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Developing Engineering-oriented Educational Workshops Within a Student Branch

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***Abstract*—The development of two educational workshops, one on energy efficiency and one on human-machine interfaces, is detailed and discussed. Attraction to engineering is not created as much as lost at early ages through current education methods. Through positive, hands-on experiences with engineering in K-12 education, this trend can be turned. IEEE student branches have as part of their mission the education and creation of quality educational resources for the public. After searching in vain for suitable inexpensive material, the IEEE student branch Leuven decided to design and create two workshops on engineering topics for an audience of 10-12 year olds. Handling this as a repeatable project, the student branch found partners to create a low budget project for the attendees. Using the skillset of the specific partners and organizers optimally on the subtasks, a successful repeatable cooperation is realized. This paper discusses the environment in which the project is realized, the steps to it, and how it (indirectly) benefits the organizing student branch.**

***Index Terms*—Arduino, Scratch, Student branch, K-12 education, workshop design**

I. Introduction

IEEE's mission as a humanitarian organization, is to foster technological innovation and excellence [1]. As such, one of their core values is to encourage education as a fundamental activity of engineers [2]. As an organisation, IEEE commits to provide quality educational resources, not only to their members, but also to educators, parents, students, and the public [3]. In concreto, IEEE cooperates with industry, universities and governments to educate students at pre-college level in science, math, engineering and technology [4].

IEEE hosts many educational programs aimed at pre-university audiences. Two of them focus on K-12 audiences: Teacher-in-service program (TISP) and Try Engineering. Through TISP [5], IEEE volunteers are trained to aid teachers to bring engineering lessons into the classroom. Try Engineering [6] hosts free lesson plans for teachers as well as information on the engineering profession.

IEEE's student member count, as illustrated in Fig. 1, is slowly but steadily increasing in most regions [7]. However, this growth is smaller than the reported increase in students graduating in IEEE's fields of interest (science, engineer, math, informatics) [8], as illustrated in Fig. 2.

ESAT, the Department of Electrical Engineering of the University of Leuven, houses educational facilities for eight electrical engineering masters, as well as eight research groups [9]. It is keen on education through hands-on projects, and requires all its bachelor students to cooperate on a large integrated project [10]. Furthermore, there is a long tradition in participating in pre-university education. Several educational programs for K-12 students are hosted, organized and designed by ESAT or its research groups. Very successful are the summer camps targeted at 10 - 14 year olds, e.g. Ir. 13 [11].

Closely related to ESAT is the RVO-society, which develops

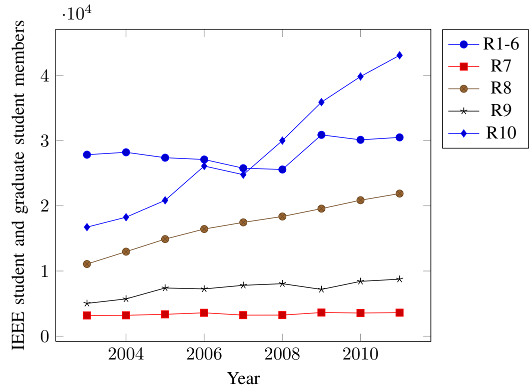

Fig. 1: IEEE student and graduate student member counts [7].

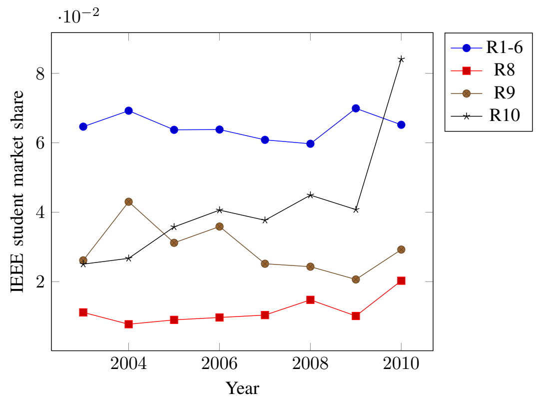

Fig. 2: Ratio of IEEE student members per student count, differentiated by IEEE region. Unesco data not available in this time period for region 7 [7], [8].

educational material on the topic of recent developments in technology and science. It functions as a bridge between education and research, aimed at schools and industry [12].

