in blended learning environments, the influence of (1) external factors and (2) internal factors on learners' self-regulatory behaviour was investigated.

Investigating the relationship between learners' self-regulatory behaviour and the design of blended learning environments is essential to determine how environmental attributes that support self-regulated learning (external factors) impact learners' self-regulatory behaviour (e.g., Butler, 1998; Ifenthaler, 2012; Kassab et al., 2015). In this study, learners' (n=120) self-regulatory behaviour was investigated in six ecologically valid blended learning courses. Using the instrumentalized framework for the description of support for self-regulated learning in blended learning environments, the constellations of attributes were captured for each course. Log files were analysed, resulting in three main self-regulatory behaviour profiles. Based on Vermunt and Vermetten (2004) these profiles were called (a) self-regulators, (b) external regulators, and (c) lack of regulation regulators (or 'mis-regulators'). Finally, statistical trials were carried out to determine whether particular profiles occurred significantly more under particular constellations of attributes (external factors). The results of the analysis show a significant impact of the design of the blended learning environment on the occurrence of particular profiles. These results are in line with prior research on designing learning environments for self-regulated learning that demonstrates the importance of informed environmental design (e.g., Azevedo & Hadwin, 2005; Boekaerts & Corno, 2005; Dabbagh & Kitsantas, 2004; Schraw et al., 2006).

The main finding that learners' self-regulatory behaviour differs significantly depending on external factors supports the assumption that external factors may influence learners' self-regulated learning in blended learning environments. Similarly, without identifying the relationship between learners' self-regulatory behaviour and their learner characteristics (internal factors) it is difficult to determine how differences among learners (internal factors) impact learners' self-regulatory behaviour (e.g., Bransford et al., 2000; Endedijk et al., 2014; Zimmerman, 2002). In line with prior research (e.g., Greene & Azevedo, 2007), we studied the relationships between learners' self-regulatory behaviour and their cognitive (i.e., prior domain knowledge), motivational (i.e., expectancy value) and metacognitive variables (i.e., metacognitive awareness). Learners' (n=25) self-regulatory behaviour was investigated in an ecologically valid blended learning course. We described the instructional context to ensure comparability throughout the study. A prior-domain-knowledge test and questionnaire consisting of parts of the Motivated Strategies for Learning Questionnaire and the Metacognitive Awareness Inventory were administered. Finally, log files were analysed using event sequence analysis. The majority of the learner variables were shown to be associated with significant differences in self-regulatory behaviour. These results are in line with prior findings indicating that different levels of learner variables (internal factors) result in different self-regulatory behaviour (e.g., Lopez et al., 2013; Zimmerman & Martinez-Pons, 1990). Again, the finding that learners' self-regulatory behaviour differs significantly depending on internal factors supports the assumption that internal factors may also influence self-regulated learning in blended learning environments.

Section Three in brief

External factors and internal factors seem to influence learners' self-regulatory behaviour and may as a result influence learners' self-regulated learning in blended learning environments. Based on this insight, empirical investigations were done to identify under which conditions (external factors) learners' with particular learner variables (internal factors) were affected in which way. Two empirical studies were administered with the aim of developing design guidelines for two of the attributes identified as inherent parts of the support of self-regulated learning in blended learning environments, namely (1) reflection cues and (2) calibration cues.

As literature on blended learning emphasizes the importance of self-regulation for learning in blended learning environments (e.g., Boekaerts, 1999; Greene & Azevedo, 2007; Vohs & Baumeister, 2016) and the role of learners' self-reflection for self-regulated learning (e.g., Lin, Coburn, et al., 2016; Pajares & Schunk, 2001; Schunk & Zimmerman, 1998), this first study investigated whether cues for reflection affect learners' self-regulated learning by examining changes in learners' self-regulatory behaviour and learning outcomes. A pre-post and control-experimental condition design was applied in a blended learning environment in which learners (n=41) in the experimental condition received cues for reflection, while learners in the control group did not. The cues for reflection were designed in line with current literature (e.g., Lehmann et al., 2014; Lust et al., 2011; Pannese & Morosini, 2014; Renner et al., 2014). Pre-tests on learners' internal factors were administered and data on learners' self-regulatory behaviour was collected. The results show that learners in the experimental condition used significantly more sequences related to self-testing and monitoring others. As regards learners' learning outcomes, the results show a significant increase in unfavourable motivational outcomes. Additionally, reflection-cue-use data show it was unlikely that this observation occurred because of learners not using the cues. In combination, these results led to the finding that if cues for reflection are designed in line with current literature, self-reflection is evoked, and does affect self-regulated learning. However, for this self-regulated learning to be goal-directed, learners need to be guided towards the strategies required to meet instructional expectations successfully (e.g., Pintrich, 2002; Veenman, 1993). The results obtained were in line with literature (e.g., Ardasheva et al., 2017; van den Boom et al., 2004).

The second empirical study investigated whether cues for calibration affect learners' self-regulated learning. Based on the outcomes of the previous study, learners' ability to act on the cues provided was incorporated as an additional dependent variable. The aim was to establish a more accurate picture of the effect of support for calibration on self-regulated learning. This study investigated whether providing cues for calibration affects learners' self-regulated learning in blended learning environments, and whether this effect is different for learners with different metacognitive abilities. Also in this empirical study, the effect was investigated by examining changes in learners' self-regulatory behaviour and learning outcomes. A pre-post and control-experimental condition design with two experimental conditions was applied in a blended learning environment. Learners in the experimental conditions received either functional validity feedback or functional and cognitive validity feedback. Learners in the control condition did not receive any cues. The cues were designed in line with current insights on the design of cues for calibration (e.g., Balzer & Doherty, 1989; Butler & Winne, 1995; Schraw, 2009). Learners' self-regulatory behaviour was analysed using event sequence analysis. Learners' post-test learning scores was subjected to multivariate analysis of covariance, using condition and learners' metacognitive ability as independent variables. It was found that interaction between condition and learners' metacognitive abilities had a significant effect on learners' self-regulatory behaviour and learning outcomes, albeit in unexpected ways. With regard to learners' self-regulatory behaviour, the results show a significant decrease in the use of self-test and exercise sub-sequences when learner had high levels of metacognitive abilities and belonged to the condition in which they received most support. With regard to the effect on learners' learning outcomes, learners with high levels of metacognitive abilities in the functional validity condition decreased in learning confidence, whereas learners in the functional and cognitive validity feedback condition increased significantly in judgement of learning, indicating they became more accurate at calibrating their performance. However, this was only the case for learners with specific characteristics and no increase in performance was found. Based on these results and further comparison with the current literature, we conclude that when cues for calibration are provided through functional and cognitive validity feedback, learners' calibration capabilities increase. Yet for this to result in goal-directed self-regulated learning, learners need to be supported in applying the cognitive and metacognitive strategies needed (e.g., Ardasheva et al., 2017; Dinsmore & Fryer, 2018). Here, too, the results were in line with previous research (e.g., Eva et al., 2012; Szabo et al., 2018; Timmers et al., 2015).

In the remainder of this discussion, I first summarize the main findings of the research project before discussing the methodological choices and their consequences. I then outline a number of potential considerations for future research. Finally, in the conclusion, I describe how the project has contributed to four main research areas and to educational practice.

Main findings

Each of the studies presented in the three sections of this thesis contributed to the validation of the conceptual framework under investigation, and therefore provide insights into support for learners' self-regulated learning in blended learning environments. Seven main findings can be distilled from the studies presented.

First, through the investigation of current literature on the support for self-regulated learning in blended learning environments, seven attributes were identified as external factors influencing learners' self-regulated learning. The combination of these attributes comprises a support system for learners' self-regulated learning in blended learning environments and functions as a basis for investigating environment design. Second, the seven attributes identified enabled us to develop an instrumentalized framework for describing support for self-regulated learning in blended learning environments. In doing so, we were able to characterize blended learning environments in terms of their support for self-regulated learning and assure instructional stability in empirical investigations. Combining this instrument with existing instruments for capturing internal factors allows us to map the factors that influence self-regulated learning more thoroughly. Third, the investigation of methods for measuring learners' self-regulated learning not only offers more tangibility and transparency but also answers the call for methodological frameworks that are in line with current conceptualizations of self-regulated learning. By operationalizing the measurement of self-regulated learning and of the internal and external factors that influence it, we succeeded in operationalizing the conceptual framework as a whole. Fourth, descriptive investigations show that learners' self-regulatory behaviour differs significantly depending on the external factors provided, supporting the assumption that external factors influence learners' self-regulatory behaviour, and may therefore influence learners' self-regulated learning in blended learning environments. Fifth, the same was found for internal factors. Learners' self-regulatory behaviour proved to be significantly different depending on learners' internal factors, supporting the assumption that internal factors influence learners' self-regulatory behaviour and may as a result also influence learners' self-regulated learning in blended learning environments. The findings of these two descriptive studies demonstrate the link between internal and external factors, giving credibility to the validity of the conceptual framework provided. Based on this framework, sixth, the investigation of the effect of cues for reflection led to the finding that when cues for reflection are designed in line with current literature, self-reflection is evoked, and self-regulated learning is affected. However, for this self-regulated learning to be goal-directed, learners need to be guided towards the strategies required to meet instructional expectations successfully. Seventh, and in addition, the investigation of cues for calibration showed that depending on learners' metacognitive abilities cues might evoke a decrease in learning confidence and that when cues for calibration are provided through functional and cognitive validity feedback, learners' calibration capabilities increase. Yet for this to result in goal-directed self-regulated learning, learners might need to be supported in applying the cognitive and metacognitive strategies required.

Taken together, the main findings provide a conceptual framework for the investigation of the support for self-regulated learning in blended learning environments. Such a framework may, in the future, also contribute to the systematic design of blended learning environments that support learners' self-regulated learning (e.g., Oliver & Trigwell, 2005; Reigeluth, 2013). Additionally, the empirical investigation and implementation of this framework demonstrate complex relationships between the support provided, learners' characteristics, and the influence of these two elements on learners' self-regulated learning, confirming that learners do not always respond to instructional interventions as intended by instructors (e.g., Collazo et al., 2015; Lust et al., 2011; Winne & Hadwin, 1998). With regard to the latter, the two empirical investigations show the difficult relationship between cue use and self-regulated learning: even when learners do use the cues provided, they might not do this in a goal-directed fashion with the aim of improving their performance. Although we were unable to report improved performance, the studies do illustrate the capability of the conceptual framework provided to generate fine-grained insights into (1) the interaction between internal and external factors influencing learners' self-regulated learning and (2) the relationship between learners' self-regulatory behaviour and their learning outcomes. In support of Gašević et al. (2015) this might allow us to shift towards gaining insights into how learning environments should be designed in order to support different types of learners in improving their self-regulated learning.

Methodological issues

The current research project in general, and the two empirical studies in particular (Chapters 6 and 7), are characterized by three important methodological choices. As a result of these choices, certain advantages and limitations should be kept in mind when interpreting the findings.

Explorative nature of the research project

The research project took a deliberately explorative approach, for multiple reasons. First, as mentioned above, very little existing research is available on the internal factors and external factors influencing learners' self-regulated learning in ecologically valid settings. The explorative approach resulted in the identification of the seven attributes and the establishment of methods and instruments for performing descriptive analyses. However, we were not able to investigate the attributes' relationships to each other, nor their relationship to learners' internal factors. The latter is of less importance as the main aim of the attributes is to characterize blended learning environments, rather than to evaluate them. Second, an explorative approach was taken as a consequence of the still relatively limited number of research studies that use data from log files to inform the design of blended learning environments, let alone event sequence analysis to analyse patterns or profiles in learners' self-regulatory behaviour and its relation to learners' self-regulated learning. Experimental self-regulated learning research has already generated explanatory findings about learners' self-regulatory behaviour (e.g., Azevedo et al., 2016; Molenaar & Chiu, 2015; Winne et al., 2017). Despite this contribution, these findings remain difficult to transfer to ecologically valid contexts (e.g., Azevedo, 2014). As a result of this, for example, event sequence analysis was administered in a manner that was as data-driven as possible, often leading to highly context-specific, difficult-to-interpret results. Thirdly, a specifically explorative approach was taken in the two empirical studies. Although the two empirical studies generated a number of theoretical and practical insights, it is more that they demonstrate the usefulness of the conceptual framework rather than provide in-depth information to research and practice on how to design or integrate cues for reflection and calibration. Overall, because of the explorative nature of the research project presented in this doctoral thesis, we were unable to hypothesize in detail about how specific constellations of internal and external factors influence learners' self-regulated learning. Subsequently, we could not hypothesize about what self-regulatory behaviour to look for.

Online versus blended learning environments

Although the research project as a whole explored both the online and classroom-based components of blended learning environments, the descriptive and experimental studies focused more exclusively on the online component. In addition, while the classroom-based component of the blended learning environment was described and kept stable throughout the descriptive and experimental studies, the interventions did focus mainly on the online component. This choice was made because of the focus on unobtrusive measurements, safeguarding the ecological validity of the investigations. As the literature refers to the combination of both online and classroom-based instruction as one of blended learning's inherent strengths (e.g., Bliuc et al., 2007; Garrison & Kanuka, 2004; Graham, 2006), we must acknowledge that this approach might have prevented us from exploring the full potential of blended learning environments.

Ecological validity and internal validity

In response to claims about the limited usefulness of educational research in practice (e.g., Sandoval & Bell, 2004), this research project aimed to keep the ecological validity of the insights gained as high as possible. Ecological validity was strived for by applying unobtrusive measurements and practical, feasible interventions in authentic courses. This is illustrated by the involvement of a mix of genuine educational contexts. The instructors and learners in these contexts often had little to no experience of research. The target groups were learners from a variety of backgrounds, ranging from second-chance learners to Bachelor students pursuing an academic degree. Because of this diversity of contexts, the results might have been influenced by variables we did not account for. We are also aware of the "credibility gap" (e.g., Levin & O'Donnell, 1999) between studies with high external and internal validities, which consists in the notion that ecologically valid results cannot be produced with what are considered to be scientific methods. We attempted to overcome this critique by applying study designs and methods that are consistent with experimental self-regulated learning research.

Further directions

While this research project has its merits, more research is needed to clarify a number of remaining issues. Future research might benefit from the lessons learned during this research project. In what follows, I discuss the challenges for future research.

Factors influencing learners' self-regulated learning

A first set of directions for further research relates to the factors influencing learners' self-regulated learning. In our investigation of these factors, we found that both internal and external factors affected learners' self-regulated learning. Although this finding is clear, some considerations deserve our attention.

<u>Internal factors</u>

With regard to learners' internal factors, we investigated a broad range of cognitive, motivational and metacognitive variables in terms of their influence on learners' self-regulated learning. The finding that some of the learner variables did not influence learners' self-regulatory behaviour might indicate either that (1) they do not affect learners' self-regulatory behaviour as measured in this way, or that (2) the cognitive, motivational and metacognitive variables used (and measured) are not stable, and fluctuate too much for a difference in learners' self-regulatory behaviour to be established. In recent years we have observed a shift in measuring self-regulated learning away from single-measurement self-report instruments, and the same shift might be desirable for some of the internal factors (i.e., motivation), as there are indications that these factors are not stable enough to be measured only once or twice through self-report measurements (e.g., Entwistle, 2014). A consideration for future research might therefore be to investigate the stability of learners' internal factors, as without insights into their nature no conclusive claims can be made about their effect on learners' self-regulatory behaviour and no alignment with support for self-regulated learning can be made (e.g., Dick, Carey, & Carey, 2005).

<u>External factors</u>

With regard to external factors, the research project presented one of the first frameworks to describe support for learners' self-regulated learning in blended learning environments. Such a framework enables description, and thus provides a reference frame to enable comparisons of learning environments. Obviously, a first consideration for future research is to investigate other frameworks which describe support for self-regulated learning, because without such insights it is impossible to propose decontextualized hypotheses and ensure environmental control during investigations (e.g., Boekaerts & Corno, 2005; Dabbagh & Kitsantas, 2004). A second consideration for further research is the investigation of the relationships among the seven attributes. This project considered only the main effects of the attributes, but it is certainly possible that interaction effects also play a role (e.g., Margaryan, Bianco, & Littlejohn, 2015). A further elaboration of the conceptual framework might render it more useful in directing future design efforts (e.g., Confrey, Maloney, & Gianopulos, 2017). A final consideration for future research is to investigate the optimal unit of analysis for describing support for learners' self-regulated learning in blended learning environments. The studies undertaken during this project take a whole-topic approach, describing blended learning environments using a relatively large grain size (28 days to 56 days). As pointed out by Winne and Baker (2013), for example, different cognitive and metacognitive processes might be affected at different instructional levels and thus require different units of analysis. In summary, (1) a broader range of frameworks for describing support of self-regulated learning, (2) more detailed insights into the interrelatedness of external factors, and (3) differential units of analysis would enable us to investigate self-regulated learning in a more focussed way by applying different descriptive frameworks to answer different questions.

