Pedagogical content knowledge in preservice preschool teachers and its association with opportunities to learn during teacher training

Joke Torbeyns, Sandy Verbruggen, and Fien Depaepe

KU Leuven, Center for Instructional Psychology and Technology, Dekenstraat 2, postbox 3773, 3000 Leuven, Belgium

Correspondence concerning this article should be addressed to Joke Torbeyns, KU Leuven, Center for Instructional Psychology and Technology, Dekenstraat 2, postbox 3773, 3000 Leuven, Belgium. Phone: +32 16 325718. E-mail: joke.torbeyns@kuleuven.be

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KU Leuven, Belgium

Abstract

Teachers' pedagogical content knowledge (PCK) importantly contributes to instructional quality and student outcomes. We aimed to complement the limited insights into preservice preschool teachers' PCK, and its association with opportunities to learn (OTL), during teacher training. We offered 162 first-to-final-year preservice preschool teachers from two different teacher training institutes in Flanders (Belgium) a recently developed scenario-based instrument addressing students' understanding of preschoolers' (mis)conceptions and appropriate instructional strategies in the domain of early mathematics. Our findings revealed quantitative differences between first-year students' PCK on the one hand and second-year and third-year students' PCK on the other hand. We did not observe any quantitative differences in PCK between second-year and third-year students. Additional analyses on students' errors pointed to qualitative differences between first-, second- and third-year students' PCK. We interpret these findings in view of students' OTL during teacher training, and discuss their theoretical and methodological implications for future work in the domain of teacher competence.

Keywords (4 to 6 keywords): pedagogical content knowledge; preschool; early mathematics; scenario-based instrument; opportunities to learn; teacher training

1. Introduction

For several decades already, the characterization of teacher quality has been considered a timely issue for both researchers and practitioners in the field of education. *Teacher quality* refers to the teacher-specific competencies that enable favorable educational outcomes (Cochran-Smith and Fries 2005). Cumulative evidence indicates that teachers' professional knowledge importantly contributes to instructional quality and student outcomes (see, e.g., the review by Depaepe et al. 2013; and the meta-analysis by Hattie 2009). This knowledge is acquired in formal, profession-specific learning environments, including teacher training (Darling-Hammond et al. 2005; Grossman 1990; Shulman 1987). Teachers' pedagogical content knowledge has been identified as an important component of their professional knowledge (Blömeke et al. 2015; Depaepe et al. 2013). Teachers' *pedagogical content knowledge* refers to "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman 1987, p. 8). Two major components of teachers' pedagogical content knowledge are (1) teachers' knowledge of students' (mis)conceptions, and (2) their knowledge of instructional strategies (Depaepe et al. 2013; Shulman 1986). Given the contribution of young children's mathematical competencies to their further academic and professional career (Duncan et al. 2007) and the scarcity of studies on preschool teachers' professional knowledge in the domain of early mathematics (Blömeke et al. 2017; Ginsburg and Amit 2008), we aimed at investigating preservice preschool teachers' mathematical pedagogical content knowledge, taking into account the theoretical and practical opportunities to learn during teacher training.

1.1 Teacher competence: conceptual and methodological framework

Although researchers generally agree on the importance of teacher competence for instructional quality and student outcomes, there is far less consensus on the definition and measurement of this concept. As Blömeke et al. (2015) discuss, competing competence definitions can be fruitfully integrated into one process-oriented model, in which teacher competence is conceptualized as a horizontal continuum that consists of multiple facets or dimensions. The first major dimension refers to teachers' *disposition*, defined as their cognitive, affective and motivational competencies. Teachers' content knowledge (CK) and pedagogical content knowledge (PCK) are part of their cognitive competencies. Teachers' affective and motivational competencies include, among others, their self-efficiency and interest in the specific subject domain. The second major dimension includes teachers' *situation-specific skills*, defined as their perception, interpretation and decision-making in concrete classroom situations. The third dimension is teachers' actual observable behavior or *performance* during teaching practice. According to this model, teacher competence needs to be conceptualized as one continuum that integrates these three dimensions: it is defined as a complex competence in which unobservable complex cognitive, affective and motivational competencies complement situation-specific perception, interpretation and decision-making processes underlying actual teaching behavior. The integration of these different aspects of teacher competence into one model allows researchers to overcome unproductive dichotomies between conceptualizations that focus on only one part of the continuum.

The conceptualization of teacher competence as a horizontal continuum that integrates teacher disposition, situation-specific skills and actual performance has also important methodological implications. Rather than focusing on either cognitively-inspired or situation-oriented measurement instruments and analysis techniques, Blömeke et al. (2015) pleaded for the integration of a broad range of assessment and analytic approaches (for similar arguments, see Depaepe et al. 2013; Kaiser et al. 2015). Previous studies mainly relied on one specific type of measurement approach, ranging from cognitively-inspired paper-and-pencil tests to address teacher's cognition, affect and motivation, through video vignettes or video stimulated interviews to assess their situation-specific skills, to classroom observations with the aim of investigating their actual teaching behavior. As argued by Blömeke et al. (2015), the integration of different measurement approaches can seriously enhance our understanding of the different facets underlying teacher competence as well as their interrelations. The recent studies by Kaiser et al. (2017), by Knievel et al. (2015), and by Krauss et al. (2019), complementing cognitively-inspired paper-and-pencil tests to assess teachers' CK and PCK with video vignettes to analyze their situation-specific skills, are fruitful examples of such an integrated approach. In the present study, we especially focus on preservice teachers' PCK as an essential facet of their competence.