The 'Kinderuniversiteit' [13] (Children's University) is a annual event organized by the University of Leuven. Across the university, several workshops are held for children, to bring them into contact with science, engineering and academic studies. The age group for these particular workshops was 10 - 13 year olds, on the topic of residential electric heating and lighting.

Each college, university or technical institute can organize student members into an IEEE Student Branch, which represents IEEE and fulfills the needs of the members and the missions of IEEE [14]. Such student branches may host a Women In Engineering (WIE) affinity group. Part of the mission of IEEE WIE is to facilitate the development of programs and activities that promote the entry into and retention of woman in engineering programs [15].

The decisive moment considering careers in science, technology, engineering and math (STEM) is at an early age. Children in the developed world do not see science as a solution to environmental and other world problems [16]. In case science and technology interests children, they do not feel enticed by current education methods [17]. Because traditional STEM teachings at secondary school are abstract, not hands-on, not related to reality or societal improvement, girls loose interest at an early age and hardly find their way into higher STEM education [18], [19]. Early positive and hands-on exposure has proven highly effective in reverting this trend [17], [20], [21].

The University of Leuven hosts the IEEE student branch Leuven [22]. The IEEE student branch Leuven is one of the oldest student branches of Region 8. Current membership is composed of 29 Student Members and 156 Graduate Student Members, of which 20 actively participate in the organization of activities. Last year, 15 technical and 9 non-technical activities were organized. Two student branch chapters are active: a PES chapter with 19 members and a joint IAS/IES chapter with 12 members. This student branch hosts the only WIE affinity group within the Benelux Section, with a membership count of 13. The WIE affinity group was approached by the department ESAT concerning cooperation and workshop creation for the 2012 edition of the 'Kinderuniversiteit'. Not encountering the necessary hands-on, realistic and society-focussed material in IEEE's educational programs, the student branch developed its own.

This paper describes two workshops developed by the IEEE student branch Leuven. The position and skill set of a student branch within a university environment to design and host such workshops is emphasized, and the positive indirect results for the student branch are demonstrated. The design requirements for such a project, from the student branch point of view, are discussed. The content of the two workshops, from design to hosting, are detailed. The focus of the paper is the reproducibility of these and similar workshops by other student branches, in an effort to expand IEEE's educational material, increase the attraction of K-12 education to STEM careers, and indirectly, promote IEEE to the larger public.

A. K-12 Education Complementing Student Branch Activities

Student branches are the local representation of IEEE, targeting the IEEE student members of their host institution in particular, the students of their host institution at large, and the general public by extension.

A student branch consists out of at least twelve (graduate) student members. An IEEE student branch is well positioned within the atmosphere of a university. It has a direct relation to IEEE, and access to its experience and support, in exchange for the obligation to maintain its quality and reputation. It is typically registered with the university or technical institution as a student organization, and can rely on its experience and facilities to host activities, in exchange for delivering quality activities for their students and the public. It is normally related to the technical or electrical engineering department of the university.

Also, as an IEEE student branch can access students from various engineering and non-engineering disciplines in cooperation, transcending research groups, departments and faculties. Within an IEEE student branch, active members will typically have different motivations and intentions with the student branch, which can broadly be categorized in social, technical and skill interests. Children in K-12 education are not the prime target demographic of a student branch, as they can't become members. There are no direct channels a student branch can request fundings from to create or host activities targeted at these children. There are no direct benefits within IEEE related to hosting such workshops.

However, from the perspective of a student branch, organizing activities does not need a direct benefit within IEEE. First, student branches are encouraged to organize activities to the liking of their members, within the scope of IEEE's mission and vision, respecting its ethics. Second, there are secondary channels available to fund such projects if applicable and needed, e.g. the IEEE Foundation and national or university funds for education. Third, the indirect benefits, such as member satisfaction, experience and positive contacts for such projects can outweigh any possible direct benefits.