Learners' self-regulatory behaviour and self-regulated learning

A second set of directions for further research relates to learners' self-regulatory behaviour and self-regulated learning. In this research project, learners' behavioural reactions to different internal and/or external factors is referred to as self-regulatory behaviour. Subsequently, learners' self-regulated learning is referred to as self-regulatory behaviour that is directed towards achieving goals imposed on the learners externally. To optimize and further align the measurement of self-regulated learning through learners' self-regulatory behaviour and learning outcomes, some methodological and practical directions should be considered.

Investigation of self-regulatory behaviour

Throughout the studies undertaken as part of this doctoral research, event sequence analysis was used to investigate learners' self-regulatory behaviour. This approach was chosen because of the inherent characteristics of self-regulated learning. Based on our experiences, several considerations should be raised. A first consideration for future research relates to the transferability to ecologically valid contexts of insights on self-regulatory behaviour indicators gathered in experimental contexts. The event sequence approach used in our studies relied on insights gleaned from experimental contexts (e.g., Azevedo, 2002; Winne & Hadwin, 1998) as a starting point for investigating learners' self-regulatory behaviour in ecologically valid settings. In line with for example Azevedo (2014), it became clear that transferring self-regulatory behaviour indicators obtained in experimental contexts to ecologically valid contexts is extremely difficult. Hence, in the studies conducted during this research project, behaviour was not recoded as theoretically meaningful self-regulation-related processes prior to any analysis. As a consequence, the results cannot always be directly related to self-regulation and self-regulated learning. Future research might therefore benefit from focusing on the identification of generalizable ontologies of self-regulatory behaviour indicators that have been tested and are thus transferable between experimental and ecologically valid contexts. Doing this could allow for the generation of more meaningful insights (e.g., Jeske et al., 2014).

A second consideration relates to the conceptualization of self-regulatory behaviour and its operationalization. Event sequence analysis requires a substantial number of parameter settings to be decided upon and choices made. Given the lack of guidelines on making such choices in the theory-driven self-regulated learning literature (e.g., Winne, 2014; Winne & Baker, 2013), we opted to take a data-driven approach, which is not uncommon in learning analytics research (e.g., Ali et al., 2014; Beheshitha et al., 2015; Gašević, Jovanović, Pardo, & Dawson, 2017; Gašević, Mirriahi, Dawson, & Joksimovic, 2017). It does have a downside, however, namely that it requires the use of arbitrary parameter settings. In the studies presented in this thesis, parameter settings were communicated consistently. Not all of the settings might be desirable from a conceptual (self-regulated learning) point of view. Questions might arise with regard to data transformations, assumptions about the distance between different events, and so on (e.g., Molenaar & Järvelä, 2014). Therefore, a consideration for future research might be the need to establish explicit links between conceptions of self-regulatory behaviour and the operationalization of analyses and thus provide a theory-driven justification for the operationalization of measurements. In turn, such a justification could be challenged using data-driven approaches, propelling the investigation of self-regulatory behaviour to a more complete understanding (Gašević et al., 2015). Third, as demonstrated in the study investigating our methodological framework for the event sequence analysis of learners' self-regulatory behaviour, self-regulated learning research takes a wide range of approaches to identifying patterns in learner' self-regulatory behaviour. The result is a lack of transparency and systematicity. Another consideration for further research therefore relates to combining efforts within the broader field of using log file data for exploring self-regulated learning. Future research could focus on bridging the gaps between measurement approaches to overcome transparency and systematicity issues in self-regulated learning research (e.g., Kuhn, 2012). With shared methodological frameworks, self-regulated learning research might evolve towards more transparent methods, comparative studies and empirical, ecologically valid applications (e.g., Poole et al., 2016; Stark & Vedres, 2012). Finally, the event sequence method used in this research project focusses only on the use of log files to investigate learners' self-regulated learning through the relation of behaviour and outcomes. Yet, the quest for insights into learners' behaviour (e.g., life choices, learning outcomes, even buying behaviour) is ongoing in many fields. Therefore, a final consideration relates to the multidisciplinary nature of investigations of behavioural data. Future research would do well to bring together insights and expertise from different fields of research (e.g., computer science, economics, mathematics) to overcome these challenges (e.g., Bannert et al., 2017).

Investigating learning outcomes

It cannot be denied that performance is one of the most important variables for self-regulated learning and education in general (e.g., Allan, 1996; Popham et al., 1969). However, in the studies undertaken in this doctoral research, the interventions were only found to have significant effects on motivational (i.e., goal orientation and academic self-concept) and metacognitive (i.e., metacognitive awareness and judgement of learning) variables. One consideration for future research on the effect of instructional interventions might be to strengthen interventions by, for example, equipping learners with the appropriate cognitive and metacognitive skills needed to also improve their performance (e.g., Alkhaldi et al., 2016). Another consideration for research might be to increase the sample sizes during similar empirical investigations, and so increase the statistical power of the statistical tests used (Mapstone, 1995). Because of the ecologically valid nature of the studies, we applied a commonly used opportunity sampling method (Bhattacherjee, 2012). When sampling only the available learners, low statistical power might occur, producing false negatives. Such false negatives often lead to the underappreciation of the effect of interventions and mean that potentially significant effects on the variables go unobserved.

Enhancing learners' goal-directed responsiveness to cues

The findings of this doctoral research project indicate that learners who differ in internal factors also react differently to cues. To gain more insight into learners' cue use, we should address some considerations related to their operationalization.

Learners' cue perception

Both of the intervention studies revealed that providing cues to support learners' self-regulated learning has no influence on learners' performance, but does affect other learning outcomes (i.e., goal orientation, learning confidence, and judgement of learning). In line with Pintrich (2002) and Veenman (1993), we hypothesized that this reaction to the cues may have occurred because learners perceived the cues differently than intended. Learners might have received insufficient directions on the cognitive and metacognitive strategies required to be able to see that the cues were not meant to be corrective and to respond to them in a goal-directed manner. This hypothesis is also supported by current research (e.g., Ardasheva et al., 2017; Dinsmore & Fryer, 2018): when learners receive functional validity feedback they decrease in learning confidence; however, when learners receive the same feedback accompanied by cognitive validity feedback, their learning confidence does not seem to be affected and instead an increase in their judgement of learning is observed. Similar findings were obtained in the first empirical study performed in this project, which focused on the use of cues for reflection (Chapter 6). Learners increased in performance avoidance when they received cues for reflection, rather than directing their own learning towards improved performance. As learners' cue perception is seen as one of the biggest drivers of cue use (e.g., Callender et al., 2016; Hacker et al., 2008), a potential avenue for future research could be to investigate the relation between cue design and learners' perceptions of these cues. Thus, research might identify cue features that prevent learners from taking advantage of the most basic types of feedback, for example outcome feedback (e.g., Bannister, 1986; Hoch & Loewenstein, 1989).

Learners' cue use

The first empirical study (Chapter 6) showed that all learners in the experimental condition used the reflection cues provided and that there were no differences in use between learners with different internal factors. However, enhanced performance was not found. In the second empirical study (Chapter 7), we attempted to overcome the problem of insufficient direction on the cognitive and metacognitive strategies needed by providing cognitive validity feedback. We observed an increase in learners' judgement of learning, but still no improvement in performance. In line with Alexander (2018) and Tricot and Sweller (2014), we hypothesized that for improved performance, learners need not only to be supported in identifying and recalling cognitive and metacognitive strategies, but also to be guided towards how to apply the cognitive and metacognitive strategies to their own contexts. Despite this insight, it is not clear what information would most help learners improve their performance (e.g, Narciss, 2017). Future research could attempt to identify the reason behind the lack of goal-directed use. Does the key to goal-directed learning lie in (1) the identification of cognitive and metacognitive strategies (e.g., Muis et al., 2016; Winne & Jamieson-Noel, 2002), (2) the availability of cognitive and metacognitive strategies (e.g., Pintrich, 2002; Veenman, 1993), (3) the inclination to use the proposed cognitive and metacognitive strategies (e.g., Hannafin, Land, & Oliver, 1999; Hoskins & Van Hooff, 2005), or (4) the combination of all of the above? Identifying the nature of goal-directed cue use would facilitate more effective designs (e.g., Collazo, Elen, & Clarebout, 2017).

Conclusions

In the three sections of this thesis, (1) instruments and methods were investigated and proposed to operationalize the conceptual framework, (2) the impact of both internal and external factors on learners' self-regulatory behaviour was investigated to test the conceptual framework, and (3) the conceptual framework was empirically investigated, establishing its potential for the future construction of guidelines on fostering support for learners' self-regulated learning in blended learning environments. The research project has contributed to four research fields, namely blended learning, self-regulated learning, learners' cue use and learning analytics. In what follows, I describe the contributions made to each of these fields and, finally, to educational practice.

From a blended learning research perspective, the research project adds to existing research by providing a conceptual framework for investigating support for learners' self-regulated learning in blended learning environments. Such a framework enriches the field with an approach incorporating (a) internal and external factors influencing learners' self-regulated learning, and (b) learners' self-regulated learning as observed through learners' self-regulatory behaviour and learning outcomes. This approach responds to the call for frameworks to support learners' self-regulated learning (e.g., Oliver & Trigwell, 2005; Reigeluth, 2013). By investigating the different elements of the conceptual framework, we provided an instrument and method for characterizing blended learning environments, which may in turn ensure instructional stability during empirical investigations. In addition, the research proposed a methodological framework for investigating learners' self-regulated learning. These elements enabled us to operationalize the conceptual model. Finally, through the empirical investigation of the conceptual framework, we demonstrated its potential in the construction of future guidelines on support for learners' self-regulated learning in blended learning environments. Most importantly for the field of blended learning research, the doctoral project highlights the considerations to be addressed when designing and implementing support for self-regulated learning in blended learning environments.

With regard to contributions to self-regulated learning research, the doctoral project extends the insights of Winne and Hadwin (1998) on the influence of internal and external factors on learners' self-regulated learning to the blended learning field. By investigating the factors that influence learners' self-regulated learning in such environments, the model extends the external validity of the assumption that both internal and external conditions influence learners' self-regulated learning. Secondly, in proposing a methodological framework for using event sequence analysis to investigate learners' self-regulatory behaviour, the research project attempts to foster dialogue on what is required to achieve this successfully. Additionally, in applying the methodological framework, the research project aims to bridge the gap between strictly experimental settings and ecologically valid settings when it comes to the investigation of learners' self-regulatory behaviour. Finally, the studies on the effect of cues for reflection and calibration adds to the micro-level application of the Winne and Hadwin (1998) theory. Both studies reveal the intertwined relationship between cognitive and task conditions that influence learners' self-regulated learning, raising questions about the nature of the underlying self-regulated learning processes.

From a cue use research perspective, the doctoral project reveals that learners with different capabilities react differently to the support provided (e.g., Collazo et al., 2015; Lust et al., 2011; Winne & Hadwin, 1998). This finding is at the core of the conceptual framework. The research project shows that different constellations of internal factors influence learners' behavioural reactions and learning outcomes under identical instructional conditions. The studies also show that instruction affects learners' cue perception and cue use, and that further investigations are needed to clarify the relationship between learners' internal factors and cues in order to maximize learners' success with them.

The project's contributions to the field of learning analytics lie in its further development of the use of event sequence analysis in exploring ecologically valid contexts from a data-driven perspective. The bottom-up/top-down interplay between the data-driven approach and existing self-regulated learning theory could prove valuable in bridging the gap between learning and analytics. Both of the empirical studies conducted during this project also incorporated cue-use analysis, self-regulatory behaviour analysis and the analysis of learning outcomes, and therefore add to the body of literature illustrating the potential of learning analytics for unobtrusive on-line measurements and adaptive support for learners.

Finally, with regard to educational practice, the research project once again highlights the roles played by instruction and the learner in successful self-regulated learning and learning outcomes. These roles appear to be particularly significant in blended learning environments. The doctoral project also questions the persistent belief in blended learning environments' effectiveness, especially the belief that blended learning technologies themselves always evoke the desired learner behaviour. In fact, as previous research has shown, blended learning environments actually pose particular challenges to learners. The results of this project highlight the need to consider internal and external factors to support learners' self-regulated learning in order to help them overcome these challenges. The research project also provides a conceptual framework for describing support for learners' self-regulated learning in blended learning environments. By using this framework to illustrate the effect of learners' internal factors on their self-regulatory behaviour in identical instructional conditions, the research reveals the relation between internal factors and learners' self-regulatory behaviour and confirms that learners react differently to the same instruction. In the two empirical studies, we explored this finding in more depth by investigating the effect of cues for reflection and calibration on learners' self-regulated learning. The results demonstrate the complex interplay between external factors (instructional conditions) and internal factors (i.e., cognitive, motivational and metacognitive factors), thus underscoring the importance of tailoring support to learners' characteristics.

The findings presented in this doctoral thesis are not intended to raise or answer questions about whether blended learning environments should be used for education and instruction, or whether they are better or worse than other instructional approaches. The real question, in fact, is how a blended learning environment – and indeed any learning environment – should be designed to help all learners succeed. My conclusion is that in order to overcome the challenges that today's blended learning environments pose to learners, we must further our understanding of how design attributes impact upon self-regulated learning. This doctoral research represents a step forward in this process and a step towards informed design that helps learners take control and regulate their own learning.

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APPENDICES

Chapter 1 – Appendix 1

Summary of publications reported on, including identified attributes and learner variables.
(**IX** = Independent variables, **DX** = dependent variables, **Att.** = attributes and **LX** = Learning variables)

Reference	Aim	Variables & Methodology	Results	Attributes & Learner variables
Ai-Lim Lee et al. (2010)	• To determine whether motivation is positively related to learning outcomes. • To determine whether spatial ability moderates the influence of motivation on learning outcomes.	**IX:** virtual-reality features, interaction experience, usability, learning experience, psychological factors and learner characteristics. **DX:** learning outcomes. **N=**232. **Method:** quant. quasi-experiment + survey.	• Presence, motivation, cognitive benefits, control and active learning, reflective thinking and usability positively influence learning outcomes (performance achievement, perceived learning effectiveness and satisfaction).	**Att.:** authenticity, personalization, learner control, reflection and interaction. **LX:** cognition and motivation.
Alant and Dada (2005)	• To examine issues of syndicate learning in a web-based environment.	**IX:** facilitating discussion, onsite visit, study material, technology, online discussion, feedback and assignments. **DX:** overall evaluation of the course. **N=**19. **Method**: qual. case study.	• The authentic web-based medium presented seemed to be an effective tool for academic discussion and problem solving. Nonetheless, learners need to be supported in using the web-based medium to enhance academic discourse.	**Att.:** authenticity, personalization, learner control, scaffolding, reflection and interaction. **LX:** motivation.
Aleven and Koedinger (2002)	• To investigate whether self-explanation can be scaffolded effectively in a classroom environment using a Cognitive Tutor.	**IX:** procedural knowledge and declarative knowledge. **DX:** score answer items. **N=**41. **Method**: quant. experiment + pre and post-test.	• Scaffolding with a cognitive Tutor (guided) is more effective when learners explain their steps by providing references to problem-solving principles. • Tutor feedback helped learners improve their explanations.	**Att.:** scaffolding, reflection and interaction. **LX:** cognition and metacognition.
Anseel et al. (2009)	• To determine whether performance will increase more in a group who receive reflection instructions combined with feedback. • To determine whether participants with a high need for cognition will engage more in reflection after feedback during reflection than their counterparts.	**IX:** age, education, tenure, feedback, instructions completed, learning goal orientation, need for cognition, involvement, word count and reflection. **DX:** task performance. <u>Study 1</u>: **N=**640. **Method**: quant. experiment + pre and post-test. <u>Study 2</u>: **N=**488. **Method**: quant. experiment + survey.	• Reflection (written) combined with (external) feedback improved task performance more than when learners received only a feedback report. Reflection only enhanced performance in combination with external feedback. • The reflection strategy proposed may be less effective for individuals low in need for cognition, low in learning goal orientation and low in personal importance as they will be less inclined to write down their thoughts.	**Att.:** calibration, reflection and interaction. **LX:** cognition and metacognition.
Artino (2009a)	• To examine personal factors relating to academic success in an online course.	**IX:** learning strategies, motivational beliefs and achievement emotions. **DX:** overall satisfaction and continuing motivation. **N=**481. **Method**: quant. quasi-experiment + survey.	• Task value beliefs positively predict elaboration and metacognition and satisfaction and continuing motivation. • In autonomous contexts where learners do not interact with an instructor or other learners, adaptive motivational beliefs may be vital for initiating cognitive and metacognitive engagement.	**Att.:** learner control. **LX:** metacognition and motivation.