1.2 Teachers' pedagogical content knowledge: conceptual and methodological approach

Shulman (1987) was the first to address teachers' PCK as an essential facet of teacher competence. He defined it as a type of knowledge that is unique for teachers, integrating both content and pedagogy. As discussed by Depaepe et al. (2013), most studies on teachers' PCK in the domain of mathematics relied on a cognitive approach to investigate this important component of teacher competence.

Studies formulated from a *cognitive* perspective define PCK as static domain-specific knowledge that can be assessed independently of the classroom context. In line with this definition, advocates of the cognitive perspective investigate teachers' PCK mainly via knowledge-focused paper-and-pencil tests. Although the cognitive perspective allows large-scale assessments of teachers' PCK and, as such, enables the design of measurement instruments of high psychometric quality and systematic analyses of teachers' PCK in relation to other teacher characteristics, instructional quality and student achievements, this perspective also has its weaknesses. Specifically, its decontextualized definition and operationalization of PCK limits our insights into the major characteristics of this type of knowledge and its complex interactions with the actual classroom context in which it is applied. It is therefore necessary to complement the findings coming from cognitively-inspired studies with investigations that attempt to take into account the characteristics of the actual classroom context as well. Such integrative attempts relate to a more *situated* perspective on PCK, in which PCK is conceptualized as dynamic knowledge-in-action that can be understood only in close relation to the specific classroom context. Given the close relation between teachers' PCK and the classroom context, advocates of the situated perspective typically rely on classroom observations and teacher interviews to investigate teachers' PCK. Classrooms observations and teacher interviews allow qualitatively rich and detailed analyses of teachers' PCK, but are hard to apply in large-scale assessments.

Taking into account the plea for an integrated approach towards the study of teacher competence (Blömeke et al. 2015) and the strengths and weaknesses of cognitively-inspired and situation-oriented perspectives on PCK (Depaepe et al. 2013), we designed the present study to analyze preservice preschool teachers' PCK from a cognitively-inspired perspective, but with special attention to its enactment in concrete classroom situations (cf. the situation-oriented perspective). Concretely, we defined teachers' PCK as their knowledge of children's (mis)conceptions and instructional strategies in the domain of mathematics, and used a scenario-based instrument consisting of written descriptions of concrete classroom situations to assess this knowledge (see also Gasteiger et al. 2019). Following this approach, we investigated a large group of preservice preschool teachers' PCK in relation to the theoretical and practical opportunities to learn during teacher training.

2.3 The scenario-based instrument

McCray (2008) did pioneering work on preschool teachers' PCK, following a scenario-based approach. In his scenario-based interview, he confronted preschool teachers with a written description of a typical preschool situation (i.e., a *scenario*). The scenario included mathematically-rich interactions between the children, and was followed by a series of open-response questions that invited the teachers to reflect on the scenario in view of early mathematical development. Teachers' responses to these scenario-related reflective questions were next analyzed in terms of their ability to notice and enhance young children's early mathematical skills in play-based situations—their PCK.

The scenario-based instrument of McCray (2008) formed the basis for both small-scale interview studies and large-scale paper-and-pencil investigations on preschool teachers' PCK in the domain of mathematics. Using the original scenario-based instrument of McCray (2008), McCray and Chen (2012) and Lee (2017) investigated in-service preschool teachers' PCK in an interview format. These studies revealed a positive association between preschool teachers' PCK and their instructional quality and preschoolers' learning outcomes (McCray and Chen 2012) as well as differences in preschool teachers' PCK amongst the different topics of the early mathematics curriculum (with higher PCK for number sense, measurement, and classification than for patterns, operations, shapes, and spatial relations) and amongst teachers with more versus less years of teaching experience (favoring the former).

Complementing these small-scale interview studies, Anders and Rossbach (2015), Lee (2010), and Oppermann et al. (2016) investigated larger samples of in-service preschool teachers via a modified version of the scenario-based instrument. These researchers confronted their participants with the same scenario as the interview studies, but addressed preschool teachers' PCK in written format, asking them to write down their responses to the scenario-related questions. These large-scale studies revealed positive associations between, on the one hand, preschool teachers' PCK and, on the other hand, their emotional attitudes towards mathematics and their mathematical self-efficacy (Anders and Rossbach 2015; Oppermann et al. 2016). Moreover, preschool teachers' PCK was found to differ with regard to both curricular topic (with highest PCK scores for number sense) and teaching experience (favoring more experienced teachers) (Lee 2010).

