Development of Open-Source Interactive Smart Energy House for K12 Engineering Education on Residential Energy Efficiency

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INTRODUCTION

The need for engineers in the developed world is expected to grow significantly in the next 10 years. The Bureau of Labor Statistics [1] predicts a 1.7 % annual growth for the engineering job market in the United States. IBISWorld [2] predicts a 3.7% annual growth until 2008-2018 for the worldwide engineering services. However, engineering (and science and technology oriented jobs in general) as a professional choice is in decline within the developed world, with a growth of reported tertiary education graduates in science, technology, engineering and math (STEM) fields between 2007-2010 of 2.5%, lower than the growth of all reported tertiary education graduates (3.3%) [3][4]

Lack of graduating engineers is likely to continue, as current children in the developed world do not see science as a solution to environmental nor other world problems [5]. A recent study of children's capabilities in math and sciences suggests that EU- 27 countries have a large proportion of children with low skills (avg. 20 % at level 2 or less) [6]. To stimulate children to be interested in math and sciences, early positive and hands-on exposure has proven highly effective [7][8][9].

Those children that do develop an interest in science and technology, are not enticed by current education methods. Traditional STEM teaching methods at secondary school are abstract, not hands-on. Especially girls loose interest when the teachings are not related to reality or societal improvement [5]. This loss of interest at an early age turns into a lower entrance into higher STEM education [10][11].

Several European countries have developed programs to encourage students' interest in STEM careers. Many are government initiatives [12] though in various countries, industry as well as academia have organized events to stimulate STEM interests at a young age. Kinderuniversiteit is an initiative of the University of Leuven [13], which is organized annually since 2005, to bring children into contact with science, engineering and academia. It combines classic lectures with several technically inclined workshops, specially targeted at primary school children.

Annually, the Kinderuniversiteit launches a call for suitable workshops. In 2012, the IEEE student branch of Leuven, in cooperation with ESAT [14] and EnergyVille [15], developed such a workshop [16]. The topic of this workshop is residential energy consumption and the influence of smart grid technology. This topic is chosen for two main reasons, the current importance as well as the relevance to children.

Firstly, 32 % of the total consumption of energy world-wide is related to the buildings sector IEA (2012). New technologies and building concepts are created to reduce the use and increase the efficiency of energy. Within Europe, several European directives focus on the residential sector, setting benchmarks for building energy efficiency [17][18] Among those, the importance of efficient lighting in its direct and indirect effects on energy use through their impact on the thermal management of buildings has been recognized. This resulted in the banning of all sales of incandescent light [19] within Europe, and the United Nations Environment Programme ”en.lighten” [20] to promote and coordinate efforts to roll out energy efficient lighting. To increase awareness, all household appliances are required to indicate by labeling and standard product information the consumption of energy and other resources [21].

Secondly, the residential energy use is the part of the total energy use that children can influence most. From turning on the television, switching on the lights, opening a window, children use and control energy. The relevance and reality of the topic increase the effectiveness of early exposure to science, especially for girls.

During the development of this workshop, several educational materials were reviewed. Several tools were found to be either strongly restricted [22][23][24] in their possibilities for adaptation, others are unsuitable for workshop use [25], or prohibitively expensive [26][27] These conclusions lead to the design of a new educational tool [28] for the particular needs of this workshop.

This paper describes the development, content, flow and results of this workshop. The main principles that guided the design are discussed. To finish, the success of the workshop is evaluated.

1 WORKSHOP CONTENT, MATERIAL AND FLOW

1.1 Workshop Content

The design of the 1/24 scale model of a house is detailed in [28] and is provided open-source [29]. It is designed to be stored in a compact form, allowing for easy transport. Furthermore, the pieces are sized to be handled by children's hands, using dull, lightweight and durable materials: medium density fiberboard (MDF) and acrylic glass (AG). the largest piece is the base plate and measures 30 cm by 25 cm; the smallest is a window hinge and measures 2.6 cm by 1.7 cm. A constructed house can be seen in *Fig. 1*. To be able to look inside the house, two of the walls and the intermediate floor are made from AG. On the ground floor there is a garage and an entrance hall with stairs leading to the upper floor. The upper floor is a single big room with a window. The roof can be removed easily, to allow the users to install model household appliances. A floor plan is given in *Fig. 2*. A set of model household appliances is provided, including a television, fridge, washer, tumble dryer. Furthermore, a few appliances are actually electrified: lighting and heating.