Artino (2009b)	• To explore the extent to which learners' thoughts, feelings, and actions are associated with the nature of an online course and how that course relates to them personally.	**IX:** motivational beliefs, achievement emotions, self-regulated learning behaviours , prior knowledge of course material. **DX:** academic outcomes. **N=**481. **Method**: quant. quasi-experiment + survey.	• Learners' motivational beliefs and self-regulatory behaviours are related to the nature of the online course and how courses relates to them personally.	**Att.:** authenticity, learner control and interaction. **LX:** cognition, metacognition and motivation.
Artino and Jones (2012)	• To explore the relations between several discrete achievement-related emotions (boredom, frustration, and enjoyment) and self- regulated learning behaviours (elaboration and metacognition) in an online course.	**IX:** cognitive appraisals and achievement emotions. **DX:** self-regulated learning behaviours. **N=**302. **Method**: quant. quasi-experiment + survey.	• Negative achievement emotions are associated with lower levels of self-regulation, whereas enjoyment is associated with higher levels of elaboration and metacognition. • Learning will be improved when negative emotions are minimized and positive emotions are maximized. • The learning task and the technology should be considered in the design of learning environments.	**Att.:** scaffolding and interaction. **LX:** cognition and metacognition.
Artino and Stephens (2009)	• To explore potential developmental differences in self-regulated learning. In particular. • To examine whether there are motivational and self-regulatory differences between undergraduate and graduate learners enrolled in online courses.	**IX:** motivational beliefs, processing strategies and motivational engagement. **DX:** experience and courses completed. **N=**194. **Method**: quant. survey.	• Learners come to online courses with different levels of online experience and exhibit different levels of motivation and self-regulation while learning online. • Instructors have to consider their online audience, adjusting the type and amount of structure, support, and scaffolding they provide during online instruction (provide explicit instructional support and structure, develop learners' self-efficacy and scaffold online discussions).	**Att.:** scaffolding and personalization. **LX:** metacognition and motivation.
Barzilai and Eshet-Alkalai (2015)	• To determine whether epistemic perspectives and viewpoint comprehension predict information source integration. • To explore how epistemic perspectives moderate the impact of conflicts on viewpoint comprehension.	**IX:** viewpoint comprehension, integration of sources, epistemic perspectives. **DX:** ability. **N=**170. **Method:** experiment + survey + log file analysis.	• Learners' epistemic perspectives can be one of the factors that predict comprehension of source viewpoints. • The strength in which an epistemic perspective is endorsed is considered as an indicator of learners' tendency to adopt that perspective in a particular context.	**Att.:** authenticity and scaffolding. **LX:** cognition.
Brusso and Orvis (2013)	• To investigate whether unattainable goal, and subsequently a large goal-performance discrepancy, may negative impact subsequent videogames. • To provide a remedy for mitigating this negative impact on training effectiveness.	**IX:** goal-setting advice and self-regulation. **DX:** subsequent performance, initial performance goal and initial goal-performance discrepancy. **N=**429. **Method:** quant. experiment + survey.	• Unattainable goal-setting early in videogame-based training has a negative impact on subsequent training performance, and that trainees' self-regulation coupled with goal commitment may serve as mechanisms underlying this relationship. • Instructors should be wary of learners setting goals without advice.	**Att.:** learner control, calibration and interaction. **LX:** cognition and metacognition.
Casillas and Gremeaux (2012)	• To explore how medical learners assessed a website dedicated to cardiovascular rehabilitation, and collecting their suggestions in order to	**IX:** medical information and design. **DX:** quality of the website and knowledge improvement. **N=**18. **Method:** quant. experiment + pre- and post-test + interviews.	• Learners do not seem to see the websites as a properly adapted tool to prepare them. This type of learning material appears to be significantly useful for short-term knowledge improvement.	**Attributes:** interaction and scaffolding**. LX:** cognition.

	meet their expectations and the goals of second cycle medical studies.		• The immediate impact of this type of multimedia support tool on improving learners' knowledge seems nevertheless relevant and interesting.	
Chen (2014)	• To develop a conceptual model to investigate the determinants of college learners' proactive stickiness with a web-based English learning (WBEL) environment.	**IX:** proactive stickiness, learning gratifications, computer self-efficacy, learning outcome expectations, social environmental, interaction, learning climate, system characteristics and digital material features. **DX:** learning outcomes. **N=**306. **Method**: quant. survey.	• Computer self-efficacy, system characteristics, digital material features, interaction, learning outcome expectations and learning climate are critical affecting factors in determining learner learning gratifications with web-based English learning.	**Att.:** authenticity, personalization, learner control and interaction. **LX:** cognition, metacognition and motivation.
Chia-Wen et al. (2011)	• To explore the effect of a redesigned course, integrating web-enabled self-regulated learning (SRL) with variations in online class frequency on enhancing learners' skills of deploying database management system (DBMS).	**IX:** online class frequency and web-enabled self-regulated learning. **DX:** computing skills. **N=**112. **Method:** quant. experiment + test + survey.	• Self-regulatory interventions helped learners become more responsible for their learning and contribute to further success. • Formal education should also develop learners' informal learning ability for a lifelong learning process. It is suggested that instructors ideally support self-regulatory interventions.	**Att.:** interaction. **LX:** metacognition and motivation.
Cholowski and Chan (2004)	• To explore learners' clinical problem solving based on a model consisting of their motivational orientation, prior knowledge, diagnostic reasoning and diagnostic solutions.	**IX:** motivational orientation, prior knowledge, diagnostic reasoning and diagnostic solutions. **DX:** clinical problem solving. **N=**135. **Method**: quant. survey + test.	• Instructors need to address each contributing component of the problem-solving. Including attention for underlying motivational orientation in undertaking the task and on the way new information is linked with prior knowledge.	**Attributes:** scaffolding**. LX:** cognition, metacognition and motivation.
Clark et al. (2015)	• To identify the processes that key stakeholders perceive to be most important in facilitating a positive impact of continuing professional education on practice.	**IX:** organizational structure, partnership working, a supportive learning environment and changing practice. **DX:** continuing professional education. **N=**31. **Method**: qual. interviews.	• A positive learning culture, effective partnership between learners with understanding of each other's perspectives, aspirations and constraints and a supportive learning environment in both the practice setting and education environment are central to establishing a culture and context that positive influences learning.	**Att.:** interaction. **LX:** cognition.
Corbalan et al. (2008)	• To investigate the influence of difficulty and support of the learning tasks on the learners competence scores. • To investigate whether perceived task load would make learning more effective and efficient. • To assess whether shared control has positive effects on learner motivation.	**IX:** task difficulty, competence, task load, training time and germane load. **DX:** learning outcomes, learning efficiency and task involvement. **N=**55. **Method**: quant. experiment + log-file analysis + survey.	• Learning outcomes of learners who received adaptive training were higher, and they experienced a lower task load during practice than learners who received non-adaptive training. • Learners in the shared-control conditions showed higher task involvement. Choice provided positively influenced the amount of effort invested in learning, combined with higher learning outcomes.	**Att.:** authenticity, personalization, learner control and interaction. **LX:** cognition, metacognition and motivation.
Cox et al. (2006)	• To determine whether web-based and faculty-led learners demonstrated improved knowledge and attitudes about caring for the underserved.	**IX:** faculty-led and web-based course. **DX:** knowledge, attitudes, and skills. **N=**100. **Method**: quant. experiment + pre- and post-test.	• Compared to learners in the established curriculum, both web-based and faculty-led learners demonstrated improved significant knowledge and attitudes. Results also indicate that Faculty-led and web-based curricula can equally improve learner knowledge, attitudes, and skills.	**Att.:** interaction. **LX:** cognition and motivation.

Cramer et al. (2014)	• To determine whether certified education changes learners' empowerment, job satisfaction, and clinical competency over time.	**IX:** empowerment, job satisfaction, intent to turnover, clinical competency, technological skills. **DX:** course satisfaction. **N=**84. **Method**: quant. survey	• Certification significantly improved empowerment, satisfaction, and competence (can reduce persistently high learner turnover rates). • Changes in empowerment and competency did not affect changes in job satisfaction.	**Att.:** interaction. **LX:** cognition and motivation.
Dai and Huang (2015)	• To analyse the effectiveness of three remedial instruction models, including e-learning, blended-learning and traditional instruction.	**IX:** active learning strategy, mathematics learning value, factors of self-awareness, learning method, learning plan and achievement goal. **DX:** learning motivation. **N=**94. **Method**: quant. survey.	• Active learning strategy, mathematics learning value, factors of self-awareness, learning method learning plan and achievement goal influence learning motivation.	**Attributes:** interaction. **LX:** metacognition and motivation.
Davis and Yi (2012)	• To leverage the hierarchical view of traits, to develop a theory-grounded, integrative model of broad personality and IT-specific traits.	**IX:** computer anxiety and computer self-efficacy. **DX:** web utilization. **N=**230. **Method**: quant. survey.	• Links between personal innovativeness and openness, social cues exuding adventurous, creative, and expressive behaviour will be more effective at retention than cues tailored toward reducing anxiety or conscientiousness.	**Att.:** Interaction. **LX:** motivation.
Demetriadis et al. (2008)	• To investigate whether learners' learning and problem-solving performance in ill-structured domains can be improved, whether elaborative question prompts are used to activate learners' context-generating cognitive processes, during case study.	**IX:** scaffolding. **DX:** portfolio score. **N=**32. **Method**: quant. experiment + pre-test + survey.	• Scaffolding treatment had a significant main effect on learners' performance (epistemological beliefs profile and scaffolding treatment interact, learners with complex epistemological beliefs learners benefiting most). • It is possible to improve individual learning in a technology environment, by implementing questioning strategies.	**Att.:** Authenticity and interaction. **LX:** cognition, metacognition and motivation.
Donnelly (2010)	• To investigate, in a tutorial setting, the factors that govern the success of interaction in blended problem- based learning.	**IX:** use of face-to-face PBL tutorials, online journal entries, use of video conferencing, use of asynchronous discussions and use of synchronous chat and international guest collaboration. **DX:** interactions as transactions and interaction in blended problem-based learning. **N=**17. **Method**: qual. observation + quant. log file analysis + interview + self-reflective papers.	• Conditions for the effectiveness of blended learning: the selection of authentic tasks within the problem which demand a division of labour between the face-to-face and the online environments, the maintenance of common goals and motivation, the mutual expectations of learners and tutors, the awareness of the individual role and group leadership, and changes in these and the availability of appropriate communication tools.	**Att.:** authenticity and interaction. **LX:** cognition, metacognition and motivation.
Doo (2006)	• To identify facilitating factors and constraints of skills practice in online learning environments.	**IX:** social self-efficacy, prior knowledge, interview experiences, enjoyment, usefulness, perception about learning, cognitive retention of learning content, verbal interview skills and behaviour based interview skills. **DX:** number of skills practice sessions. **N=**23. **Method**: qual. case study + interviews.	• Instructors should facilitate learners' skills practice, by: designing an appealing enough course to make learners involved. If learners already have substantial prior knowledge or cognitive knowledge of the interpersonal skills set presented emphasize that cognitive understanding not guarantees successful execution, ensure appropriate learning environments for practicing and use mental practice if learners feel the discrepancies between online learning and offline practice.	**Att.:** interaction. **LX:** cognition.

DuBois et al. (2008)	• To describe the content, format, and outcomes of one of the National Institutes of Health (NIH) courses and share key lessons learned about formats and assessment methods.	**IX:** content and format. **DX:** knowledge of research ethics, ethical problem-solving skills, and levels of confidence in addressing ethical issues in mental health research. **N=**40. **Method:** quant. experiment + pre- and post-test + survey.	• Learners in the distance course were less satisfied and dropped out more easily. This was attributable to technical difficulties, the lack of face-to-face contact and the fact that the course did not offer the flexibility that many distance-learning courses offer. Although they had the opportunity to interact during case discussions, few participants did this. It is concluded that without interactivity, case discussion cannot achieve its aims.	**Att.:** reflection and interaction. **LX:** motivation.
Gerhard, Moore, and Hobbs (2004)	• To provide a theoretical underpinning for understanding the relevance of learner embodiments and co-presence within three-dimensional collaborative computer interfaces.	**IX:** (no-)co-presence, composition and interaction model used. **DX:** experience of immersion, involvement and awareness. **N=**20. **Method:** quant. experiment + pre- and post-test + survey.	• Co-presence simulated by real-life agents can complement avatar technology and potentially achieve permanent presence of all learners by using a hybrid agent model.	**Att.:** authenticity and interaction. **LX:** metacognition and motivation.
Giesbers, Rienties, Tempelaar, and Gijselaers (2013)	• To investigate the relationship between available tools used, learner motivation, participation, and performance on a final exam in an online course.	**IX:** motivation. **DX:** final exam scores. **N=**110. **Method**: quant. experiment + survey.	• Higher levels of autonomous motivation did not have any significant higher participation rate or use of richer communication tools in web- or video-conferences. • Significant effect was found for higher participation rates in the web-and video-conferences with the use of richer tools. Learners who took part in more interactive web-and video-conferences had higher scores on the final exam.	**Att.:** authenticity, personalization and scaffolding. **LX:** cognition and motivation.
Gomez et al. (2010)	• To describes the implementation and evaluation results of a classroom application of a team-based learning process, which was modified to include computer mediation.	**IX:** motivation, perceptions of team members and perceiving of team interactions. **DX:** team interactions, perceived learning, enjoyment, learning outcomes. **N=**73. **Method**: quant. survey.	• Motivation influences the relationship between team interactions and perceived learning. • Enjoyment is affected by motivation and perceptions of team members' contributions, with the implication that learners who perceive that the team interactions are adding value to their education will better enjoy learning and will experience higher-level learning outcomes.	**Att.:** scaffolding and interaction. **LX:** cognition and motivation.
Govaere et al. (2012)	• To determine whether guided use of multimedia learning materials will result in significantly lower levels of cognitive load and higher levels of self-efficacy.	**IX:** conventional classroom, individual DVD use, guided individual DVD use, guided classroom DVD use, cognitive load and self-efficacy. **DX:** knowledge and skills acquisition. **N=**178. **Method:** quant. experiment + pre- and post-test + survey.	• Significant superior impact of studying with the DVD on skills acquisition and higher levels of self-efficacy. In addition, experimental conditions that build on guided usage of the multimedia application, result in superior performance.	**Att.:** authenticity and interaction. **LX:** cognition and metacognition.
Gulikers et al. (2005)	• To explore the effects of an authentic electronic learning environment on learner performance and experiences.	**IX:** perceived authenticity, experienced motivation, perceived as innovativeness, extend of confusion, experienced support and extend of explorative behaviour. **DX:** performance on the final report. **N=**34. **Method:** quant. experiment + test + survey.	• No evidence was found for the expected superiority of the authentic learning environment. The most likely explanation for this finding is that the learning task was identical for both conditions. This is a strong argument for the idea that an authentic task and an authentic context are two different things.	**Att.:** authenticity and interaction. **LX:** cognition and motivation.