Confronted with the methodological and practical challenges of collecting, scoring and analyzing teachers' answers to the open-response questions in the above mentioned interview and paper-and-pencil studies, Gasteiger et al. (2019) developed a new scenario-based measurement instrument to address preschool teachers' PCK. In line with previous studies using the scenario-based instrument with open-response questions of McCray (2008), this new scenario-based measurement instrument confronts preschool teachers with written descriptions of typical classroom situations that involve mathematically rich interactions between the children. Different from McCray (2008)'s instrument, the scenarios are followed by a series of multiple-choice questions focusing on preschoolers' mathematical abilities and teachers' instructional strategies to enhance the development of these abilities. Although these multiple-choice questions do not allow researchers to collect qualitatively rich data on teachers' PCK, they have clear methodological advantages when compared to open-response questions. First, the responses to multiple-choice questions are easy to score, without the need to agree on clear and objective coding schemes and additional extensive training for all scorers (contrasting the need to develop methodologically strong coding schemes that are strictly applied by well-trained scorers in case of open-response questions). Second, both the collection and the scoring of the responses to multiple-choice questions require little time (contrasting the serious time investment for both participants and researchers when using open-response questions). Gasteiger et al. (2019) investigated the psychometric qualities of their new instrument in research with both preservice and in-service preschool teachers in Germany. Their findings provided empirical support for both the reliability and the validity of their scenario-based instrument. Given the methodological strengths of this new scenario-based instrument in terms of administration and scoring as well as reliability and validity, we used an adapted version of the instrument developed by Gasteiger and colleagues (2019) to investigate Flemish preservice preschool teachers' PCK.

2.4 Opportunities to learn during teacher training

Schmidt and colleagues (2011) distinguished among different types of OTL during teacher training that impact the development of PCK. These authors define OTL as "the content to which future teachers are exposed as a part of their teacher preparation programs" (Schmidt et al. 2011, p. 140). Concretely, they distinguish four main types of OTL during teacher training, namely, theoretical courses on CK, theoretical courses on PCK, theoretical courses on general pedagogy, and practical experiences. Although these four types of OTL are assumed to be fundamental for acquiring teacher competence and are shown to differ among different teacher training institutes in both the national and international context (Blömeke et al. 2014; Schmidt et al. 2011), empirical investigations on their associations with the acquisition of PCK in preservice teachers in general, and preservice preschool teachers specifically, are scarce.

The limited number of available studies all point to theoretical courses on PCK in the domain of mathematics as the major source for acquiring this important type of knowledge during teacher training for preservice teachers at the preschool level (Blömeke et al. 2017) and beyond (Blömeke et al. 2014; Kleickman et al. 2013; Qian and Youngs 2016). Although teaching experience was shown to be important for the further development of PCK in in-service teachers (Kaiser et al. 2017), also at the preschool level (Lee 2010, 2017), there is currently no strong empirical evidence for the assumed contribution of practical courses such as student internships to the acquisition of PCK during teacher training. Kleickmann et al. (2013) questioned the contribution of teaching experience alone for the development of PCK during teacher training (secondary school level). On a related note, Strawhecker (2005) pointed to the superior effectiveness of theoretical courses with field experiences (i.e., teaching experience embedded in theoretical courses) for the development of PCK in preservice primary school teachers, compared to only theoretical courses or only field experiences.

The scarce empirical investigations on, and—relatedly—empirical support for, the contribution of practical experiences to the acquisition of PCK during teacher training is of serious concern, given the assumed relevance of this type of experience at both the theoretical and practical levels. We aimed to complement current insights into the contribution of theoretical and practical experiences to the acquisition of PCK during teacher training by analyzing preservice preschool teachers' PCK in view of their theoretical courses on PCK in the domain of mathematics and their practical experiences, i.e., student internships.

1.3 The present study

The study was conducted in Flanders, Belgium. Flemish preschool education is open for children aged 2-and-a-half years up to 6 years. Flemish preschool education is organized in three preschool years: the first year includes 2-and-a-half to 4-year-olds, the second year 4–5-year-olds, and the third year 5–6-year-olds. Although Flemish preschool is not compulsory, more than 95% of Flemish children in these age ranges attends preschool education. Preschool teachers are expected to stimulate the development of core competencies in all curricular domains, i.e., (Dutch) language, mathematics, science and technology, arts, social and emotional development and physical skills. The Flemish government formulated developmental goals in each curricular domain that preschool teachers need to strive for in all preschoolers, without the requirement that all goals be effectively reached by all preschoolers. The development of core competencies is stimulated in informal learning situations. These informal learning situations typically consist of age-appropriate play-based learning activities, mainly focusing on core competencies from different curricular domains in an integrated way (although curricular-specific activities are also organized, albeit to a lesser extent).

Flemish preschool teachers are all trained as generalists, which means that they are trained to acquire all competencies that are needed to enhance preschoolers' development in all curricular domains. They are trained as professional bachelors, at non-university teacher training institutes. The bachelor program involves three years of training. It consists of 180 ECTS credits (i.e., 60 ECTS credits per year of training), including 45 ECTS credits for practical internships. Early mathematics is one of the theoretical courses offered during teacher training, next to theoretical courses in all other curricular domains and in general pedagogy and psychology. Student internships typically focus on teaching competencies in all curricular domains (and not only mathematics), aiming for the informal and play-based stimulation of different core competencies in an integrated way.