The non-profit character of student branches enables easy sharing of information and experience with professors, departments, staff or students. The large diversity between members allows an enormous benefit when facing problems, as the pooling of knowledge and experience is increased.

Student branches of some size will concurrently prepare several events. This makes time savings possible, by combining preparations of several activities.

At most universities and institutions, student branches will acquire their own sponsorships and funding for the largest parts. This drives them to find the cheapest practical solution, realizing more activities for the same contributions. This focus is helpful when designing and creating the necessary components for workshop equipment.

II. APPROACH

The different aspects of developing a tool for the workshops, targeted at K-12 education, as within the concept of 'Kinderuniversiteit', are described here. First, the requirements concerning the design, are discussed from a student branch perspective. Second, the organizational aspects are discussed in historical order.

A. Design requirements from student branch perspective

Designing a workshop and the necessary tools yields many requirements. In this article, the requirements created by the budget and team of a student branch are discussed. The resources needed for the development, both financial and time, are of concern to the student branch. Producing it with limited tools and storing it until further use also fall under the student branches responsibilities.

1) Inexpensive: As the first development costs are funded by the student branch, the total cost of the tool has to be kept low. If the tools can be reused after the workshop, a full write-off is avoided.

2) Open: Keeping the mission and vision of IEEE in mind, the use of open-source hardware and software is strongly preferred. All self-sourced parts of the platform, both physical and software, must be provided open-source. Everybody may freely use, copy or expand upon the provided material.

3) Durable and Robust: The physical durability of the tool must resist children's coordination skills. Playfulness may not be a barrier to operating the tool, as creative playing enhances learning. The tools should be able to withstand typical drops, wrong operation or creative play without significant damage or impact on the functionality of the tool. Physical and electronic components should be able to continue to realize their function, without need for tuning.

4) Transportable and Compact Storage: To be able to reuse the tool at a future occasion, it must be easily transportable, restricting the size and weight of the stored tool. While the tool is not in use, it must be easily stored in a compact form.

5) Acquirable or Producible: The tool must be easy to acquire, using only limited resources of the Student Branch. Self-sourced designs consequently must be easy to produce using widely available and inexpensive tools or infrastructure. To benefit others, the open-sourced design must be reproducible.

6) OS independent: Different institutions use Linux or Windows operating systems or both. To increase opportunities of future use of the tool, if computer software is required, OS independent software is strongly preferred.

B. Planning and people

1) Call for Workshop: Half a year before the actual workshop, Kinderuniversiteit contacted the department ESAT, which contacted the WIE officer in the Leuven Student Branch. There was a call to organise a number of workshops within the framework of Kinderuniversiteit, taking place October 13th, 2012. The workshop duration should be 2 h and 8-13 year olds will attend. The goal of Kinderuniversiteit is to generate enthusiasm for the concept of a university.

Fig. 3: A 'Hello world' programming example in Scratch.

For the course of one day, children attend a lecture and a workshop before noon and another lecture and workshop in the afternoon. During the lectures, the children go to university classrooms, listen to actual professors explaining topics within their field of interest in a simple and relatable manner. At the workshop, the children get the time to experiment in groups of about 20. The only restriction on the topic of the workshop is that it should be related to actual content in education at the university. Two topics related to the research of the SB members were identified: human-machine interfaces and energy efficiency.

2) Usable Tools: A search for usable tools on the two chosen topics was performed. Scratch is a programming language learning tool, designed to allow children to intuitively create and design computer programs [23]. In this graphical programming environment, a computer program is constructed by drag and drop using the computer mouse. Syntactic problems are avoided by using different colors and shapes for functionalities. The building blocks to create a program fit together only when the code is syntacticly sound, as demonstrated in the 'Hello world' programming example in Fig. 3.