Ho and Dzeng (2010)	• To examine the effectiveness of 'safety education to prevent falls' by different learning modes used to assess safety behaviour and learning effectiveness during the education training period.	**IX:** platform function and contents design. **DX:** learning effectiveness. **N=**83. **Method**: qual. interview + test + survey + observation + document analysis.	• An e-learning environment is effective if it motivates the learner, provides the content needed for learning, and creates a learning context. • The smoothness of network, easy operation of platform, affinity of user interface and the test assessment of learning ability are the impressions of learner. Learning satisfaction is essential for learning effectiveness. • Content must include multimedia animation, actual case introduction, self-achievement simulation, and suitability of teaching materials unit, which will influence the learning satisfaction of learning effectiveness and raise performance.	**Att.:** interaction. **LX:** cognition and motivation.
Ho and Swan (2007)	• To examine the actual participation and dynamics that occur in online discussions and their relationship to learner learning outcomes.	**IX:** quantity, quality, relevance, and manner. **DX:** learner participation. **N=**15. **Method:** quant. quasi-experiment + log file analysis.	• Strong correlation was found between learners' Gricean ratings and their final course grades, and between learners' Manner ratings and their conference grades. • An important relationship between the Gricean elements and learner performance was found.	**Att.:** reflection. **LX:** motivation.
Hodges and Murphy (2009)	• To explore the influence of the four traditionally hypothesized sources of self- efficacy on learners' self-efficacy beliefs regarding learning mathematics in an asynchronous environment.	**IX:** mastery experiences, vicarious experience, social persuasion, and physiological / affective states. **DX**: self-efficacy beliefs. **N=**99. **Method**: quant. survey.	• Courses offered using an emporium model should be designed to include elements which provide positive vicarious experiences and support positive affective and physiological beliefs toward the courses.	**Attributes:** calibration**. LX:** metacognition.
Hughes et al. (2013)	• To examine the cognitive and motivational antecedents and outcomes of learner-controlled practice difficulty in relation to learning a complex task.	**IX:** self-efficacy, metacognition, self-evaluation, general mental ability, videogame experience, task knowledge, pre-training skill, practice performance, post-training performance, learner-controlled practice difficulty and adaptive transfer performance. **DX:** task knowledge, performance, and adaptability. **N=**118. **Method:** quant. experiment + survey + log-file analysis.	• Strong direct effects of learner-controlled practice difficulty on both task knowledge and post-training performance. Moreover, practice difficulty was positively related to adaptive performance via its relationships with both task knowledge and post-training performance. • Motivational mechanisms of pre-training self-efficacy and positive error framing also exhibited significant positive relationships with learner-controlled practice difficulty.	**Att.:** learner control and interaction. **LX:** cognition, metacognition and motivation.
Hung and Hyun (2010)	• To examine how East Asian international learners who were enrolled in the 'curriculum and instruction' course reflect upon their learning experiences.	**IX:** learning attitudes, curricular and pedagogic decisions, individual circumstances, epistemological transition and accumulated schemata, situation after arrival, factors affecting learning attitudes and participation, and epistemological transition. **DX:** learning experience. **N=**12. **Method**: qual. interviews.	• Learners with low prior knowledge require an inclusive curriculum and learning context provided by the instructors to sustain the learning experience. • Metacognitive reasoning based on learners' initial circumstance and academic advising arrangement with an advisor played a critical role, starting with the earliest stage of first arrival.	**Att.:** Personalization and interaction. **LX:** metacognition and motivation.

Hung et al. (2011)	• To investigate the role of the multimedia disclosure method for informed consent and its contribution to higher learning motivation and learning interest, to better remembering, comprehension and satisfaction than the conventional method.	**IX:** disclosure method and psychosocial learning processes. **DX:** learning outcomes. **N=**112. **Method:** quant. survey.	• Different disclosure methods lead to significantly different learning motivation and learning interest and outcomes. • During the psychological learning processes, learning motivation and learning interest were positively correlated with learning outcomes (remembering, comprehension, and satisfaction), and correlations with comprehension and satisfaction were significant.	**Att.:** interaction. **LX:** cognition, metacognition and motivation.
Ibabe and Jauregizar (2010)	• To assess the degree to which learners take advantage of a self-assessment tool. • To explore the relationship between different metacognitive variables and academic performance and/or making use of activities oriented to learning of the relevant material.	**IX:** availability of a self-assessment tool, interactive self-assessment exercises and different metacognitive variables. **DX:** taking advantage, better grades, academic performance. **N=**116. **Method:** quant. experiment + test **+ s**urvey.	• Better academic performance for learners that use interactive self-assessment were measured. • It seems that even learners with low motivation levels made use of these tools. Finally, the need to include self-assessment in the curriculum, with a view to improving learners' metacognitive knowledge.	**Att.:** interaction. **LX:** cognition and metacognition.
Ioannou, Brown, and Artino (2015)	• To evaluate differences in learners' discourse and actions when they used a wiki with discussion vs. a forum with attached MSWord documents for asynchronous collaboration.	**IX:** collaboration, complexity, monitoring & planning, other content, expansion, deletion, content-editing, formatting & spelling. **DX:** wiki and forum use. **N=**34. **Method**: qual. case study.	• Significant differences can be found in the use of a wiki with discussion vs. a forum. This illustrates the expanding nature of a forum and the condensing nature of a wiki. • In a wiki, groups tend to be collaborative, whereas in a threaded discussion, groups tend to be more cooperative.	**Att.:** scaffolding and interaction. **LX:** cognition and metacognition.
Jonas and Burns (2010)	• To undertake a module evaluation which formed part of the universities' teaching and learning strategy.	**IX:** limited IT skills, feeling isolated, lack of perception regarding e-learning, motivation and development of independent learning skills, reduction in travel costs and positive academic support for learning. **DX**: learning outcomes. **N=**13. **Method**: quant. survey.	• Six factors that restricted the achievement of learning outcomes: use of IT skills, feeling isolated, lack of perception regarding e-learning, motivation and development of independent learning skills, reduction in travel costs and positive academic support for learning).	**Att.:** scaffolding and interaction. **LX:** cognition, metacognition and motivation.
Kim and Ryu (2013)	• To assess a web-based formative peer assessment system emphasizing learners' metacognitive awareness for their performance in ill-structured tasks.	**IX:** attitudes toward peer assessment, motivation, identification of the context, clarity of the id process, completeness of the id, justification, critical thinking and creativity. **DX:** metacognitive awareness and performance. **N=**122. **Method:** quant. experiment + survey.	• Sequential metacognitive learning processes help learners monitor their learning and adapt strategies that are not working effectively. • Peer interaction and back-feedback gave learners more control over their learning.	**Att.:** learner control, scaffolding and reflection. **LX:** metacognition.
Kobak, Craske, Rose, and Wolitsky-Taylor (2013)	• To develop a web-based Cognitive Behaviour Therapy training course, to increase accessibility to the training.	**IX:** guidance and feedback. **DX:** effectiveness and user satisfaction. **N=**36. **Method**: quant. experiment + pre- and post-test + survey.	• Feasibility in the form of learner satisfaction is an important factor when developing training. • Learners had high levels of satisfaction with both the clinical content and the technical features of the training. Being able to obtain training online greatly increases accessibility and dissemination. The fact that the training was done by an experienced, but newly trained,	**Att.:** reflection and interaction. **LX:** motivation.

			psychologist gives promise for increased dissemination of the applied training as well.	
Koh and Chai (2014)	• To employ cluster analysis to categorize teachers into groups based on their self-reported technological pedagogical and content knowledge before they were engaged in lesson design activities as part of their professional development.	**IX:** pre-technological knowledge, pre-pedagogical knowledge, pre-content knowledge, pre-pedagogical content knowledge, pre-technological content knowledge, pre-technological pedagogical knowledge and pre-technological pedagogical content knowledge. **DX:** effectiveness and user satisfaction. **N=**266. **Method:** quant. experiment + survey.	• For in-service teachers who were already familiar with curriculum, the transformation of content with technology-based approaches needs to be emphasized in design activities. • Both pre-service and in-service teachers, regardless of their cluster membership, it seemed clear that the design process was inherently complex and could be better scaffolded with distributed intelligence.	**Att.:** authenticity, scaffolding and interaction. **LX:** cognition and motivation.
Koke and Norvele (2008)	• To determine whether the encouragement of learners to use learning strategies can be a design-purpose of study materials. • To determine whether a component that explicitly teaches learning strategies is a key element of the study process.	**IX:** metacognitive strategies, all strategies, except for metacognitive, inferencing, using of context for comprehension transfer, practicing different contexts, all cognitive strategies, communicative and social strategies. **DX:** strategy awareness. **N=**222. **Method**: quant. quasi-experiment + survey + qual. interview.	• Direct teaching components for learning strategies in a distance learning course improve the learners' strategy awareness. They may contribute to the empowerment of learners as autonomous learners, by reducing their anxiety, by fostering reflection, metacognition and by providing a sense of achievement. • Comprehension of learning strategies in distance learning form can be fostered by the implementation of a direct learning strategy. While providing opportunities for practicing these strategies in authentic learning situations and encouraging awareness of the metacognitive strategies during the study process can be directed towards the sustainable use of the acquired strategies.	**Att.:** authenticity, personalization and calibration. **LX:** cognition and metacognition.
Kovačević et al. (2013)	• To provide plausible information about the effect of educational game design on improving general knowledge and results.	**IX:** exam grades, learned by designing computer games, traditional learning circumstances. **DX:** learning outcomes and self-reported experience. **N=**125. **Method:** quant. experiment + survey + qual. interview.	• Learners were interested in alternative ways of learning because it enabled them to learn in a different way, to show their creative skills and not the last, the concept of fun proved to be exceptionally important. • Content of learning (programming game) as well as context (game design) could be defined in terms of relevance and curiosity evoking.	**Att.:** authenticity, personalization, calibration and interaction. **LX:** cognition.
Kuo et al. (2012)	• To propose a hybrid learning mechanism for improving learners' web-based problem-solving abilities via the combination of the cognitive apprenticeship model and the collaborative learning strategy.	**IX:** interest in learning social studies, immersion in learning social studies, capability of learning social studies, usefulness of learning social studies and attitude toward problem-solving. **DX:** problem-solving ability and learning attitude. **N=**58. **Method:** quant. experiment + survey.	• The method integrating cognitive apprenticeship and collaborative learning mechanisms in an online inquiry-based learning environment has great potential to promote middle- and low-achievement learners' problem-solving ability and learning attitudes. • Hybrid approaches could ease their learning anxiety via the inspection of high- achievement peers, while think aloud is essential for these learners when conducting the cognitive apprenticeship process.	**Att.:** authenticity, scaffolding and interaction. **LX:** cognition and metacognition.

Lafuente Martínez, Álvarez Valdivia, and Remesal Ortiz (2015)	• To explore the role of e-assessment in making the learning process more visible to the instructor, while revealing its impact on the adjustment of ensuing feedback.	**IX:** e-assessment. **DX:** learning process visibility. **N=**73. **Method:** qual. document analysis + interview.	• Promote peer-to-peer communication which can be recorded by a wide range of technological tools throughout the activity. Use asynchronous text-based communication as it is still a highly effective device to enable high learning transparency. • Consider formative assessment activities as a means for gathering information to improve feedback, and not only to control and grade learners. Engage learners in dialogic-guidance feedback formats. Learners expect support, they must receive it. In case of overburden, focus on the monitoring of collaborative activities as they provide an open window to the learners' learning process.	**Att.:** authenticity, personalization, learner control, reflection and interaction. **LX:** metacognition and motivation.
Law and Sun (2012)	• To develop a four-dimension evaluation framework and apply it to an empirical study with digital educational games in geography.	**IX:** learning experience, gaming experiences, usability. **DX:** learning efficiency. **N=**16. **Method:** quant. experiment + pre- and post-test.	• Activity theory can be used to describe user experiences in digital educational games. Four dimensions were identified: gaming experience, learning experience, adaptively and usability.	**Att.:** Learner control and interaction. **LX:** cognition.
Leen and Lang (2013)	• To explore motives of young and old learners to participate in two ICT-course settings: e-learning and face-to-face courses. • To exploring individual differences in learning motivation between young and older learners in the field of computer based learning.	**IX:** belonging, instrumentality, personal growth, and competition. **DX:** learning motivation and personality. **N=**211. **Method:** quant. survey.	• Older learners expressed stronger motives of belonging and personal growth, and thus expressed a stronger interest in self-determined and intrinsic learning and social motives. Young learners, in contrast, strongly endorsed competitive-related motives of learning. • Older learners showed higher instrumentality when the difference between chronological age and subjective age is big.	**Attributes:** interaction**. LX:** motivation.
Liaw et al. (2010)	• To explore positive factors for the acceptance of m-learning systems.	**IX:** learners' satisfaction, learners' autonomy, system functions, interaction and communication activities. **DX:** acceptance toward mobile learning. **N=**152. **Method:** quant. quasi-experiment + survey.	• Enhancing learners' satisfaction, encouraging learners' autonomy, empowering system functions, and enriching interaction and communication activities have a significant positive influence on the acceptance of m-learning systems. • A classification for m-learning affordances is presented: educational content and knowledge delivery application, adaptive learning application, interactive application, collaborative application and individual application.	**Att.:** personalization, calibration, scaffolding and interaction. **LX:** motivation.
Lin (2011)	• To explore the determinants of the e-learning continuance intention of learners with different levels of e-learning experience. • To examine the moderating effects of e-learning experience on the relationships among the determinants.	**IX:** frequency of negative critical incidents, perceived ease of use and attitude. **DX:** continuance intention. **N=**83. **Method**: quant. survey.	• Five exogenous constructs have a direct or indirect effect on the learners' continuance decision, namely negative critical incidents, perceived ease of use, perceived usefulness, quality attributes cumulative satisfaction, and attitude. • Negative critical incidents and attitude are the key drivers of continuance intention in the e-learning environment,	**Att.:** calibration and interaction. **LX:** metacognition and motivation.

			irrespective of the user's prior level of e-learning experience.	
Lin et al. (2012)	• To identify characteristics of a website encourage enjoyable online learning. • To identify what design guidelines lead to websites that support enjoyable online learning experiences.	**IX:** engagement, affect and fulfilment. **DX:** web enjoyment experiences. **N**=615. **Method**: quant. survey.	• Identification of characteristics: novelty, harmonization, no time constraint, proper facilitations and associations. • Identification of guidelines: designing multisensory learning experiences, creating a storyline, mood building, fun in learning, and establishing social interaction.	**Att.:** learner control and interaction. **LX:** motivation.
Lin, Zimmer, and Lee (2013)	• To identify perspectives of teachers and learners of podcasting acceptance on campus.	**IX:** individual differences, facilitating conditions and social influences. **DX:** behavioural intent. **N=**99. **Method**: quant. survey.	• There is a positive relationship between performance expectancy and behavioural intention and between effort expectancy and behavioural intention. • Individual difference factors for the learner showed significant paths to effort expectancy for only personal innovativeness and self-efficacy. Finally the relationship between personal innovativeness and performance expectancy was significant.	**Att.:** interaction. **LX:** cognition and metacognition.
Ma (2012)	• To identify the advantages and disadvantages of computer-aided online distance learning for college teachers.	**IX:** conception on learning (metacognition and cognitive strategies). **DX:** learning outcomes and academic performance. **N=**118. **Method**: qual. case study + interview.	• Advantages of online distance learning: resourcefulness and adaptability or flexibility were identified. • Disadvantages of online distance learning: limited interaction (lack of interaction causes problems), little instructional variation, the metacognitive and cognitive strategies needed, self-regulation needed and IT-skills needed were identified.	**Att.:** personalization and interaction. **LX:** cognition and metacognition.
Makoe, Richardson, and Price (2008)	• To investigate whether learners' approaches to learning via online peer assessment will show a stronger relationship to learning outcomes than their respective conceptions of learning.	**IX:** self-conceptions of learning. **DX:** learning outcomes and approach to learning. **N=**163. **Method**: quant. experiment + qual. interview.	• At the main level there was a significant association between conceptions and approaches. • Learners embarking on distance education seem to hold distinctive conceptions of learning, which suggests that conceptions of learning are culturally and contextually dependent.	**Att.:** interaction. **LX:** cognition and metacognition.
Martens et al. (2010)	• To determine what the effects of positive, neutral or negative feedback presented to collaborating teams of learners, on learners' intrinsic motivation, performance and on group processes are.	**IX:** positive, neutral or negative feedback. **DX:** learners' intrinsic motivation, performance and group processes. **N=**138. **Method:** quant. experiment + survey.	• Significant positive effect of feelings of autonomy and competence on report of interest. They reduce the interest variance between sessions substantially. • More autonomous learners gain more interest than their peers from positive respectively negative feedback. The relative interest gain of autonomous learners from negative feedback is striking. Feelings of competence also facilitate the effects of positive and negative feedback.	**Att.:** authenticity, calibration, reflection and interaction. **LX:** cognition, metacognition and motivation.