The house parts are designed to be manufactured in a 'fab lab' [30]. A fab lab is a workshop offering tools for computer controlled fabrication such as laser cutters. The developed designs can be reproduced without modification in laser cutters which can cut 300 mm x 600 mm x 6 mm MDF and AG. The house can be constructed without glue, being held together just by friction. Furthermore, MDF and AG are inexpensive and safe. AG may shatter under excessive pressure, but only breaks into large dull pieces.

For the control, lighting and heating system, a 12 V power supply is needed. Such a voltage is safe to touch, but still allows enough power to be provided to the electrical heating system to allow fast heating. The heating equipment uses an 18 Ω 10 W resistor. At 12 V, the heating power is 8 W. The lighting system uses LEDs. MOSFETs are used as relays to switch the electrified household appliances, through the micro controller.

The Arduino open-source electronics prototyping platform is used as micro controller [31]. Arduino is inexpensive and designed to be easy to use by people with very limited experience with electronics. A number of outputs as well as inputs can be addressed, which allows for control of the appliances through environmental measurements, e.g. temperature. Arduino has a USB interface and can be readily programmed from, and communicate with, a PC. The chosen Arduino UNO platform is equipped with an 8-bit Atmel AVR ATmega328 micro controller with 32 kB flash memory.

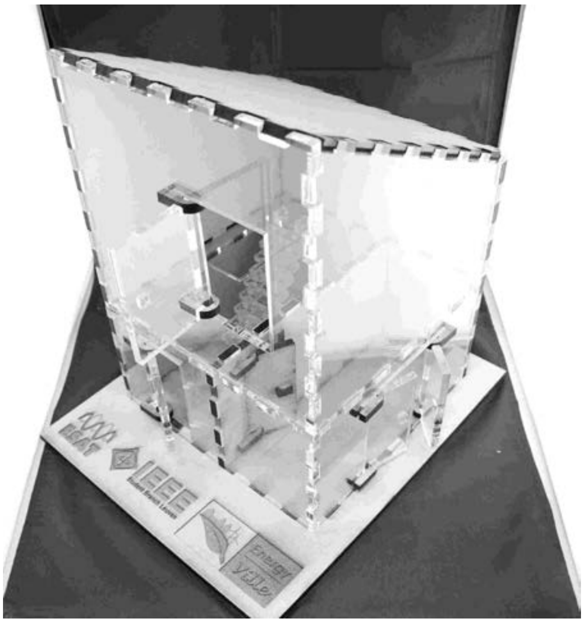

Fig. 1. Assembled workshop house model.

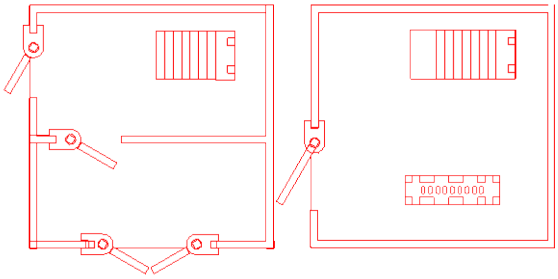

Fig. 2. Floor plan of house model

fng templates.

1.2 Programming

Scratch is a programming language learning environment [32] It allows chil- dren to learn to create computer programs intuitively through a graphical programming environment. A computer program can be created just by dragging and dropping code building blocks, using the computer mouse. The code building blocks have a variety of shapes, which must fit together to have a syntactically correct program. S4A (scratch for Arduino) is based on Scratch, and allows for interfacing with Arduino through the graphical programming environment [33]. Through the Arduino, the programs can interface with the physical word, by collecting measurements from sensors or by controlling devices. In this case, the Arduino is used as a measurement interface to the PC running S4A, which is actually taking the control decisions. Nevertheless, independent control could be implemented.

S4A requires that a special program is uploaded to the Arduino hardware. This program takes set points from the PC communicated through USB and sends back measurement data, at a period of 75 ms. A reference program is implemented that takes care of basic tasks such as calibrating sensors, reading measurements, converting them into interpretable quantities and showing the results. This allows power measurements and energy consumption over time to be shown in real time on the computer screen. Additional functionality, such as intelligent lighting and heating control is implemented by the workshop attendees. *Fig. 3* shows the energy metering visualization in the S4A reference program.

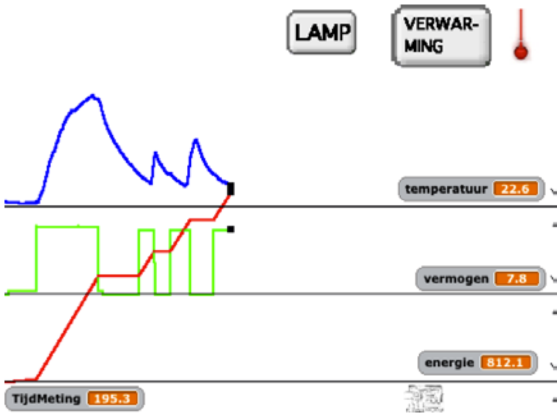

Fig. 3. Screenshot of S4A visualization.