Picoboard [24] is a sensor board developed to work with Scratch. Human-machine interfaces can be demonstrated through the Picoboard. On the Picoboard, basic sensors such as a button and a slider are available, and external sensors can be connected as well. Electro encephalogram (EEG) cup electrodes can be used to demonstrate less obvious human-machine interfaces.

For the energy efficiency educational tool, multiple options were considered. Reference [25] creates educational tools about energy for K-12 education; [26] creates informative boxes, with predetermined lessons for limited target age group; [27] provides free lesson plans with relation to residential energy, for limited age groups, without full scope approach and [28] offers an educational kit on sustainable living, at high cost with little creative possibilities or interaction. It is concluded that no available tool for energy education offers the combination of inexpensiveness, openness and durability.

3) Prototyping: As no perfectly suited educational tools were found, the need to develop a tool became eminent. After brainstorming, it was decided to develop a new educational tool for energy efficiency education and to develop a human-machine interface with a PC using the commercial PicoBoard. Scratch would be used in both projects.

Through Scratch, programs can be made which interface with the physical world through sensors and actuators. For the energy education, a scaled model of a house is to be developed, to explain the energy flows in the residential setting, well-known by the target audience. The children may interact through a display to learn about and control the energy flows in the real-world model. A scale model of a house was built using the local fab lab infrastructure. A lighting and heating system was developed and controlled using a micro controller.

For the neurosensors' workshop, the Picoboard was adapted to read voltage inputs, preliminary cost estimation of the OEG sensors and amplifiers, and a visual game in Scratch was made.

4) Final Design and Funding: The educational design of the workshop had not yet started, however, technology demonstrations could be given using the prototype hardware to validate the concept. Colleagues and professors were asked to assess the designs. Technical and educational oriented discussions soon followed and the design could be finalised. The inexpensive Arduino electronics platform was chosen for the control and measurement of the lighting and heating systems, through a self-developed interface board.

Funding was needed to finalize the tool and to manufacture enough platforms for the workshops. Using the feedback and the prototype, funding was obtained from a research institute and the department for the first ten complete sets. The inexpensive Picoboard was used for the human-machine interaction. Minor modifications to the wiring and a self-developed interface board are necessary. With the feedback and prototype, funding was obtained from the department for the first ten sets.

5) Manufacturing: Next step is the production of the tools. To keep costs as low as possible, the design was developed to be manufactured as easy as possible. For the human-computer interface, this meant developing an easy solderable sensor interface, and selection of best reuseable electrodes. For the energy house, this means restricting construction needs to using infrastructure typically available in a Fab Lab [29]. Three plates of 300 mm x 600 mm x 6 mm are required: two wooden ones and a single acrylic glass one.

The time required for the manufacturing of the platforms for the workshop had to be assessed. For a single house, the laser cutting time is 2.5 h. To organize a workshop for twenty children, it was estimated that ten houses were needed, requiring a total cutting time of 25 h. Three laser cutters are available in the local fab lab, however they are used intensely and on a first come first serve basis. Consequently, the availability of the laser cutters was determined a high risk. A single through-hole interface board could be soldered in about 30 minutes. Soldering equipment is widely available in the department of electrical engineering, and the micro-electronics student branch members enthusiastically showcased their experience in soldering.

6) Team: The IEEE student branch Leuven counts active members from both student and graduate student level in the board level. Their affiliations cover Computer Sciences, Robotics, Biomedical engineering, Micro-electronics and Power engineering. Through the experience gained with event organization, the active volunteering for services to the department, the habit of contacting the sponsors as well as professors of interest for preliminary advice on organizing activities within their topic, and the good relations with graduate student members, the network of support from professors, department, university, students and sponsors is extensive.

A number of different skills were required to develop the houses: e.g. architectural design, soldering, software development, analog electronics and neurosensor technology. Additionally, time was needed to manufacture the houses and interface boards. Whereas the laser cutting is automated, putting in plates and collecting the manufactured pieces is not. An operator is required to stay in the vicinity of the laser cutter, to periodically restart the cutting process with new plates or designs. Additionally, educational guidance tools for the workshop attendees is required. It was chosen to develop a step-by-step manual explaining how to build the house. A photographer took pictures demonstrating the construction phases.