The present study investigated PCK in the domain of mathematics in three cohorts of preservice preschool teachers coming from two different teachers training institutes. The three cohorts of students differed in both theoretical and practical OTL. The first cohort, first-year preservice preschool teachers, had received no theoretical courses on PCK in the domain of mathematics and did not yet engage in teaching (practical experiences). The second cohort, second-year preservice preschool teachers, had successfully completed all theoretical courses on PCK in the domain of mathematics and had received limited teaching experience. The third cohort of final-year preservice preschool teachers had also completed their theoretical courses on PCK in the domain of mathematics, but had more teaching experience than the second-year students. We measured all preservice preschool teachers' PCK via an adapted version of the scenario-based measurement instrument of Gasteiger and colleagues (2019). We analyzed first-, second- and third-year preservice preschool teachers' PCK. On the basis of previous studies on the contribution of theoretical courses on PCK to its acquisition during teacher training, we expected differences in PCK between first-year students who had not yet received theoretical courses on PCK in the domain of mathematics and second- and third-year students who had finished all theoretical courses on PCK in the domain of mathematics. We additionally expected differences between second- and third-year students on the basis of their practical OTL, with higher PCK in third-year than in second-year students.

2. Method

2.1 Participants

We invited all first- to third-year preservice preschool teachers from two different teacher training institutes in Flanders, Belgium. In line with the Flemish teacher training regulations, their professional bachelor program consisted of 180 ECTS credits (60 ECTS credits per year), with about ¼ of the credits related to internships. Table 1 describes the scheduling as well as the credits related to early mathematics PCK courses and internships per teacher training institute per year. Table 1 further includes the background characteristics of the students: the number of participating students, their gender (number of female students), age (in years) and educational track in secondary education (academic, vocational, technical/arts).

Table 1. Descriptive characteristics of the teacher training program and participants per teacher training institute per year

Teacher training institute	Year	Theoretical courses on early math PCK			Internships			*n*	*n* female	Age in years (*SD*)	Educational track sec. education[a]		
		Semester 1	Semester 2	ECTS credits	Semester 1	Semester 2	ECTS credits				AC	VO	T/A
1	1	--	X	3	X	X	9	29	27	21.28 (3.57)	2	13	14
	2	X	--	3	X	X	15	13	13	21.08 (1.12)	4	4	5
	3	--	--	0	X	X	21	22	22	27.91 (7.55)	5	7	10
2	1	--	X	3	X	X	6	31	31	19.90 (1.08)	6	6	19
	2	X	--	3	X	X	14	52	49	21.62 (1.98)	6	12	34
	3	--	--	0	X	X	25	15	12	23.60 (4.94)	3	5	7

Note. [a]AC = academic, VO = vocational, T/A = technical and arts. Given both the small number of students who followed the Arts educational track in secondary education and the similarities between the Arts and Technical education track, we grouped the students who followed the Arts educational track in secondary education (first year: *n* = 2; second year: *n* = 5; and third year: *n* = 3) with the students who followed the Technical educational track.

All first- to third-grade students from both teacher training institutes were invited to participate to the study. We received the active informed consent of 202 students. As there is a strong selection between the first and second year of teacher training, first-year students who did not successfully end their first year of teacher training were excluded from the final sample. The final sample consisted of 162 students (154 female students; 60 first-year, 65 second-year and 37 third-year students, see Table 1).

As shown in Table 1, the schedule and the number of credits for both the early mathematics PCK courses and the internships during the three-year teacher training program were highly comparable between the two teacher training institutes. In both teacher training institutes, theoretical courses on PCK in the domain of mathematics were scheduled in the second semester of the first year of training and in the first semester of the second year of training, accounting for 3 of the 60 ECTS in each respective year. As we conducted the study at the start of the second semester, the first-year students had not yet engaged in teaching activities at the moment of the data collection. The second-year students had fulfilled teaching activities during about 3 weeks (in the second semester of their first year and the first semester of their second year). The third-year students had completed about 10 weeks of internship (in their first, second, and first semester of third year) but still needed to start their long-term internship period of 9 weeks (second semester of third year of training). It is important to note here that the PCK courses focused on preservice preschool teachers' PCK in the domain of early mathematics, with only limited attention given to their CK in this domain. In the theoretical courses on PCK, important insights into the early mathematical abilities of preschoolers and the effective stimulation of these abilities were accompanied with concrete examples. During their internship periods, the students designed and implemented informal play-based learning activities for preschoolers, with discussion of both the content and the organization of these activities with mainly the preschool teacher who supervised them and to a lesser extent their teacher trainer from the teacher training institute. As the students of the two teacher training institutes did not differ in their background characteristics (i.e., gender, age, educational track in secondary education), we decided to group the students together across the two teacher training institutes in all further analyses.

2.2 Instrument

All students were offered an adapted version of the preschool PCK test developed by Gasteiger and colleagues (2019). In line with the original instrument, the adapted instrument included four concrete descriptions of preschool situations that allow mathematical interactions and reflections, namely, two situations on number, one situation on measurement and one situation on geometry. Each situation was followed by a series of multiple-choice items addressing the major components of preschool teachers' PCK (i.e., students' (mis)conceptions and appropriate instructional strategies). Appendix 1 presents an example from the domain of number, including the description of the situation and two sample items.