Mauroux et al. (2014)	• To develop a mobile and online learning journal to support reflection on workplace experiences.	**IX:** attitude toward using technologies, motivational support, response to changes, perceptions of the work environment, feedback / support / guidance (prompts), attitude toward reflection and intention to use. **DX:** usage behaviour. **N=**16. **Method:** quant. quasi-experiment + log file analysis + qual. interview + survey.	• Three influencing factors: interest, acceptance and the need for participation and feedback from instructor. • Implications: stimulation of reflection is important, strong guidance and feedback about reflection, relevance of the mobile and online learning journal and use of the mobile and online learning journal. • The use of reflective online learning journals, without the incentive of marks, is relevant and feasible.	**Att.:** reflection. **LX:** metacognition and motivation.
Michalsky (2014)	• To develop and test the self-regulated learning-profession vision scheme for assessing pre-service teachers' integration of professional vision considerations while analysing two delivery modes for teaching of self-regulated learning: direct and indirect teaching.	**IX:** cognition, metacognitive and motivational strategies. **DX:** self-regulation. **N=**26. **Method:** qual. case study + pre- and post-analysis.	• Active management of motivational processes is essential. • This by using causal attribution, action control and feedback.	**Att.:** authenticity, learner control, scaffolding, reflection and interaction. **LX:** metacognition and motivation.
Michinov and Michinov (2007)	• To investigate group development during an online learning session among learners involved in lifelong learning.	**IX:** use of various modes of communication, need for physical contact, motivation, feelings experienced during the online learning session, perceived cohesion, group development and affect. **DX:** learner satisfaction, perceived learning outcome and evaluation. **N=**7. **Method**: qual. case study + log file analysis + survey.	• A transition period at the midpoint of the collaborative activity shows a decline of task-oriented communications, motivation and positive mood in this period. Stronger attention is particularly useful during a transition period at the midpoint of an online collaborative activity.	**Att.:** interaction. **LX:** cognition, metacognition and motivation.
Mohammadi (2015)	• To examine an integrated model of technology acceptance model and DeLone & McLean's model for predicting learners' actual use of e-learning. • To explore the effects of quality features, perceived ease of use, perceived usefulness on learners' intentions and satisfaction, along-side the mediating effect of usability towards use of e-learning in Iran.	**IX:** satisfaction (educational quality, service quality, technical system quality, content and information quality) and intention to use (educational quality, service quality, technical system quality, content and information quality, perceived ease of use and perceived usefulness). **DX:** actual use. **N=**390. **Method**: quant. survey.	• Providing an application which is aesthetically satisfying, user-friendly, structurally designed, flexible, environmentally attractive, reliable, and secure which optimizes response time and provides interactive features are recommended. • Appropriate arrangement of time and application environment, possibility of content printing and transferring by the way of application without being detached, possibility of controlling all aspects of the system while working, the presence of a fixed available menu for users, supporting content and information with images, videos, and sounds, evolving e-learning communication towards voice communication and video conference, and expanding requisite IT infrastructure are alternatives in this regard.	**Att.:** authenticity, personalization, learner control and interaction. **LX:** motivation.

Mohammadyari and Singh (2015)	• To understand the role of digital literacy the effect of e-learning on learners' performance.	**IX:** performance expectancy, effort expectancy, social influence, individuals social influence, organizational support and intent to continue using IT. **DX:** performance. **N=**34. **Method**: quant. survey.	• Significant influence of: digital literacy on learners' performance and effort expectations, performance expectations on learners' intentions to continue using Web 2.0 tools, and continuance intention on performance. • Individual digital literacy facilitates the use of e-learning, and should be considered when examining the impact of the latter on performance.	**Att.:** calibration and interaction. **LX:** cognition.
Mulder, Lazonder, and de Jong (2011)	• To determine whether gradually introducing learners to increasingly more sophisticated or comprehensive subject matter was expected to enhance performance success. • To determine whether the progression of model order was predicted to yield higher performance success than model elaboration progression.	**IX:** time on task, perspective, degree of elaboration, and order. **DX:** performance success. **N=**84. **Method**: quant. experiment + pre- and post-test + log file analysis.	• The model order progression enhanced learners' task performance, a comparison among the two model progression conditions confirmed the predicted superiority of the model order progression condition. • Comparison of learners final models indicated that model order progression and model elaboration progression learners were equally proficient in identifying which elements are relevant to their models, whereas model order progression participants more accurately modelled the relations between these elements.	**Att.: authenticity**, scaffolding and interaction. **LX:** cognition.
Niemi et al. (2003)	• To report how learners use the tutoring tool and learn self-regulation skills.	**IX:** learning skills, keywords and advance organizers, application of theories and self-assessment. **DX:** overall satisfaction and continuing motivation. **N=**256. **Method**: quant. survey.	• The tool presented is the most useful for learners who have difficulties in learning or who do not have stable learning strategies and skills, or who are at an early stage of their studies. • Tutoring towards self-regulation is highly needed. There is too little guidance for study skills and learning strategies in both campus-based and virtual studies.	**Att.:** calibration, reflection and interaction. **LX:** metacognition and motivation.
Obura, Brant, Miller, and Parboosingh (2011)	• To determine whether resident learners participating in an Internet based e-mentoring course would form a community of learners and hold regular community meetings. • To determine whether resident learners' and faculty perceptions of community of learners and Internet sessions are effective as learning experiences.	**IX:** self-regulation, peer mentoring and collaborative problem solving. **DX:** participation community of learners. **N=**10. **Method**: quant. quasi-experiment + log file analysis + survey + qual. interviews.	• Learner adoption of community of learners behaviours was observed, including self-regulation, peer mentoring and collaborative problem solving. High learner enthusiasm and value for community of learners. • High levels of acceptance of Internet learning experiences were observed, although there was room for improvement in audio-visual transmission technologies. The study demonstrated learner acceptance of community building and collaborative learning as valued learning experiences.	**Att.:** personalization and interaction. **LX:** metacognition.
Oosterbaan, van der Schaaf, Baartman, and Stokking (2010)	• To explore the relationship between the occurrence of reflection (and non-reflection) and thinking activities (e.g., orientating, selecting, analysing) during portfolio based conversations.	**IX:** reflection. **DX:** orientating on the task, orientating on one's own portfolio, judging negatively, attributing to oneself, attributing to others and circumstances intending. **N=**21. **Method:** quant. quasi-experiment + coding schemes.	• Thinking activities comparing, analysing and concluding occurred significantly more often during reflection than during non-reflection. Orientating on the task, selecting and describing, occurred significantly less often during reflection.	**Att.:** authenticity, reflection. **LX:** metacognition.

			• The outcomes show that the occurrence of certain thinking activities can be an indication of reflection.	
Raupach, Munscher, Pukrop, Anders, and Harendza (2010)	• To examine whether participation in an online module on 'the differential diagnosis of dyspnoea' impacts on learner performance in a multiple-choice examination.	**IX:** interest, perceived ability to use a computer and perceived knowledge. **DX:** learner satisfaction, perceived learning outcome and evaluation of the online module. **N=**74. **Method**: quant. experiment + pre- and post-test + survey.	• Learners using an online module scored higher in a test than learners not included in the study, despite comparable achievement levels before entering the study. • The online module is likely to have increased learners' motivation to learn, and subsequent learning was not restricted to the content of the online module.	**Att.:** personalization and interaction. **LX:** cognition, metacognition and motivation.
Ream, Gargaro, Barsevick, and Richardson (2015)	• To investigate the adapted delivery by telephone for the 'beating fatigue programme'.	**IX:** interest, perceived ability to use a computer and perceived knowledge. **DX:** learner satisfaction, perceived learning outcome and evaluation of the online module. **N=**64. **Method**: quant. experiment + qual. interview.	• Motivational interviewing appeared key to the intervention's success. • Effects of the telephone-delivered version were similar to those generated by the in-person intervention. Helping learners explore benefits of maintaining / enhancing activity establishing attainable goals and facilitating their attainment of them.	**Att.:** calibration and interaction. **LX:** metacognition and motivation.
Regan et al. (2012)	• To explore the emotional experiences of instructors in online learning environments. • To explore how instructors attempt to regulate their challenging emotions when participating in online learning environments.	**IX:** online learning environments. **DX:** regulation of emotions and feelings. **N=**6. **Method**: qual. interview.	• Overarching themes included emotions of feeling restricted, stressed, devalued, validated, and rejuvenated. • A consensus among all instructors is that continuous dialogue in a community of practice about strategies to enhance online learning environments is imperative.	**Attributes:** interaction**. LX:** metacognition.
Reichelt et al. (2014)	• To investigate the effectiveness of multimedia design principles for different target groups, to match learners' profiles.	**IX:** receiving personalized computer-based programme and receiving a formal version. **DX:** performance on transfer and retention. **N=** 127. **Method:** quant. quasi-experiment + survey + qual. document analysis.	• Personalized learning materials promote motivation and learning regardless of the target population. Mean effect sizes and evidence that personalized learning material positively influences retention. • A practical implication for design is that communicative features expressed in a personalized style seem to engage learners across different educational settings in active learning processing.	**Att.:** personalization, learner control and interaction. **LX:** cognition.
Reychav and Wu (2015)	• To understand the role of five different dimensions of cognitive absorption in training outcomes and how affective and cognitive involvements leverage this learning process.	**IX:** enjoyment, immersion, dissociation, curiosity and control. **DX:** affective and cognitive involvement. **N=**501. **Method**: quant. experiment + pre- and post-test.	• Cognitive absorption plays a significant role in affecting learners' deep involvement, which in turn impacts training outcomes. • Heightened enjoyment, focused immersion, temporal dissociation, and control are crucial to leverage learning but indirectly by increasing the cognitive involvement of the trainee. The results further indicate a direct effect of heightened enjoyment, focused immersion, temporal dissociation and curiosity on perceived usefulness.	**Att.:** interaction. **LX:** cognition, metacognition and motivation.

			• Moreover, perceived usefulness has a direct effect on perceived learning.	
Roca et al. (2006)	• To propose a decomposed technology acceptance model in the context of an e-learning service.	**IX:** satisfaction, confirmation and perceived quality. **DX**: e-learning continuance intention. **N=**172. **Method**: quant. survey.	• Learners continuance intention is determined by satisfaction, which in turn is jointly determined by perceived usefulness, information quality, confirmation, service quality, system quality, perceived ease of use and cognitive absorption. • Instructors can increase learners' usage intention by improving their beliefs of how the e-learning system can enhance their performance and effectiveness.	**Att.:** interaction. **LX:** metacognition and motivation.
Sansone et al. (2011)	• To examine whether individual interest in computers moderated the effect of adding usefulness information predicting higher engagement levels, which in turn predicted motivation and performance outcomes.	**IX:** individual interest, anticipated usefulness, anticipated interest. **DX:** engagement, motivation, performance outcomes, regulation of interest and learning online. **N=** 108. **Method:** quant. experiment + survey.	• Individual interest in computers did not directly affect motivation and performance outcomes, nor did it directly affect learners' patterns of engagement during the lesson. • When there was little pre-existing interest, the explicit connections to how individuals could use the skills in real life were more motivating when framed in terms of potential work applications.	**Att.:** authenticity, personalization. **LX:** cognition, metacognition and motivation.
Sansone, Smith, Thoman, and MacNamara (2012)	• To examine learners' self-reported use of strategies to motivate studying for the first exam.	**IX:** self-grades importance, persuade self to work, real life application, enjoyment of game, enjoyment of other learners, enjoyable links, interest and first exam grades. **DX:** final interest and final grades. **N=** 110. **Method:** quant. experiment + survey.	• Learning online did not differ with learning in the on-campus context in the degree to which learners reported using motivational strategies that emphasized the value of potential studying-related outcomes. • Strategies aimed at enhancing or sustaining motivation to reach learning outcomes may be more defined in terms of strengthening why learners should exert effort and persist in the learning task, and these kinds of strategies may be less dependent on the learning context. • Discouraging exploration of the Internet may negatively impact learners' ability to sustain interested engagement while learning on their own.	**Att.:** scaffolding and interaction. **LX:** cognition, metacognition and motivation.
Siampou et al. (2014)	• To examine the differences between online synchronous and offline face-to-face collaboration in the context of a computer-supported modelling task.	**IX:** collaboration type. **DX:** modelling processes, interactions and learning outcomes. **N=**16. **Method:** quant. quasi-experiment + qual. observation.	• Learners who worked online in pairs emphasized analysis and synthesis, they also demonstrated a higher learning gain. Offline pairs needed the instructors' support and demonstrated stronger social interaction. • Actions of offline dyads were more numerous, the dyads that worked online seemed to present more task oriented actions.	**Att.:** authenticity, calibration, scaffolding and interaction. **LX:** cognition and metacognition.

Smith et al. (2008)	• To examine what registered care home nurses' and senior care home assistants' educational priorities regarding stroke care are and how they conceive stroke care will be delivered.	**IX:** preferred type of delivery and reasons to undertake further training. **DX:** perceived need for stroke training. **N=**134. **Method:** qual. interview + survey.	• Senior care assistants needed more information on multidisciplinary team working while care home nurses were more concerned with ethical decision-making, accountability and goal setting. • Both the care home nurses and senior care assistants are clear that stroke education should be to the benefit of their resident population.	**Attributes:** personalization**.** **LX:** metacognition and motivation.
Strang (2011)	• To determine whether knowledge articulation dialogue increases online university science course outcomes.	**IX:** teaching method. **DX:** final grades. **N=**52. **Method:** quant. quasi-experiment + test.	• When the knowledge articulation dialogue online facilitation method was applied, learners went through a learning curve effect, but thereafter, their knowledge articulation was be strengthened. • If the questioning approach was used, this may result in favourable scores early on, but overall the remaining deliverables and final marks may be lower. • It is suggested this knowledge articulation dialogue method would better suit quantitative subject matter courses.	**Att.:** reflection and interaction. **LX:** cognition.
Tan and Richardson (2006)	• To investigate the writing of short messages, using a sociocultural perspective of literacy as a social discursive practice that implicates identity construction.	**IX:** SMS messages, messages in class and online messages. **DX:** out-of-school practices. **N=**31. **Method:** qual. document analysis + interviews.	• In assigned school writing, the activity was one of language study and practice entailing the maintenance of school values and academic and examination discourse. School writing, done within the examination-oriented and often teacher-centred class, consisted of set text types that fit examination genres. • In learners informal interactions, learners wrote freely to maintain friendship ties, to overcome boredom, and basically to fulfil their need for meaningful communication. Content in learners' messages was unguarded and uncensored, revolving mainly around relationships, school and social life.	**Att.:** authenticity, personalization and interaction. **LX:** metacognition and motivation.
Tao (2008)	• To comprehend the teachers' and learners' perceptions on concerns toward e-learning issues.	**IX:** learning effect, administrative challenges, customization, geographic and content integration and instructional design challenges. **DX:** perception on institutional e-learning issues **N=**145. **Method**: quant. survey.	• Learners have black-or-white perceptions on the use of e-learning, they see learner and administrative support as crucial and rather feel a lack of competitive awareness on the professional market.	**Att.:** personalization and interaction. **LX:** metacognition.
Taplin, Kerr, and Brown (2013)	• To analyse the monetary value learners place on having access, via the internet, to recorded lectures in a blended learning context.	**IX;** university fixed price for iLectures to maximize revenue and learner demographics. **DX:** learner choice to purchase iLectures at a fixed price and learner perceptions of iLectures and face-to-face lectures. **N=**1932. **Method:** quant. survey.	• It is necessary to be cautious of qualitative valuations of iLectures. • It appears that some learners may agree that something is worthwhile if they perceive it to be free.	**Attributes:** interaction**. LX:** motivation.