7) Workshop: A location with the necessary infrastructure had to be found: a PC for each house and enough power sockets, as each house requires an external power supply.

III. Development of a human-computer interface

The goal of this multidisciplinary workshop is threefold. The first goal is to teach children that the human body produces electric signals during its normal functioning. Moreover, the brain uses such signals to communicate with the body, e.g. to instruct the arms to move. The second goal is to demonstrate that these signals can be measured, sent to a computer and visualized. The third goal is to create a system which measures the changes of the electro-oculogram (EOG) signals as a result of voluntary movement of the eyes and to control a computer game with these signals. This final phase also involved introducing the basic principles of programming.

A. Tool

EOG is based on the following principle. The eye, with its positive pole at the cornea and negative pole at the retina forms a dipole. Therefore, it is a source of a steady electric potential field. As the eye moves, the dipole changes orientation causing alterations in the potential field. The resulting electrical signal is measured by the EOG. Two pairs of disposable Electro encephalogram (EEG) cup electrodes, produced by Medimax [30] were placed on the skin on the temples and above and below the midline of the right eye. These electrode pairs can respectively measure the change in the electrical potential field caused by the horizontal and vertical movement of the eye. A reference electrode was also placed on the middle of the forehead. The signals are captured and amplified in two stages. First an instrumentation amplifier INA333, with

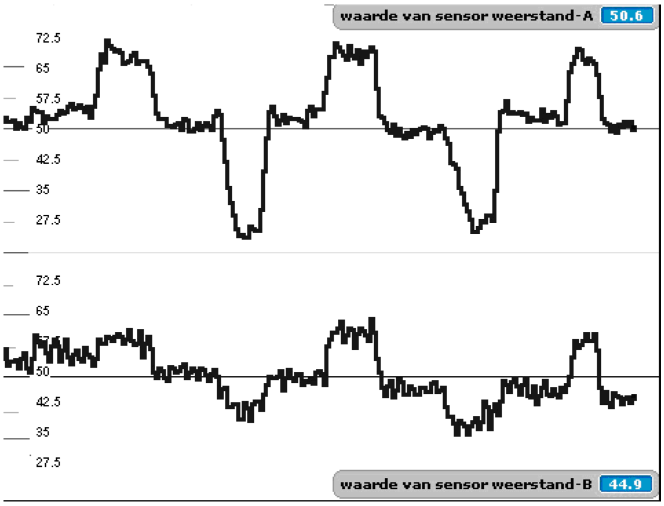

Fig. 4: Typical EOG signal during up and down movements of the eye.

Fig. 5: EOG-based human-computer interface controlling a computer game was developed during a workshop for 10-12 year olds.

amplification of 10 captures the signal. Second, an inverting amplifier OPA333 with an amplification of 50 amplifies the signal. In the feedback loop of this opamp is a condensator which serves as a low-pass filter (30 Hz). In between the two stages is a high-pass filter to eliminate drift (0.01 Hz). The analog signal was digitized with the A/D converter built in to Picoboard [24]. The EOG signals were visualized using a custom program developed in Scratch. Typical EOG signal patterns are shown in Fig. 4. The upper signal is the potential difference measured between the electrodes placed below and above the eye, the lower signal is the potential difference measured between the electrodes placed right and left from the eyes. Note that the signal corresponding to the vertical movement of the eye is more pronounced to the upper signal. The signal change on the lower graph is due to deviation from horizontal movement or due to imprecise positioning of the electrodes.

B. Workshop

Three example programs were developed in Scratch and provided for the participants. The first program served to visualize the EOG signals and was fully functional. The EOG signal was recorded from one of them while moving the eyes. The task of the other participant was to analyze the signal changes corresponding to the eye movements in different directions.