Each situation was followed by two different types of multiple-choice items. The first type of multiple-choice items focused on preschool teachers' insights into children's mathematical abilities (see items labeled A in Appendix 1). Each item presented a specific mathematical ability. The respondent was asked to indicate whether (a) the child masters the respective ability, (b) the child does not master this ability, (c) the mastery level of the relevant ability is not observable in the situation, or (d) s/he does not know the answer to the item. The second type of multiple-choice items addressed preschool teachers' knowledge of instructional strategies to enhance the mathematical abilities involved in the situation (see items labeled B and C in Appendix 1). Each item presented four different instructional activities, and the respondent was asked to indicate which instructional activity is most effective to stimulate the child's mathematical abilities as presented in the situation.

We included the four preschool situations and the related multiple-choice items from the original instrument in our adapted version of the instrument. These four situations and their accompanying items were translated into Flemish and retranslated into German by two experts in the Flemish and German languages. In view of the Flemish preschool curriculum, we complemented the four situations from the original instrument with one additional situation on time measurement. This additional situation on time measurement is presented in Appendix 2.

We also added items addressing preschoolers' mathematical abilities to equalize the number of items per situation and reformulated some items in view of the concepts Flemish preschool teachers need to master at the end of their training (e.g., Situation 1, Item A3: use of the term "one-one correspondences" in the Flemish version of the questionnaire instead of the term "unequivocal mapping" in the original German instrument). These two adaptations resulted in an instrument consisting of five scenarios of mathematically-rich preschool situations, followed by eight multiple-choice items addressing preschoolers' mathematical abilities in the situation and two multiple-choice items focusing on effective instructional strategies to enhance these abilities. All items were scored according to a binary scale (0 for an incorrect answer, 1 for a correct answer), with a maximum test score of 50.

To assess the reliability of the adapted version of the instrument, we calculated its internal consistency via Cronbach's alpha. Students' responses were used as data for these reliability analyses. Cronbach's alpha for the instrument as a whole was .74 for the sample as a whole (first-to-final-year students), and close to .70 for the different cohorts (respectively .69, .71 and .71 for the first-, second- and third-year students). We also evaluated the content validity of our instrument by offering it to seven experts in the domain of early mathematics. The expert panel was conducted simultaneously with the data collection in the students, and involved meetings with the experts and one member of the research team. The group of seven experts consisted of three members of the Flemish preschool education inspection team and four teacher trainers with expertise in the domain of early mathematics. All experts positively evaluated the content validity of the instrument, but suggested some changes in view of a clearer formulation of some of the items in future studies.

2.3 Procedure

We offered all students our PCK instrument in the first weeks of the second semester. The instrument was offered collectively (paper-and-pencil test; collective test administration per year of training) during regular course hours at the teacher training institutes. The data collection was guided by a student researcher and the early mathematics teacher educator of the teacher training institute. The students were asked to read the five descriptions of the preschool situations carefully and answer all items related to the respective situations by marking the correct response. All students had 60 minutes time to complete the instrument. We registered students' written responses per situation per item.

2.4 Analyses

We addressed our major research question in two steps. We first analyzed quantitative differences in PCK between first-, second- and third-year students on the basis of an ANOVA on students' scores, with year of training (1, 2, 3) as independent variable and controlling for students' educational track in secondary education (academic, vocational, technical/arts). As these quantitative analyses provide no information about the specific weaknesses in students' PCK, we explored in the second step whether the students from the three cohorts were confronted with the same difficulties in answering the different test items. Concretely, for each cohort, we identified the items that were difficult for most students in the cohort, i.e., items with an accuracy score of .50 or less. We first compared the items that confronted the students with difficulties among the three cohorts (i.e., same or different items erroneously answered), and next looked for similarities and differences in first-, second- and third-year students' erroneous responses on these most difficult items.

3. Results

Students' scores on the PCK instrument ranged from 14 to 46 (maximum test score = 50), with a mean score of 34.15 (SD = 5.76). We conducted an ANOVA on students' PCK scores (total test score) with year of training (1, 2, 3) as independent variable and controlling for students' educational track in secondary education (academic, vocational, technical/arts). Students' educational track in secondary education did not contribute to their level of PCK, p. = .22, but their year of training did, $F(2, 157) = 14.27$, $p < .001$. First-year students (M = 31.18, SD = 5.35) scored lower on the PCK instrument than second-year and third-year students (respectively, M = 35.91, SD = 5.32 and M = 35.86, SD = 5.26; $ps < .001$). There were no quantitative differences in PCK scores between second-year and third-year students (p. = .99).

We next did a qualitative analysis of students' erroneous responses on the most difficult items. This analysis consisted of two steps. In the first step, for each cohort of students we examined which items had a mean accuracy level of .50 or less. In the second step, we explored the similarities and differences in the selected erroneous multiple choice alternatives across the three cohorts of students for all these items.

In the first step, we identified 18 items that were answered incorrectly by at least half of the first-year students: 12 items addressing preschoolers' (mis)conceptions and 6 items related to appropriate instructional strategies. The group of second-year students answered 13 of these 18 items also at an accuracy level of .50 or lower (i.e., 9 items on preschoolers' [mis]conceptions and 4 items on appropriate instructional strategies); this group of students did not answer any other item at an accuracy level of .50 or lower. Third-year students answered (only) 11 of these 13 items with low accuracy (i.e., .50 or lower): 8 items on preschoolers' (mis)conceptions and 3 items on appropriate instructional strategies.