Ting (2013)	• To proposes a notion for helping instructors design an innovative mobile learning practice in specific subject domain. • To determine whether learners accept the proposed learning activity and perceive the claimed learning benefits	**IX:** relationship, perception and attitude toward learning technology. **DX:** willingness to use learning technology. **N=**57. **Method**: quant. experiment + pre- and post-test + survey.	• Mobile technologies add new dimensions to learning activities, both the personal and portable nature of the devices, as the kinds of learning interactions they can support. Mobile learning enables learners to interact and capture experiences in both physical and social realms, and makes learning more experiential and multifaceted. • Guidelines: mapping subject content onto social interactions, recording social interactions, synthesis of group behaviours and subject content and delivery of instructional information and visualization of the design framework.	**Att.:** authenticity, learner control, scaffolding, refection-evoking and interaction. **LX:** metacognition and motivation.
Tseng and Kuo (2010)	• To propose and validate a self-regulation model that explores the effects of social capital and social cognitive factors on knowledge-sharing behaviour.	**IX:** community identity and interpersonal trust. **DX:** social awareness, knowledge-sharing behaviour and knowledge-sharing self-efficacy. **N=**?. **Method**: quant. survey.	• Knowledge-sharing behaviours in the online community exhibit a triadic interplay among the community identify, interpersonal trust, social awareness, learners' perception of self-efficacy, and knowledge-sharing behaviour in the online environment.	**Att.:** interaction. **LX:** metacognition.
Verhagen, Feldberg, van den Hooff, Meents, and Merikivi (2012)	• To fill the research gap between the growth and commercial potential of virtual worlds and the relatively little knowledge about users' motivations to engage in them.	**IX:** perceived usefulness, entertainment value, economic value, perceived ease of use, escapism and visual attractiveness. **DX:** attitude towards using a virtual world, entertainment value, perceived usefulness. **N=** 846. **Method:** quant. survey.	• Strong direct effects of the extrinsic motivation perceived usefulness and the intrinsic motivation entertainment value on the attitude towards virtual world usage. • Higher levels of economic value, perceived ease of use and escapism contribute to the perceived entertainment value and usefulness of virtual world systems. • Visual attractiveness did not contribute to the perceived usefulness of virtual worlds.	**Att.:** personalization, calibration and interaction. **LX:** metacognition and motivation.
Vighnarajah et al. (2009)	• To investigate learners' perception on participation in a discussion platform, on the importance of practicing self-regulated learning strategies and on the development of self-regulated learning strategies through participation in the discussion platform.	**IX:** intrinsic goal orientation, extrinsic goal orientation, control of learning beliefs, self-efficacy for learning and performance, metacognitive self-regulation, time and study environment, effort regulation, peer learning and help seeking. **DX:** overall development of self-regulated learning strategies. **N=**50. **Method:** quant. experiment + survey.	• Learners acknowledged practicing self-regulated learning strategies. Frequent strategies appear to be intrinsic and extrinsic goal orientation, control of learning beliefs, rehearsal, elaboration, critical thinking, peer learning, and help seeking. • Strategies that interest learners the least are task value, effort regulation, and metacognitive self-regulation.	**Att.:** calibration, scaffolding and interaction. **LX:** metacognition.
von Bastian and Oberauer (2013)	• To examine the impact of working memory training on a broad set of transfer tasks.	**IX:** working memory training. **DX:** transfer tasks. **N=**137. **Method:** quant. experiment + pre- and post-test.	• Degree of improvement in the training tasks correlated positively with the magnitude of transfer. • Differential effects of training different functional categories of working memory and executive functions could explain why previous studies yielded mixed results.	**Att.:** authenticity**. LX:** cognition.

Weaver, Oji, Ettienne, Stolpe, and Maneno (2014)	• To assess the impact of a hybrid teaching methodology on improving critical thinking in an health policy elective course.	**IX:** hybrid teaching methodology. **DX:** critical thinking. **N=**8. **Method**: quant. quasi-experiment + pre- and post-test + qual. interview	• Learners reported that their ability to effectively participate improved significantly although the assessment showed mixed findings. • The course benefited from being new and giving the learners a broad view. • Critical thinking was improved among the learners.	**Att.:** personalization, scaffolding, reflection and interaction. **LX:** cognition and metacognition.
Wesiak et al. (2014)	• To determine whether scaffolding services support self-regulated learning in an augmented simulator.	**IX:** scaffolding service, training in the simulator and augmented simulator. **DX:** relevance for real life experiences, self-regulated learning, and enhanced learning experience. **N=** 113. **Method:** quant. experiment + log-file analysis + survey.	• Addition of thinking prompts by the scaffolding service was beneficial. Time spent with the simulation increased. • Positive effect of the refinements of thinking prompts and / or affective element added to the scaffolding service. • The type of notes taken by the learners, during the think aloud method, supports the assumption that scaffolding support fosters metacognition and reflection.	**Att.:** authenticity, personalization, learner control, calibration, scaffolding and interaction. **LX:** metacognition and motivation.
Xie et al. (2013)	• To determine how social conflict evolve in an online class and what the relations between social and learning interactions in an online social learning environment are.	**IX:** social interaction. **DX:** learning interaction. **N=**18. **Method**: qual. case study + interviews.	• A model of social conflict evolution within the learning community is identified consisting of five general phases: cultural initiation, social harmonization cycle, escalation of conflict, intervention and stabilization, and adjourning. • Strong relationships between social and learning interactions during these five phases of social conflict development.	**Att.:** authenticity and interaction. **LX:** motivation.
Yang and Tsai (2010)	• To investigate college learners' conceptions of and approaches to learning via online peer assessment (PA).	**IX:** online peer assessment. **DX:** conceptions of and approaches to learning. **N=** 163. **Method:** quant. quasi-experiment + qual. interviews.	• Conceptions emphasizing on fragmented and cohesive learning tended to be associated with approaches focusing on surface and deep learning. • Approaches to learning via online peer assessment were less related to the learning outcomes than conceptions of learning. • Support for deep learning is advisable.	**Att.:** scaffolding and reflection. **LX:** metacognition and motivation.
Yu et al. (2007)	• To investigate the feasibility of developing e-learning. • To examine reasons for adopting or rejecting e-learning as an alternative way to conduct continuing education for public health nurses.	**IX:** age, education level, marital status, job position and previous experience in web-based learning. **DX:** feasibility of adopting e-learning as an alternative way of continuing education and reasons for adopting or rejecting e-learning. **N=**233. **Method**: quant. survey.	• Asynchronous e-learning courses are suitable for individuals with high self-control, it allows them to learn in remote locations according to their own needs and pace. • Needs assessment is strongly recommended in the programme preparation stage. Only by fulfilling learners; individual needs, reducing learning barriers, increasing their motivation and self-controlling ability, can this approach be successful.	**Att.:** personalization and learner control and reflection. **LX:** metacognition and motivation.

Chapter 2 – Appendix 1

Course: …

Topic: …

	1	2	3	4	5	
	Never	Little	Somewhat	Much	Always	
Does the learning environment contain authentic real-world relevance?			0			Comments
Is an authentic context provided that reflects the way the knowledge will be used in real life?						
Are authentic activities provided?						
Is there access to expert performances and the modelling of processes provided?						
Are there multiple roles and perspectives provided?						
Is there support for collaborative construction of knowledge provided?						
Is articulation provided to enable tacit knowledge to be made explicit?						
Is authentic assessment of learning within the tasks provided?						
Does the learning environment contain personalization?			0			Comments
Is the personalization name-recognized?						
Is the personalization self-described?						
Is the personalization cognitive-based?						
Does the learning environment allow learner control?			0			Comments
Is control of pacing allowed?						
Is control of content allowed?						
Is control of learning activities allowed?						
Is control of content sequence allowed?						
Does the learning environment scaffold support?			0			Comments
Is support tailored to the learner through continuous monitoring?						
Is the support fading over time?						
Does the support fade over time?						
Does the learning environment entail interaction?			0			Comments
Is learner-content interaction facilitated?						
Is learner-instructor interaction facilitated?						
Is learner–learner interaction facilitated?						
Is learner-interface interaction facilitated?						
Is vicarious interaction facilitated?						
Does the learning environment contain reflection cues?			0			Comments
Does the reflection-for-action approach applies?						
Does the reflection-in-action approach applies?						
Does the reflection-on-action approach applies?						
Does the learning environment contain calibration cues?			0			Comments
Is a strategy applied to guide learners to delay metacognitive monitoring?						
Is a strategy applied for the provision of forms that guide students to summarize content?						
Are timed alerts given that guide students to summarize content?						
Is a strategy applied for helping learners review the ''right'' information?						
Is a strategy applied for effective practice tests, that provide students with records of their performance on past tests as well as items (or tasks) on those tests?						

Chapter 4 – Appendix 1

Attributes	Main question	Sub question
Authenticity	Does the learning environment contain authentic real-world relevance?	• Is an authentic context provided that reflect the way the knowledge will be used in real life? • Are authentic activities provided? • Is there access to expert performances and the modelling of processes? • Are there multiple roles and perspectives provided? • Is there support for collaborative construction of knowledge? • Is articulation provided to enable tacit knowledge to be made explicit? • Is authentic assessment of learning provided within the tasks?
Personalization	Does the learning environment contain personalization?	• Is the personalization name-recognized? • Is the personalization self-described? • Is the personalization cognitive-based?
Learner-control	Does the learning environment allow learner control?	• Is control of pacing allowed? • Is control of content allowed? • Is control of learning activities allowed? • Is control of content sequence allowed?
Scaffolding	Does the learning environment scaffold support?	• Is support tailored to the learner through continuous monitoring? • Does the support fade over time? • Is there a transfer of responsibilities over time?
Interaction	Does the learning environment entail interaction?	• Is learner-content interaction facilitated? • Is learner-instructor interaction facilitated? • Is learner-learner interaction facilitated? • Is learner-interface interaction facilitated? • Is vicarious interaction facilitated?
Reflection cues	Does the learning environment contain reflection cues?	• Does the reflection-for-action approach apply? • Does the reflection-in-action approach apply? • Does the reflection-on-action approach apply?
Calibration cues	Does the learning environment contain calibration cues?	• Is a strategy applied to guide learners to delay metacognitive monitoring? • Is a strategy applied for the provision of forms that guide students to summarize content? • Are timed alerts given that guide students to summarize content? • Is a strategy applied for helping learners review the 'right' information? • Is a strategy applied for effective practice tests that provide students with records of their performance on past tests as well as items (or tasks) on those tests?

Chapter 4 – Appendix 2

1. Authenticity

The use of the word authentic is open to interpretation. A sustainable amount of attempts to define this concept transparently is done (see e.g., Bennet, Harper, & Hedberg, 2002; Herrington, 2005; Wesiak et al., 2014). Definitions range from real-world relevance (Wesiak et al., 2014), needed in real-life situations (Sansone et al., 2011) and of important interest of the learner for later professional life (Grimmett & Neufeld, 1994) to models that focus on applying conceptual knowledge or skills, such as critical thinking or problem solving (Young, 1993). Based on their literature review Van Laer and Elen (2016b) defined authenticity as the real-world relevance (both to the learners' professional and personal life) of on the one hand the learning environment (e.g., Herrington, Oliver, & Reeves, 2003; Petraglia, 1998; Roth & Bowen, 1995) and on the other hand the task (e.g., Merrill, 2002; Reigeluth, 1999; van Merriënboer & Kirschner, 2001). Guidance question for identifying authenticity in learning environments and learning tasks are:

- *1.1. Authentic context.* Is an authentic context provided that reflect the way the knowledge will be used in real life? In designing online learning environments with authentic contexts, it is not enough to simply provide suitable examples from real-world situations to illustrate the concept or issue being taught. The context needs to be all-embracing, to provide the purpose and motivation for learning, and to provide a sustained and complex learning environment that can be explored at length (e.g., Brown, Collins, & Duguid, 1989; Honebein, Duffy, & Fishman, 1993; Reeves & Reeves, 1997).
- *1.2. Authentic activities.* Are authentic activities provided? The learning environment needs to provide ill-defined activities which have real-world relevance, and which present a single complex task to be completed over a sustained period of time, rather than a series of shorter disconnected examples (e.g., Bransford, Vye, Kinzer, & Risko, 1990; Lebow & Wager, 1994).
- *1.3. Expert performance.* Is there access to expert performances and the modelling of processes? In order to provide expert performances, the environment needs to provide access to expert thinking and the modelling of processes, access to learners in various levels of expertise, and access to the social periphery or the observation of real-life episodes as they occur (Collins, Brown, & Newman, 1989).
- *1.4. Multiple roles.* Are there multiple roles and perspectives provided? In order for students to be able to investigate the learning environment from more than a single perspective, it is important to enable and encourage students to explore different perspectives on the topics from various points of view, and to 'criss cross' the learning environment repeatedly (Collins et al., 1989).
- *1.5. Collaborative knowledge construction.* Is there support for collaborative construction of knowledge? The opportunity for users to collaborate is an important design element, particularly for students who may be learning at a distance. Consequently, tasks need to be addressed to a group rather than an individual, and appropriate means of communication need to be established. Collaboration can be encouraged through appropriate tasks and communication technology (e.g., discussion boards, chats, email, debates etc.) (e.g., Hooper, 1992).
- *1.6. Tacit knowledge made explicit.* Is articulation provided to enable tacit knowledge to be made explicit? In order to produce a learning environment capable of providing opportunities for articulation, the tasks need to incorporate inherent opportunities to articulate, collaborative groups to enable articulation, and the public presentation of argument to enable defense of the position (e.g., Edelson, Pea, & Gomez, 1996).
- *1.7. Authentic assessment.* Is authentic assessment of learning within the tasks provided? In order to provide integrated and authentic assessment of student learning, the learning environment needs to provide: the opportunity for students to be effective performers with acquired knowledge, and to craft polished, performances or products in collaboration with others. It also requires the assessment to be seamlessly integrated with the activity, and to provide appropriate criteria for scoring varied products (e.g., Linn, Baker, & Dunbar, 1991; Reeves & Okey, 1996; Wiggins, 1993).

2. Personalization

Personalization is often described as non-homogenous experiences related directly to the learner (Wilson et al., 2007), associated with characters and objects of inherent interest to the learner and connects with topics of high interest value (Cordova & Lepper, 1996). Similar to these views on personalization, based on their literature review, Van Laer and Elen (2016b) defined personalization as the modification of the learning environment to the inherent needs of each individual learner. Five major questions were raised by the current literature on the use of personalized learning environments (Devedžić, 2006; Martinez, 2002). These questions are:

- *2.1. Name-recognition.* Is the personalization name-recognized? This type of personalization aims at the acknowledgement of the learner as an individual. For example, the learner's name can appear in the instruction or previous activities or accomplishments that have been collected and stored can later be presented when appropriate.
- *2.2. Self-described.* Is the personalization self-described? Self-described personalization enables learners, (using questionnaires, surveys, registration forms, and comments) to describe preferences and common attributes. For example, learners may take a pre-course quiz to identify existing skills, preferences, or past experiences. Afterwards, options and instructional experiences appear based on the learner-provided answers.
- *2.3. Cognition-based.* Is the personalization cognitive-based? Cognitive-based personalization uses information about cognitive processes, strategies, and ability to deliver content specifically targeted to specific types (defined cognitively) of learners. For example, learners may choose to use an audio option because they prefer hearing text rather than reading it. Or, a learner may prefer the presentation of content in a linear fashion, rather than an unsequenced presentation with hyperlinks.