The second program was a simple computer game, where the player has to move a character on the screen using the right, left, up and down arrow. However, the left and down arrow functions were not implemented. The children were instructed to complete the code based on the code blocks corresponding to the left and up arrow functions.

The third program was a fully functional version of the same game. The exercise in this case was to exchange the arrow functions with expressions which move the character according to the magnitude of the EOG signal. Fig. 5 shows a participant playing the game using her eye movements.

IV. Development of an Energy House

The workshop aims to convey different energy related concepts. The first goal is to teach children what the meaning is of energy and power. The second goal is to show that household appliances consume energy at different rates. The final goal is to inform about energy efficiency. A scaled house, including lighting and heating systems, is provided to the workshop attendees. In this section, a basic description of the design is given. Full design details are provided open-source, available at [31].

A. Tool

The energy house is designed at a scale of 1/24. The largest piece is 30 cm by 25 cm (base plate) and the smallest is 2.6 cm by 1.7 cm (window hinge), which facilitates manipulation by children's hands. To be able to look into the house, two walls and the intermediate floor are manufactured from acrylic glass. A constructed house can be seen in Fig. 6. The ground floor has two rooms: a garage and an entrance hall with stairs to the first floor. The first floor is a single big room with a window. It is easy to install the heating and the lighting systems by temporarily removing the roof.

The mechanical components (walls, furniture and windows) are designed to be easily modifiable and reproducible in a 'fab lab'. There are numerous fab labs around the world, offering infrastructure such as laser cutters and machining tools to make almost anything [29].

The developed design can be reproduced without modification in laser cutter which can cut 300 mm x 600 mm x 6 mm medium-density fibreboard (MDF) and acrylic glass (AG). Teeth are used so the house can be assembled without tools. As no glue is used, the house can be disassembled, stored and transported efficiently. MDF and AG are robust, inexpensive and light-weight materials. A single house, including the electronics, weighs 2.6 kg and fits in a box of size 11 cm x 36 cm x 26 cm.

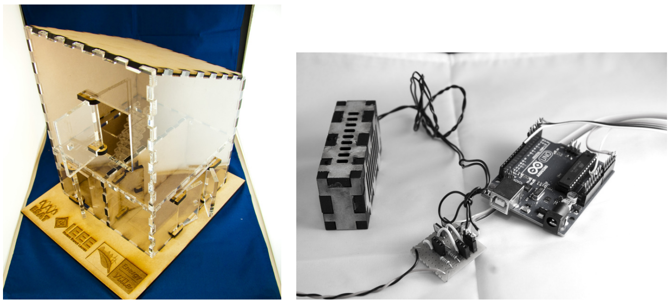

Fig. 6: Energy House and electronics used in workshop to teach 10-13 year-olds about thermal energy and lighting in a house.

A power supply voltage of 12 V is chosen. Such low voltages are safe to touch, but it is still practical enough to supply power for electric heating. The resistive heating system uses a 18 Ω/10 W resistor. At 12 V, the heating power is 8 W. The lighting system uses white LEDs. A sensor board is designed to connect the devices to and to provide basic measurements of the energy flows using voltage dividers.

Arduino is an open-source electronics prototyping platform with a microcontroller, designed to inexpensive and approachable to people with very limited experience with electronics [32]. A number of analog inputs, digital inputs/outputs (I/O) and pulse-width modulated (PWM) outputs are available. The microcontroller platform has a USB socket and can be programmed through a computer, without an external programmer. Arduino hardware is easily acquirable. MOSFETs are used to switch the devices through the Arduino.

The Arduino hardware is programmed using a language similar in syntax to C++, with some simplifications and modifications. An integrated development environment (IDE), also named Arduino, is available. It provides a basic code editor and single click code uploading to the Arduino hardware. S4A (scratch for Arduino) is a project based on Scratch which allows interfacing with Arduino [33].

A base program has been written in S4A to take care of simple tasks, e.g. sensor reading, actuator control and calibration. It also provides the methods for power measurement and energy consumption calculation, and variable price communication.