The second step focused on the incorrect answers of the first-, second- and third-year students on these most difficult items. We first explored the items that were answered at a low accuracy level in only first-year students. Four items addressing students' understanding of preschoolers' (mis)conceptions in the domain of early mathematics, and one item focusing on instructional strategies to enhance preschoolers' mathematical development, were difficult for only the first-year students. An analysis of the most frequently given wrong responses of the first-year students on these items revealed weaknesses in their theoretical understanding of preschoolers' early mathematical development and appropriate instructional interventions. For instance, in Situation 1 (see Appendix 1), the items A2 and A3 were answered with less than .50 accuracy by only first-year students. For item A2, more than half of the first-year students (i.e., 57%) thought that Max was able to say how many children wanted to play with the game and thus mastered resultative counting. For item A3, about one third of the first-year students (i.e., 32%) indicated they did not know the correct response. When asked to indicate the most appropriate instructional strategy to enhance Bas' understanding of time measurement in Situation 5 (see Appendix 2, Item B), half of the first-year students thought it would be appropriate to simply repeat the activity (i.e., 53%), pointing to weaknesses in students' understanding of effective instructional strategies.

Both first- and second-year students had difficulties in selecting an appropriate instructional strategy to stimulate the counting development of Max in Situation 1 (see Appendix 1, Item B). Only 42% of the first-year and 54% of the second-year students correctly focused on resultative counting in their instructional strategy. Counting backwards from five to one was most frequently indicated as an appropriate strategy by first-year students (i.e., 37% of the first-year students), whereas this inappropriate instructional strategy was selected by only 20% of the second-year students. The latter group of students pointed to counting forwards as a first important step in Max' counting development (i.e., 19% of the second-year students). Although both first- and second-year students answered this item with low accuracy, the erroneous responses of the two groups of students point to differences in their understanding of appropriate instructional strategies to enhance preschoolers' counting competencies.

Turning to the 11 items that were difficult for the three groups of students, we observed similar group differences in students' erroneous response patterns. For instance, when asked to indicate the most appropriate instructional strategy for Max in Situation 1 (see Appendix 1, Item C), most first- and second-year students thought that naming numbers and focusing on one-one correspondences would be beneficial for Max' counting development. By contrast, third-year students hardly suggested naming numbers as a good instructional alternative, suggesting a better understanding of valuable instructional strategies in view of preschoolers' misconceptions. Unfortunately, the analysis of students' wrong responses on the items that were difficult for all groups of students did not only reveal group differences in students' PCK but also raised concerns about the formulation of 4 items. One of these items is Item A6 from Situation 5 (see Appendix 2). About 70% of the first- and second-year students and slightly more than 50% of the third-year students stated that Bas did not yet master this skill; the high frequency of this incorrect answer might be due to a misinterpretation of the item by the students rather than weaknesses in their PCK.

In sum, our quantitative analyses of students' scores on the PCK test as a whole indicated clear differences in the level of PCK between first-year students compared to second- and third-year students, favoring the latter groups of students. These findings were supported by our analyses of students' error patterns on the items that were answered least accurately: Both the number and the type of incorrect responses differed between first-year versus second- and third-year students. Our additional analyses also pointed to qualitative differences in the incorrect responses between the second- and third-year students. Although the latter two groups of students performed equally well on the PCK test as a whole, the quality of the incorrect responses they selected on the most difficult items tended to differ, suggesting differences in their understanding of preschoolers' early mathematical development and appropriate instructional strategies to enhance this development that are not reflected in the test scores.

4. Conclusion and Discussion

Cumulative evidence points to the importance of teachers' PCK for instructional quality and student progression (Depaepe et al. 2013; Hattie 2009). Unfortunately, preschool teachers' PCK in the domain of early mathematics only recently attracted the interest of researchers (Blömeke et al. 2017; Ginsburg and Amit 2008). To complement current findings on preservice preschool teachers' PCK, we investigated a large group of first-, second- and third-year preservice preschool teachers' PCK in relation to the theoretical and practical courses provided during teacher training. We administered a cognitively-inspired scenario-based instrument to assess preservice preschool teachers' PCK, focusing on preservice preschool teachers' understanding of preschoolers' (mis)conceptions in the domain of early mathematics and effective instructional strategies in concrete preschool situations. We included theoretical courses on early mathematics PCK and practical experiences (i.e., student internships) as major opportunities to acquire PCK in the domain of early mathematics during teacher training. First-year students had not yet started with their theoretical courses on early mathematics PCK and had no practical experiences. Second-year and third-year students all had completed their theoretical courses on early mathematics PCK but differed in the number of practical experiences, with fewer practical experiences in the second-year than in third-year students' studies at that time.