3. Learner-control

Learner-control refers to the amount of control learners have over support in BLEs. Different researchers identify different kinds of learner-control. Varying from freedom of task-selection by the learner (Artino, 2009b), control of learning sequences (sequence control) (Lin & Hsieh, 2001), allowing decisions on which contents to receive (selection or content control), allowing decisions on how a specific content should be displayed (representation control) and control over the pace of information presentation (Scheiter & Gerjets, 2007). Van Laer and Elen (2016b), based on their literature review, defined learner-control as an inclusive approach based on the earlier mentioned different kinds of learner-control. Therefor learner control is a concept where learners have or have not control over the pacing, content, learning activities and content sequence. Four major questions (Williams, 1993) occur when describing learner-control in learning environments:

- *3.1. Control over pacing.* Is control of pacing allowed (Sims & Hedberg, 1995)? These traces suggest that the learners have control over the speed of presentation of instructional materials. Another element considered is the ability to control pacing, is the speed and time at which content is presented.
- *3.2. Control over content.* Is control of content allowed (Milheim & Martin, 1991)? These traces suggest that the learner is permitted to skip over certain instructional units. This option generally refers to the selection of topics or objectives associated with a specific lesson, although it does not extend to a choice of which content items are displayed. This component of learner control does not focus on the micro level of interaction, in which the learner must make certain choices in response to questions or problems. Therefore, while the learner has control over the content selected for study, the actual presentation of that content has generally remained instructor driven. Thus, there would appear to be two levels of content control—that where the learner chooses a module of study, and that where the presentation and associated display elements are also under learner control.
- *3.3. Control over learning activities.* Is control of learning activities allowed (Laurillard, 1987)? This includes options for the student to see examples, do exercises, receive information, consult a glossary, ask for more explanation, and take a quiz.
- *3.4. Control over content sequence.* Is of control of content sequence allowed? This includes provisions for the student to skip forward or backward a chosen amount or to retrace a route through the material, and options to control when to view such features as content indexes or content maps. Sequence control refers to the order in which the content is viewed, and often is defined in terms of being able to move to and fro among content items, such as those described by Gray (1988).

4. Scaffolding

Many different approaches to scaffolding have emerged from the design research on interactive learning environments, and a variety of design guidelines or principles have been proposed (Edelson, Gordin, & Pea, 1999; Kolodner, Owensby, & Guzdial, 2004). Based on their literature review Van Laer and Elen (2016b) define scaffolding as changes in the task, so learners can accomplish tasks that would otherwise be out of their reach (Reiser, 2004). This definition of scaffolding is reflected by three major questions (Puntambekar & Hubscher, 2005):

- *4.1. Contingency.* Is support tailored to the learner through continuous monitoring? The support must be adapted to the current level of the learners' performance and should either be at the same or a slightly higher level. A tool for contingency is diagnostic strategies. To provide this support, one must first determine the learners' current level of competence. Many authors have acknowledged the importance of diagnosis in relation to scaffolding (e.g., Garza, 2009; Lajoie, 2005; Swanson & Lussier, 2001).

- *4.2. Fading over time.* Does the support fade over time? Fading depends upon the learners' level of development and competence. Support fades when the level and/or the amount decreases over time.
- *4.3. Transfer of responsibility.* Is there a transfer of responsibilities over time? Responsibility for the performance of a task is gradually transferred to the learner. Responsibility can refer both to cognitive and metacognitive activities and to learners' affect. The responsibility for learning is transferred when a student takes increasing learner control.

5. Interaction

The nature of interaction in various forms of learning environments has been defined in a variety of ways, based upon the participants' level of involvement in a specific learning opportunity and the objects of interaction such as other participants or content materials. The nature of interaction is also dependent upon the contexts in which interaction occurs, in a face-to-face situation or at a distance. Van Laer and Elen (2016b) describe interaction as the involvement of learners with elements in the learning environment. Five major interaction related questions are taken into account (Woo & Reeves, 2007):

- *5.1. Learner-content interaction.* Is learner-content interaction facilitated (Hiemstra, 1993)? The first type of interaction is interaction between the learner and the content or subject of study. They are often one-way communications with a subject expert, intended to help learners in their study of the subject.
- *5.2. Learner-instructor interaction.* Is learner-instructor interaction facilitated (Moore, 1989)? The second type of interaction is learners-instructor interaction between the learner and the expert who prepared the subject material, or some other expert acting as an instructor.
- *5.3. Learner-learner interaction.* Is learner-learner interaction facilitated (Moore, 1989)? The third form of interaction is the inter-learner interaction, between one learner and other learners, alone or in group settings, with or without the real-time presence of an instructor.
- *5.4. Learner-interface interaction.* Is learner-interface interaction facilitated (Hillman, Willis, & Gunawardena, 1994)? The fourth type of interaction is learner-interface interaction, which describes the interaction between the learner and the tools needed to perform the required task.
- *5.5. Vicarious interaction.* Is vicarious interaction facilitated (Sutton, 2001)? This final type of interaction takes place when a student actively observes and processes both sides of a direct interaction between two other students or between another student and the instructor.

6. Reflection-cues

Many different definitions of reflection have been proposed over time. Dewey (1958) defined reflection as "active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends" (p. 9). Moon (1999) describes reflection as "a form of mental processing with a purpose and/or anticipated outcome that is applied to relatively complex or unstructured ideas for which there is not an obvious solution" (p. 23). Boud et al. (2013) define reflection as "a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to a new understanding and appreciation" (p. 19). All three definitions emphasize purposeful critical analysis of knowledge and experience, in order to achieve deeper meaning and understanding. Van Laer and Elen (2016b) define reflection cues as prompts that aim to activate learners' purposeful critical analysis of knowledge and experience, in order to achieve deeper meaning and understanding. This definition occurs via three major questions (Farrall, 2007; Mann et al., 2009):

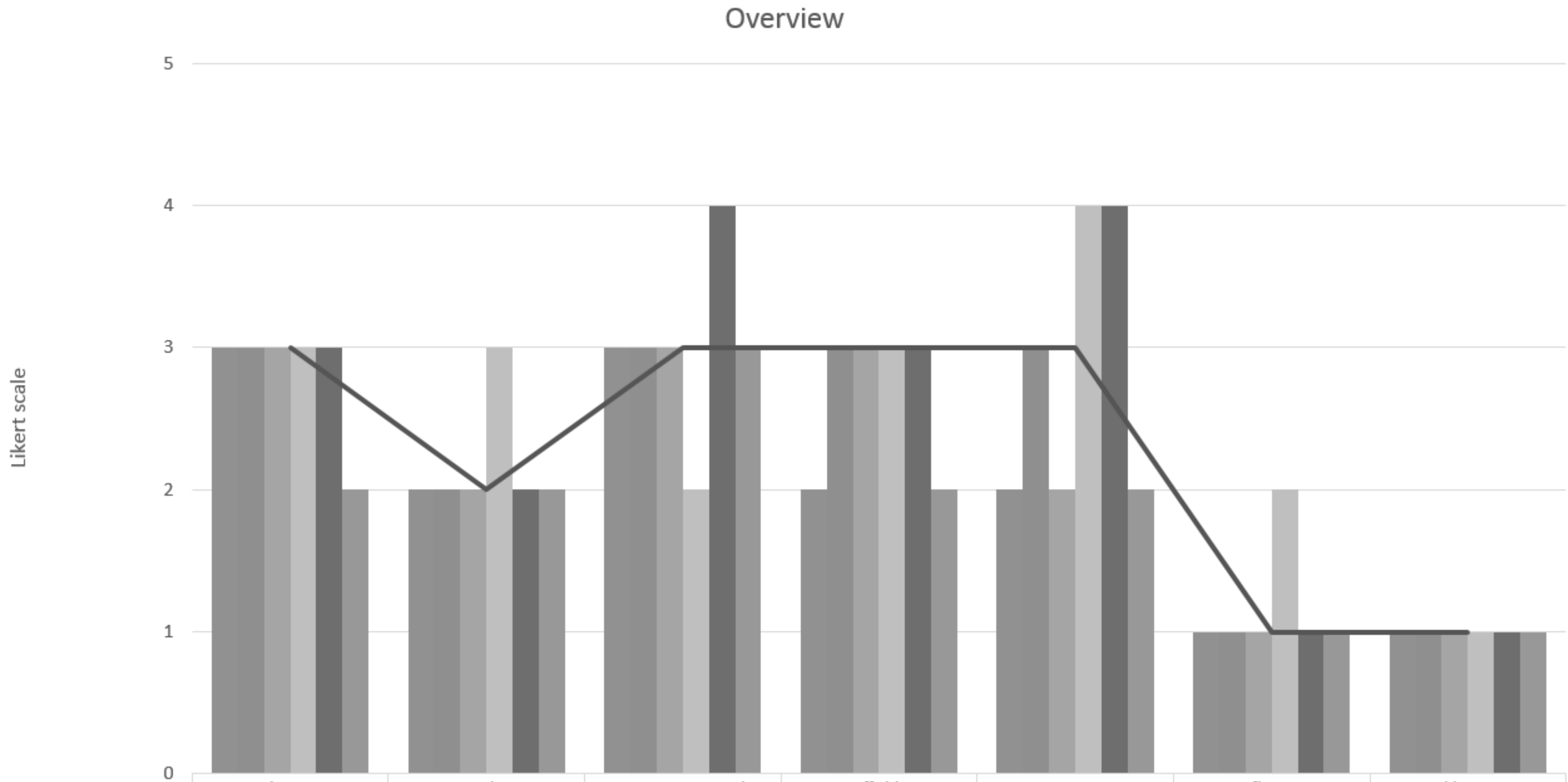
- *6.1. Reflection-before-action.* Does the reflection-for-action approach apply (Farrall, 2007)? This type is different from the other two types since it is proactive in nature. For example the instructor asks the learner about his or her personal expectations about an upcoming task.
- *6.2. Reflection-in-action.* Does the reflection-in-action approach apply (Farrall, 2007; Schön, 1987)? This type of reflection takes place while learners are performing a task. Reflective cues are given when the learner is performing a certain task. Cues are given to let him reflect upon if he needs to alter, amend, change what he is doing and being in order to adjust to changing circumstances, to get back into balance, to attend accurately, etc.? Learners must check with themselves that they are on the right track: if I am not on the right track, is there a better way? For example an instructor asks learners to review the actions they are undertaking.
- *6.3. Reflection-on-action.* Does the reflection-on-action approach apply (Farrall, 2007)? Munby and Russell (1992) describe it succinctly as the "systematic and deliberate thinking back over one's actions". Another definition which involves thinking back on what teachers have done to discover how knowing-in-action might have contributed to

unexpected action (Hatton & Smith, 1995). For example an instructor asks the learner about his or her previous experiences regarding a task that is just finished.

7. Calibration cues

Calibration is defined as the learners' perceptions of performance compared to the actual performance and perceived use of study tactics and actual use of study tactics (Bol & Garner, 2011). Calibration concerns on the one hand the deviation of a learner's judgement from fact, introducing notions of bias and accuracy and on the other hand metric issues regarding the validity of cues' contributions to judgements and the grain size of cues (Azevedo & Hadwin, 2005). Van Laer and Elen (2016b) define calibration cues as triggers for learners to test their perceptions of performance against their actual performance and their perceived use of study tactics against their actual use of study tactics. While identifying calibration cues we focus on five major questions (Nietfeld et al., 2006; Thiede & Dunlosky, 1994):

- *7.1. Cues for delayed metacognitive monitoring.* Is a strategy applied to guide learners to delay metacognitive monitoring? (Thiede & Dunlosky, 1994)This strategy is based on a phenomenon labelled 'the delayed judgement of learning effect' that shows improved judgements after a learning delay similar to improved performance associated with distributed sessions over time. For example, learners might be first asked to highlight a text and at a later time evaluate the highlighted content in terms of how well it is understood, how easily is can be retrieved, and how it relates to the learning objective. They are asked to evaluate previously made judgements.
- *7.2. Forms for summarizing.* Is a strategy applied for the provision of forms that guide students to summarize content? Summarizing information improved calibration accuracy. It is suggests that the summaries were more effective when forms and guidelines were provided (Wood, Woloshyn, & Willoughby, 1995). For example an instructor gives the learners the task to summarize a specific content component and to review it using a correction key.
- *7.3. Timed alerts.* Are timed alerts given that guide students to summarize content? Thiede et al. (2003) state that summarizing information after a delay improved calibration accuracy.
- *7.4. Review of the 'right' information*. Is a strategy applied for helping learners review the "right" information? (Bol & Garner, 2011) Learners have a tendency to select "almost learned" or more interesting content for restudy. If students were to rate test items on judgement of learning and interest they could be provided with feedback indicating that selection of content for restudy based on interest and minimal challenge may not be the best choices. For example an instructor advises the learners to select exercises that are challenging for them.
- *7.5. Effective practice tests.* Is a strategy applied for effective practice tests that provide students with records of their performance on past tests as well as items (or tasks) on those tests? (Bol & Garner, 2011) Learners should be aware of the change in behaviour they should make. By informing them of the mistakes they already made they might direct further attempts. For example an instructor gives the results of the previous test as a guideline for the completion of the next test.



	Authenticity	Personalization	Learner control	Scaffolding	Interaction	Reflection	Calibration
Environment 1	3	2	3	2	2	1	1
Environment 2	3	2	3	3	3	1	1
Environment 3	3	2	3	3	2	1	1
Environment 4	3	3	2	3	4	2	1
Environment 5	3	2	4	3	4	1	1
Environment 6	2	2	3	2	2	1	1
Total mean	3	2	3	3	3	1	1

Chapter 4 – Appendix 4

School A		School B	
Content	1. Course module viewed (p<.05) 2. Course searched 3. Course viewed (p<.05) 4. List of modules viewed 5. User logged in in course	*Content*	1. Course module viewed (p<.05) 2. Course viewed (p<.05) 3. Feedback viewed 4. List of modules viewed 5. SCORM started (p<.05) 6. User logged in in course
Content related information	6. Content posted (p<.05) 7. Discussion made (p<.05) 8. Discussion viewed (p<.05) 9. Enrolled on discussion (p<.05) 10. Message made (p<.05) 11. Message modified (p<.05) 12. Note created 13. Note removed 14. Post made 15. Subscription made on discussion 16. Subscription removed	*Content related information*	7. Discussion created (p<.05) 8. Discussion viewed (p<.05) 9. Note created 10. Note removed 11. Post made 12. Subscription made on discussion 13. Subscription removed 14. User profile viewed
Tasks and assignments	17. Assignment made (p<.05) 18. Assignment saved (p<.05) 19. Assignment sent (p<.05) 20. File uploaded (p<.05) 21. Submissions made 22. Test attempt viewed (p<.05) 23. Test made (p<.05) 24. Test started (p<.05) 25. Test viewed 26. There is an uploaded file 27. User preserved submission	*Tasks and assignments*	15. Assignment made (p<.05) 16. Assignment saved (p<.05) 17. Assignment sent (p<.05) 18. File uploaded (p<.05) 19. Test viewed 20. There is an uploaded file 21. User preserved submission
Scores and results	28. Score overview viewed 29. Status of assignment viewed (p<.05) 30. Submission form consulted (p<.05) 31. Summary test attempts viewed (p<.05) 32. Test attempt reviewed (p<.05) 33. Test checked 34. User score (p<.05)	*Scores and results*	22. Score report viewed (p<.05) 23. Status assignment viewed (p<.05) 24. Submission form viewed (p<.05) 25. Test checked 26. User score (p<.05)

Chapter 6 – Appendix 1

Before the task
- Do you have any idea which element of statistics this topic will be about?
- This topic introduces … Do you know what this concept means?
- What other concepts relate to …?
- Today we will look at … Do you have any idea how this relates to the bigger picture of this course?
- Why would you need … to complete your individual project?
- What do you need to know about … to understand it and be able to apply it?
- Do you have any idea why … is important to your professional and personal context?
- How will you approach this topic?
- Hearing the word … what would you like to do with it?
- Hearing the word … what does it mean for you?
- How are you planning to relate … to the bigger picture?
- Do you think you have the skills needed to use the information presented here?
- What will you do when you identify a lack in information?
- How do you plan to overcome problems?
- Where will you get help if needed?
- What skills do you have to deal with this topic?
- What kind of issues do you see when trying to master the concept …?
- What actions will you take when you figure out the topic is not about what you thought it would be about?
- At what point will you feel you have mastered the topic?
- When do you believe you are taking the right actions to achieve mastery of the topic?
- Which steps do you want to take to master the concept …?
- How will you ensure you take the most suitable steps to master the concept …?