B. Workshop

The attendees worked in teams to build the houses and wired and electrified them with little or no assistance, as depicted in Fig. 6. Apart from some connection reversals, all systems were build by the attendees without issues.

The manual for this workshop consists of a step by step construction with pictures, followed by simple instructions and information. The focus of the manual is on the interactive experience, and encourages the children to understand and interpret the visual representations in relation to their control actions and the conditions in the model house.

Through a developed program in S4A, the attendees are instructed to reach a predefined temperature in the house by controlling the electric heater. The process of the heating,

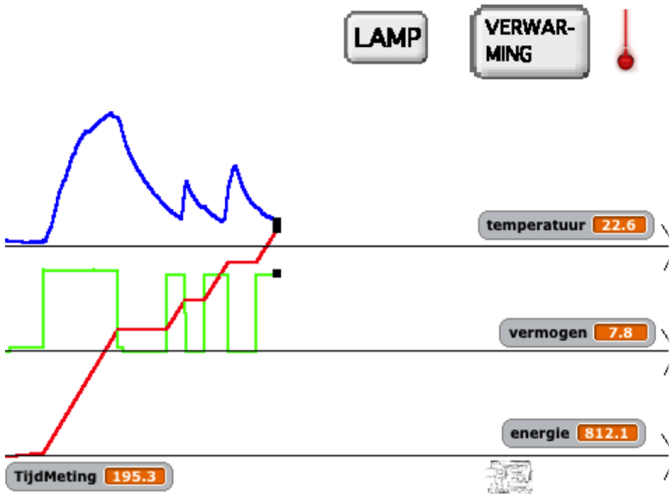

Fig. 7: Visual interface of Energy house, showing the measured temperature, used active electric power and total energy consumption.

power and energy are explained. Lighting control and thermostat functionality are implemented by the workshop attendees. The visual feedback received from S4A is demonstrated in Fig. 7. Turning of the heating, letting the house cool down, the irreversibility of transforming electric energy into thermal energy is explained. During the attempt to create a simple thermostat, the thermal time constants and latent heat of the heating unit are explained. All these elements formed a fun workshop with much room for experimentation.

V. Student Branch Outlook

The 'Kinderuniversiteit' is an event which attracts about 800 children and 350 parents, all interested in science and technology. Being present and actively cooperating promotes IEEE as a global organization to the interested parent and introduces student branches as a educational contributor to 'Kinderuniversiteit'. Furthermore, it is a solid eyecatcher to industry sponsors and helps to achieve student branch recognition within the department and university. In result of the event, both workshops have been requested for repeat performances at several future events. Though virtually none of the attendees are the primary target group of the student branch, student branch activities and members benefit indirectly from the cooperation.

The active members of the student branch directly involved with the workshops or the development of the tools receive the positive stimulus of successful completion of a project and public recognition value of their work. The diversity of the work required the cooperation and skills of the interested active members with their difference backgrounds. This created a great sense of complementarity for the student branch. The workshops represent new flagship projects for the student branch.

VI. Conclusion

Early exposure to engineering challenges increases the interest of children in STEM careers. This paper presents IEEE student branches as the creator and host of K-12 educational engineering workshops. The different aspects of creating a workshop, from people management, through partners and funding are discussed. The unique qualities of a student branch within the environment of educational institution, industry and students are shown.

The environment of the IEEE student branch Leuven, their creation of two workshops are discussed, and the experienced indirect benefits are demonstrated as an example to how any student branch could reproduce these results. The design requirements of the workshops from the student branch point of view, are reviewed. The content of the two workshops, from design to hosting, are discussed and made freely available on [31].

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ESAT has funded the construction of the first ten houses and ten Neurologic sensor boards. Energyville has funded the electronics and Arduino Uno development boards for the first ten houses. The mechanical prototyping took place at FabLab Leuven. The IEEE Student Branch Leuven took on the opportunity for education offered by the Kinderuniversiteit Leuven project of the University of Leuven.

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