4.1 Preservice preschool teachers' PCK and OTL during teacher training

As expected, first-year students performed less well on the PCK test than second- and third-year students. This finding points to the contribution of theoretical courses on PCK in the domain of early mathematics to the acquisition of this important type of knowledge during teacher training. It also supports previous conclusions on the pivotal role of theoretical courses on PCK in the development of PCK during teacher training (Blömeke et al. 2014, 2017; Kleickmann et al. 2013; Qian and Youngs 2016). Taken together, these findings have important implications for current teacher training practices, not only in Belgium (Flanders) but worldwide. First, given the pivotal role of theoretical courses in the acquisition of PCK in the domain of early mathematics, teacher trainers should devote sufficient time to these courses. Second, as our findings revealed that third-year students did not yet perform at an expert level on the PCK test, it is important to schedule such theoretical courses not only during the first years of teacher training (as was the case in the teacher training institutes that participated in the present study), but also in the upper and final years.

Although we also had expected quantitative differences in second-year and third-year students' PCK test scores, these two groups of students performed equally well on the test. This finding is in line with previous studies at the elementary and secondary school level that question the contribution of practical experiences to the acquisition of PCK during teacher training (Kaiser et al. 2017, Kleickmann et al. 2013). However, it contrasts the observed association between in-service preschool teachers' teaching experience and their PCK beyond teacher training (Lee 2010, 2017). It is important to note here that our additional analyses of the types of errors on the items that were answered least accurately, pointed to qualitative differences in the selected erroneous answers between the three groups of students, favoring the final-year students. The qualitative differences in the erroneous responses of second-year versus third-year students might indicate an additional influence of practical experiences to students' understanding of preschoolers' (mis)conceptions and appropriate instructional strategies during teacher training, that we were not able to detect on the basis of (only) students' overall test scores.

Given the mixed findings on the contribution of practical experiences to the acquisition of PCK in preservice and in-service teachers (Kaiser et al. 2017; Kleickmann et al. 2013; Lee 2010, 2017) as well as the importance of student internships in teacher training programs, future studies are required in order to disentangle their complex associations. These future studies should, first, focus on a detailed analysis of students' practical experiences during teacher training. Quantitative information about the number of credits and/or number of weeks devoted to student internships needs to be complemented with qualitative data on the theoretical courses that are foundational for and related to these practical internships, as well as the organization and content of reflective meetings with the mentors and the supervising team during the internship periods. As argued by other researchers (e.g., Evens et al. 2017; Kleickmann et al. 2013) both the quantity and the quality of students' practical experiences need to be taken into account in view of their PCK development. Moreover, practical experiences by themselves are insufficient: Critical theoretical reflections on teaching experiences can seriously enhance students' understanding of effective teaching interventions in the domain of (early) mathematics (Strawhecker 2005). Additionally, these future studies should also take into account the time spent on early mathematics during these student internships and reflective meetings, as preschool teachers are trained as generalists in many countries, including Belgium (Flanders). Consequently, the information on student internships at the general level might overestimate students' relevant practical experiences in the domain of early mathematics during their internship periods.

Secondly, to fully capture the development of PCK in early mathematics on the basis of theoretical and practical opportunities to learn, longitudinal designs, following students from their first until their final year of teacher training, are required. The analysis of the developmental trajectories of students from the start until the end of their training can reveal common as well as differential growth rates in PCK in view of theoretical and practical opportunities to learn. Finally, the participation also of in-service teachers who differ in their amount of teaching experience in the domain of early mathematics (cf. Lee 2010, 2017), can enhance our insights into the complexities of the acquisition of PCK not only during teacher training but also beyond.

4.2 Perspectives for future investigations

The current study provided additional support for the psychometric viability and the usefulness of scenario-based instruments for investigating preschool teachers' PCK (see also Gasteiger et al. 2019). Notwithstanding the strengths of this new (type of) instrument, we end our contribution with some critical reflections on its design and formulate suggestions for future investigations.

First, as argued by Blömeke et al. (2015), one can grasp the full complexity of teacher competence only on the basis of both theoretically and methodologically integrated approaches. From a theoretical viewpoint, it is important to address the different facets of teacher competence rather than focus on only one specific facet. On a related note, the integration of diverse methodological approaches can seriously enhance the complexities (of the interrelations) of the different facets. The present study focused on only one facet of teacher competence, i.e., their PCK, relying on a mainly cognitively inspired definition and measurement of this concept. Although this type of study is important for the purpose of increasing our theoretical understanding of the specific facet and the psychometric quality of the measurement instruments used to address it, future studies need to broaden both the theoretical perspective and the methodological approach. The recent studies of Kaiser et al. (2017), Krauss et al. (2019), and of Knievel et al. (2015) that complemented cognitively-inspired paper-and-pencil tests on teachers' PCK with carefully designed video vignettes to analyze these teachers' situation-specific skills, can serve as inspiring attempts to better grasp the complex domain of teacher competence.