During the task
- Based on the first part of the task, is the task about what you thought it was about?
- If not, what will you do about this discrepancy?
- What different elements do you need to combine to complete this task?
- Do you possess each of these elements?
- How does this task relate to the tasks you were given before?
- Why do you need to do this task?
- How will this task help you to master the bigger picture?
- How is this task of importance to you?
- Does this task still fulfil the role you thought it would fulfil?
- Does the task still help you to achieve your goals?
- How does this task relate to your professional and personal context?
- What can you do to maximize this fit even more?
- Are the goals you set at the beginning of the task still the best ones or did you acquire new knowledge that means you need to reframe the goals?
- What modifications do you need to make to tune your initial approach to how the task evolves?
- What do you think this task will lead to?
- Is your plan still in line with your initial one?
- How do you deal with discrepancies between what you thought this task would be about and what you know now?
- Is your plan to approach this task still appropriate to achieve the goals you set?
- Did you encounter any obstacles while solving the task?
- How did you deal with obstacles?
- I the task unfolding as expected?
- How does the unfolding of the task relate to your approach?

After the task
- Was the result of the task what you expected it to be?
- Did your idea match the final demands of the task?
- Were you able to identify the different elements of the task as expected?
- Do you see at this point how the task relates to the overall aim of the course?
- Do you understand why the instructor provided you with the different elements of the task?

- Is it clear for you what the significance of the task was?
- After completing the task, do you see the relevance for real life?
- Knowing what you know now about the task, would you approach it the same way?
- How will you approach the next task, based on the task you just completed?
- Are the goals you set for this task fulfilled?
- Was your approach appropriate to achieve the goals?
- Did your plans unfold as expected?
- Were there obstacles in achieving the goals you set?
- How did you deal with obstacles?
- Was your approach to dealing with obstacles effective?
- Are there things you will do differently if you get a similar task?
- Was the path you took to achieving the goal successful for you?
- Were the steps taken to achieve the goal sufficient?
- Was there anything you learned that will change your approach to the next task?
- Which factors contributed to the success/failure of the task?
- What advice would you give other students with regard to the task?
- What will be your approach from now on?

#	Sub-sequence	Support	p.value	statistic	index	Resid.1	Resid.2	Cramer's V
1	(Course)-(File)-(Course)-(Course)-(Course)	0.267	0.001	11.271	578.000	-1.876	2.654	0.613
2	(Course)-(Course)-(File)-(Course)	0.433	0.001	10.605	230.000	-1.585	2.242	0.595
3	(Course)-(File)-(File)-(Test)-(Test)-(Test)	0.467	0.003	8.856	205.000	-1.418	2.006	0.543
4	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)	0.467	0.003	8.856	206.000	-1.418	2.006	0.543
5	(Course)-(Task)-(Task)-(Course)	0.300	0.003	8.750	501.000	-1.633	2.309	0.540
6	(File)-(Course)-(File)-(File)	0.600	0.006	7.656	112.000	-1.155	1.633	0.505
7	(Course)-(File)-(File)-(Test)-(Test)	0.500	0.007	7.350	177.000	-1.265	1.789	0.495
8	(File)-(Course)-(Course)	0.633	0.011	6.477	93.000	-1.030	1.457	0.465
9	(File)-(Course)-(File)	0.633	0.011	6.477	94.000	-1.030	1.457	0.465
10	(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)	0.633	0.011	6.477	101.000	-1.030	1.457	0.465
11	(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)	0.633	0.011	6.477	102.000	-1.030	1.457	0.465
12	(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)	0.633	0.011	6.477	104.000	-1.030	1.457	0.465
13	(Course)-(Test)-(Course)-(Page)	0.267	0.013	6.158	594.000	-1.443	2.041	0.453
14	(File)-(Link)-(Course)	0.267	0.013	6.158	615.000	-1.443	2.041	0.453
15	(File)-(Test)-(Course)-(Test)	0.267	0.013	6.158	619.000	-1.443	2.041	0.453
16	(Page)-(Course)-(Forum)-(Forum)	0.267	0.013	6.158	644.000	-1.443	2.041	0.453
17	(Test)-(File)-(Course)	0.267	0.013	6.158	659.000	-1.443	2.041	0.453
18	(Course)-(File)-(Course)-(Course)	0.433	0.013	6.126	232.000	-1.246	1.761	0.452
19	(File)-(Course)-(Test)	0.433	0.013	6.126	246.000	-1.246	1.761	0.452
20	(Forum)-(Forum)-(Course)-(Forum)	0.433	0.013	6.126	257.000	-1.246	1.761	0.452
21	(Forum)-(Forum)-(Forum)-(Course)-(Forum)	0.433	0.013	6.126	259.000	-1.246	1.761	0.452
22	(Course)-(File)-(File)-(Course)	0.533	0.014	6.044	152.000	-1.123	1.588	0.449
23	(Test)-(Test)-(File)	0.533	0.014	6.044	167.000	-1.123	1.588	0.449
24	(Test)-(Test)-(Test)-(File)	0.533	0.014	6.044	170.000	-1.123	1.588	0.449
25	(Course)-(File)-(Course)	0.667	0.020	5.419	78.000	-0.913	1.291	0.425
26	(File)-(File)-(File)-(File)	0.667	0.020	5.419	80.000	-0.913	1.291	0.425
27	(File)-(Task)	0.667	0.020	5.419	83.000	-0.913	1.291	0.425
28	(Course)-(Course)-(Page)	0.367	0.023	5.185	334.000	-1.231	1.741	0.416
29	(Course)-(Course)-(Page)-(Course)	0.367	0.023	5.185	335.000	-1.231	1.741	0.416

30	(Course)-(File)-(Course)-(File)-(File)	0.367	0.023	5.185	337.000	-1.231	1.741	0.416
31	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)-(Course)	0.367	0.023	5.185	342.000	-1.231	1.741	0.416
32	(File)-(Course)-(Course)-(Course)	0.367	0.023	5.185	360.000	-1.231	1.741	0.416
33	(Forum)-(Forum)-(Forum)-(Forum)-(Course)-(File)	0.367	0.023	5.185	375.000	-1.231	1.741	0.416
34	(Forum)-(Forum)-(Forum)-(Forum)-(Forum)-(Course)-(Forum)	0.367	0.023	5.185	376.000	-1.231	1.741	0.416
35	(Course)-(Course)-(Course)-(File)	0.567	0.027	4.904	126.000	-0.990	1.400	0.404
36	(Forum)-(Course)-(Forum)	0.567	0.027	4.904	137.000	-0.990	1.400	0.404
37	(Test)-(File)	0.567	0.027	4.904	147.000	-0.990	1.400	0.404
38	(Course)-(Course)-(Test)-(Test)-(Test)-(File)	0.467	0.028	4.838	203.000	-1.091	1.543	0.402
39	(File)-(Course)-(File)-(File)-(Course)	0.467	0.028	4.838	211.000	-1.091	1.543	0.402
40	(File)-(File)-(Task)	0.467	0.028	4.838	216.000	-1.091	1.543	0.402
41	(Forum)-(Forum)-(Forum)-(Forum)-(Forum)-(Forum)	0.467	0.028	4.838	220.000	-1.091	1.543	0.402
42	(Task)-(Course)-(Test)	0.467	0.028	4.838	222.000	-1.091	1.543	0.402
43	(Course)-(Course)-(Course)-(Test)-(Test)-(Test)	0.700	0.035	4.464	52.000	-0.802	1.134	0.386
44	(Course)-(Course)-(File)	0.700	0.035	4.464	53.000	-0.802	1.134	0.386
45	(Course)-(Test)-(Test)-(Test)-(Test)	0.700	0.035	4.464	60.000	-0.802	1.134	0.386
46	(Course)-(Test)-(Test)-(Test)-(Test)-(Test)	0.700	0.035	4.464	61.000	-0.802	1.134	0.386
47	(File)-(File)-(Test)-(Test)	0.700	0.035	4.464	63.000	-0.802	1.134	0.386
48	(Test)-(Test)-(Course)-(Course)-(Course)-(Test)	0.700	0.035	4.464	69.000	-0.802	1.134	0.386
49	(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)	0.700	0.035	4.464	70.000	-0.802	1.134	0.386
50	(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)	0.700	0.035	4.464	71.000	-0.802	1.134	0.386
51	(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)	0.700	0.035	4.464	72.000	-0.802	1.134	0.386
52	(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)	0.700	0.035	4.464	73.000	-0.802	1.134	0.386
53	(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)	0.700	0.035	4.464	74.000	-0.802	1.134	0.386
54	(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)	0.700	0.035	4.464	75.000	-0.802	1.134	0.386
55	(Course)-(File)-(Course)-(Test)	0.300	0.035	4.464	484.000	-1.225	1.732	0.386
56	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)-(Course)-(Course)	0.300	0.035	4.464	487.000	-1.225	1.732	0.386
57	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)	0.300	0.035	4.464	488.000	-1.225	1.732	0.386
58	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)	0.300	0.035	4.464	489.000	-1.225	1.732	0.386
59	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)	0.300	0.035	4.464	490.000	-1.225	1.732	0.386

60	(Course)-(File)-(File)-(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)	0.300	0.035	4.464	491.000	-1.225	1.732	0.386
61	(Course)-(File)-(Link)	0.300	0.035	4.464	494.000	-1.225	1.732	0.386
62	(Course)-(Test)-(Test)-(Test)-(Test)-(Test)-(Course)	0.300	0.035	4.464	506.000	-1.225	1.732	0.386
63	(File)-(Course)-(Forum)-(Forum)-(Forum)	0.300	0.035	4.464	511.000	-1.225	1.732	0.386
64	(File)-(File)-(File)-(Task)	0.300	0.035	4.464	519.000	-1.225	1.732	0.386
65	(Forum)-(Forum)-(Course)-(Page)-(Course)	0.300	0.035	4.464	534.000	-1.225	1.732	0.386
66	(Task)-(Course)-(Forum)	0.300	0.035	4.464	543.000	-1.225	1.732	0.386
67	(Task)-(Course)-(Forum)-(Forum)	0.300	0.035	4.464	544.000	-1.225	1.732	0.386
68	(Task)-(Course)-(Test)-(Test)	0.300	0.035	4.464	546.000	-1.225	1.732	0.386
69	(Course)-(File)-(File)-(Test)	0.600	0.048	3.906	108.000	-0.866	1.225	0.361
70	(Task)-(Task)-(Task)	0.600	0.048	3.906	116.000	-0.866	1.225	0.361
71	(Task)-(Task)-(Task)-(Task)	0.600	0.048	3.906	117.000	-0.866	1.225	0.361
72	(Task)-(Task)-(Task)-(Task)-(Task)	0.600	0.048	3.906	118.000	-0.866	1.225	0.361
73	(Task)-(Task)-(Task)-(Task)-(Task)-(Task)	0.600	0.048	3.906	119.000	-0.866	1.225	0.361
74	(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)	0.600	0.048	3.906	124.000	-0.866	1.225	0.361
75	(Course)-(Course)-(Test)-(Test)-(Test)-(Test)	0.400	0.048	3.906	279.000	-1.061	1.500	0.361
76	(File)-(Link)	0.400	0.048	3.906	298.000	-1.061	1.500	0.361
77	(Forum)-(Forum)-(Forum)-(Course)-(File)	0.400	0.048	3.906	305.000	-1.061	1.500	0.361
78	(Forum)-(Forum)-(Forum)-(Forum)-(Course)-(Forum)	0.400	0.048	3.906	307.000	-1.061	1.500	0.361
79	(Forum)-(Forum)-(Forum)-(Forum)-(Forum)-(Forum)-(Course)	0.400	0.048	3.906	308.000	-1.061	1.500	0.361
80	(Test)-(Test)-(Course)-(Test)-(Test)-(Course)	0.400	0.048	3.906	321.000	-1.061	1.500	0.361

Chapter 6 – Appendix 3

#	Sub-sequence	Support	p.value	statistic	index	Resid.1	Resid.2	Resid.3	Resid.4	Resid.5	Cramer's V
1	(Test)-(Page)	0.28	0.008	13.846	1274	-0.53	2.37	-1.39	-0.52	1.37	0.877
2	(Course)-(Course)-(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.28	0.023	11.354	1034	1.37	-0.91	-1.39	1.81	-0.53	0.794
3	(Course)-(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.28	0.008	13.846	1260	-0.53	2.37	-1.39	-0.52	1.37	0.877
4	(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.28	0.008	13.846	1243	-0.53	2.37	-1.39	-0.52	1.37	0.877

5	(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.28	0.008	13.846	1208	-0.53	2.37	-1.39	-0.52	1.37	0.877
6	(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.28	0.008	13.846	940	-0.53	2.37	-1.39	-0.52	1.37	0.877
7	(Test)-(Test)-(Test)-(Test)-(Course)-(Course)-(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.28	0.008	13.846	957	-0.53	2.37	-1.39	-0.52	1.37	0.877
8	(File)-(Course)-(File)-(Task)	0.33	0.034	10.393	782	-0.58	2.00	-0.87	-0.71	1.15	0.760
9	(File)-(File)-(Course)-(File)-(Task)	0.33	0.034	10.393	916	-0.58	2.00	-0.87	-0.71	1.15	0.760
10	(Course)-(Test)-(Test)-(Test)-(Course)-(Test)-(Test)-(Test)-(Test)	0.28	0.028	10.879	1079	-0.53	2.37	0.04	-1.29	-0.53	0.777
11	(Test)-(Link)	0.33	0.034	10.393	906	-0.58	2.00	-0.87	-0.71	1.15	0.760
12	(Test)-(Link)-(Course)	0.28	0.023	11.354	1257	1.37	-0.91	-1.39	1.81	-0.53	0.794
13	(Test)-(Test)-(Link)	0.28	0.023	11.354	1258	1.37	-0.91	-1.39	1.81	-0.53	0.794
14	(Test)-(Test)-(Link)-(Course)	0.33	0.024	11.250	908	-0.58	0.00	-1.53	2.12	-0.58	0.791
15	(Test)-(Test)-(Page)	0.22	0.036	10.286	1756	-0.47	-0.82	-1.25	2.31	-0.47	0.756
16	(Course)-(Course)-(Test)-(Course)	0.22	0.036	10.286	1755	-0.47	-0.82	-1.25	2.31	-0.47	0.756
17	(File)-(File)-(File)-(Test)-(Test)-(Course)	0.39	0.004	15.195	710	-0.62	-0.15	-1.65	2.40	-0.62	0.919
18	(Page)-(Course)-(File)-(File)	0.28	0.023	11.354	1238	1.37	-0.91	-1.39	1.81	-0.53	0.794
19	(Page)-(Course)-(File)-(File)-(File)	0.28	0.023	11.354	1239	1.37	-0.91	-1.39	1.81	-0.53	0.794
20	(Course)-(Test)-(Test)-(Test)-(File)-(File)	0.72	0.028	10.879	167	0.33	0.57	-1.36	0.80	0.33	0.777
21	(Test)-(Test)-(File)-(File)	0.28	0.048	9.574	994	-0.53	2.37	-0.68	-0.52	-0.53	0.729
22	(Test)-(Test)-(Test)-(File)-(File)	0.28	0.048	9.574	993	-0.53	2.37	-0.68	-0.52	-0.53	0.729
23	(Task)-(File)-(Course)	0.28	0.048	9.574	992	-0.53	2.37	-0.68	-0.52	-0.53	0.729
24	(Test)-(File)-(Forum)	0.28	0.048	9.574	991	-0.53	2.37	-0.68	-0.52	-0.53	0.729
25	(Test)-(File)-(Forum)-(Forum)	0.28	0.048	9.574	990	-0.53	2.37	-0.68	-0.52	-0.53	0.729
26	(Course)-(File)-(Task)-(Task)	0.22	0.011	13.041	1470	-0.47	2.86	-0.45	-1.15	-0.47	0.851
27	(Course)-(File)-(Task)-(Task)-(Task)	0.22	0.011	13.041	1458	-0.47	2.86	-0.45	-1.15	-0.47	0.851
28	(Course)-(File)-(Task)-(Task)-(Task)-(Task)	0.22	0.036	10.286	1694	-0.47	-0.82	-1.25	2.31	-0.47	0.756
29	(Course)-(File)-(Task)-(Task)-(Task)-(Task)-(Task)	0.61	0.029	10.787	288	0.50	-1.35	-0.13	1.22	-0.78	0.774
30	(Course)-(File)-(Task)-(Task)-(Task)-(Task)-(Task)-(Task)	0.61	0.029	10.787	287	0.50	-1.35	-0.13	1.22	-0.78	0.774