Second, focusing on the scenario-based instrument that we used in the present study, further work to optimize its validity and usability is needed. The scenario-based instrument included only multiple-choice items, given their psychometric strengths and usability for large-scale assessments (cf. Kaiser et al. 2015). However, this type of item does not allow fine-grained qualitative information about the structure and content of preservice teachers' PCK and has the risk of respondents exhibiting guessing behaviors. Future studies are needed to explore the feasibility of focused qualitative interviews with selected samples on the basis of their erroneous answers, complementing our item level analyses. Such interviews can reveal qualitative differences in their PCK, comparing starting preservice teachers, their finishing peers and in-service teachers with various teaching experience (cf. Krauss et al. 2008). Although we did not find any evidence for guessing behavior in the students' accuracies and response patterns, this methodological restriction needs to be taken into account in all studies using this (and other) multiple-choice response formats. Next, the imbalanced design of the instrument, with most items focusing on preschoolers' misconceptions in the domain of early mathematics and only a minority of the items addressing effective instructional strategies, as well as the concrete wording of some of the items, require further attention. Focused methodological studies can help to increase the methodological value of this new instrument, making it suitable for large-scale studies following an integrated approach.

4.3 General conclusion

The present study complemented the current research literature on preservice preschool teachers' PCK in the domain of early mathematics by analyzing first- to final-year students'

PCK with a new scenario-based instrument and in relation to the theoretical and practical courses provided during teacher training. Our findings revealed quantitative and qualitative differences in first- to final-year students' PCK that can be interpreted in view of these students' theoretical and practical opportunities to learn during teacher training. As PCK is an important facet of teacher competence and even final-year students do not yet reach an expert level, future studies are needed to unravel the complex interplay between theoretical and practical opportunities to acquire PCK during teacher training and beyond. These studies can provide building blocks to improve current teacher training for preservice teachers and professional development initiatives for in-service teachers, and as such enhance the quality of classroom instruction and children's development in the domain of mathematics.

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Appendix 1: Scenario-based instrument, Situation 1

Max goes to the table with games. There are already four children at the table. The children want to play a game with dice. You ask Max: “How many children want to play the game?”.

Max points to himself and to each individual child at the table. Each time he points to a child, Max slowly states a number word: “One, two, three, four, five!”. He remains silent and looks at you. You ask again: “And? How many children want to play the game?”. Max restarts the counting process and points to each child individually and says: “One, two, three, four, five!”.

You show him the box with the tokens and ask: “Each player needs a token. How many tokens do we need?”. Max looks at you and shrugs.

You say: “How can we find out?”. Max takes a token and puts it next to one of the children at the table. He takes another token and puts this one next to another child at the table. He continues until every child at the table has a token. You ask: “And? How many token did you give to the children?” Max counts the tokens while pointing to them one by one and says: “One, two, three, four, five!”.

A

<u>Max</u> shows that he already knows a lot about number and magnitude. Which abilities does he master already?

Indicate the correct answer with a cross.

	He is able	**He is not able**	**Not observable in the situation**	**I do not know**
A2 Max is able to say how many children would like to play.		X		
A3 Max can make one-one-correspondences.	X			

B

Which of the following activities might help <u>Max</u> best to learn what he is not able to do yet?

Indicate <u>one</u> response.

- O Counting aloud till five with the whole group.
- X Sorting buttons per color, counting the buttons per color, and telling another child how many buttons per color there are.
- O Writing digits in the sand using his finger.
- O Counting backwards from five to one.
- O I don’t know.

C

Which of the following activities might additionally help <u>Max</u> best to learn what he is not able to do yet?

Indicate <u>one</u> response.

X Saying how many coins he has in his wallet when playing a shopping game

O Naming numbers that are presented on cards

O Asking Max to put cups and spoons on the table, with one spoon for each cup

O Using a counting rhyme to determine who can start the game

O I don’t know

Appendix 2: Scenario-based instrument, Situation 5

The preschoolers just received new toys for the class. Each child wants to play with the new toys. The preschool teacher puts an hourglass on the cupboard to indicate how long each preschooler can play with the new toys. If the hourglass shows that the time is over, the next preschooler can play with the new toys.

Bas waits for the hourglass indicating that time is over, while Mia is playing with the new toys. Bas complains: "It takes so long before it's my turn." The hourglass indicates that the time is over and Bas can play with the new toys. The preschool teacher turns around the hourglass and Bas starts playing with the new toys.

Bas plays as long as Mia with the new toys. When the hourglass shows that the time is over, Bas complains: "But the time of playing was much shorter for me than for Mia. Mia was allowed to pay more minutes than me. The hourglass is broken."

A

Bas shows that he already knows a lot about measurement and time. Which abilities does he master already?

Indicate the correct answer with a cross.

	He is able	**He is not able**	**Not observable in the situation**	**I do not know**
A5 Bas can estimate in minutes how long they played with the new toys.			X	
A6 Bas knows that time can be measured in minutes.	X			

B

Which of the following activities might help Bas best to learn what he is not able to do yet?

Indicate one response.

- o Mia and you can play once more with the toys, so that we can compare again.
- o No, the hourglass is still working. Look, we will use it again when Toon is playing with the toys.
- X How can we find out whether the hourglass is really broken? Can we check this?
- o Did Mia play for a longer or a shorter period of time with the toys?
- o I don't know.

C

Which of the following activities might additionally help Bas best to learn what he is not able to do yet?

Indicate one response.

X Timing both the hourglass and the play time of both children with a stopwatch and comparing the measured time.

O Using the hourglass for other activities as well.

O Organizing an introductory observation activity addressing different time measurement instruments (e.g., alarm clock, stopwatch, regular clock, …).

O Allowing Bas to turn around the hourglass instead of his teacher.

O I don't know.