1.3 Flow of the workshop

The workshop hosted about twelve 10 to 12 year olds and was conducted as follows. First, the attendees formed teams of 2-3 members. Each team is provided with a box containing all the platform parts. Then, they are given time to discover all the pieces and appliances. A constructed house is on display and could be inspected from up close. A building plan is provided in the manual, detailing the construction step-by-step. Depending on the technical aptitude of the team and the interest, the manual was used precariously, sparingly or neglected. The teams worked independently, but could ask for help if needed. After finishing the construction of the house, they installed a selection of appliances in the house. Finally, the electrified appliances are connected to the daughterboard of the Arduino. Simple expected issues like connection reversals were solved without negative influence on the workshop experience. Through the 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, power and energy are explained in the manual. Lighting control and thermostat functionality are implemented by the workshop attendees. 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.

2 DISCUSSION

2.1 Sustainability

The energy house is designed to demonstrate engineering principles to non-engineers. It is able to provide educational value to a wide age range, from 6 year olds to adults. Requirements of teachers and students change around the world, just as well as the knowledge of and expectations towards electric energy. The platform can be used to explain different use cases of electricity, based on the local situation. Furthermore, the platform is easily adapted to allow new appliances, communication, autonomous operation, etc.

2.2 Transparency

Hardware designs, software codes and manuals of the platform are provided open-source. Teachers, students and others can use the platform, improve it, and demonstrate new use cases. This of course requires the platform to be easily reproducible and manufacturable. To maximize reach, the platform is reproducible using inexpensive and widely acquirable components and tools. Furthermore, the electronics can be interfaced on PCs running (legacy) versions of any of the widely available operating systems: linux, mac and windows. However, administrative rights may be required. Scratch and S4A have very limited hardware requirements to run. Of course, a USB port is required to interface a conventional Arduino.

2.3 Multidisciplinarity and openness

Multidisciplinary engineering skills were required to develop the platform, and multidisciplinary skills can be obtained working with it. The related topics are micro controller programming, automation, sensors, actuators and electrical energy efficiency.

2.4 Institutional inclusiveness

For the organization of Kinderuniversiteit, the University of Leuven depends on the volunteering of its workers to organize workshops, aimed at 10-13 year olds. Within the department of electrical engineering ESAT, hands-on education is considered of primary importance in the bachelor and master engineering programmes [34]. An engineering student organization (IEEE student branch Leuven) was approached by faculty staff to organize a Kinderuniversiteit workshop on efficient use of energy. IEEE student branches bring together electrical and electronics engineering students, ranging from bachelor to PhD studies and are organized on a university basis. The student branch Leuven hosts an affinity subgroup Women in Engineering (WIE), which aims to improve the development of programs to promote the entry into and retention of women in engineering programs [35]

2.5 Creativity and professionalism

The workshop offers the attendees an interactive experience: they puzzle the houses together, connect appliances and control the appliances through the computer. This hands-on approach captivates the students as it forces then to engage and it immediately demonstrates the application the concepts discussed.

2.6 Respect for diversity and different cultures

Scratch is available in many languages. Not only the development interface but also the code building blocks are translated when the language reference is changed. The reference program uses pictograms for control and navigation. This allows children with different first languages to participate in the same workshop. Nevertheless, the workshop manual will have to be translated.

3 CONCLUSION

Feedback on the following statements was obtained from the children: The survey posed to the kids had the following questions.

Organization of the workshop

• 1. What did you think of this workshop?

• 2. I learned a lot

• 3. I would recommend this workshop to my friends

Evaluation of the workshop

• 4. The mentors were obliging and gave good answers

- 5. The mentors took the necessary time to explain things.

Evaluation of the content of the workshop

- 6. Learning to manage energy in the house is important.
- 7. I learned a lot about what a smart meter can do in my house.
- 8. The workshop and the smart energy house helped me to understand this better.
- 9. I understand energy management in a house much better than before and want to learn more about it.

All questions could be answered of a 5 step scale from very bad/boring/false to very good/fun/true. The results of the 25 attendees are given in *Fig. 5*. From the answers it is clear that the bulk of the opinions are positive or very positiveWe conclude that the workshop was a positive learning experience for the attendees.

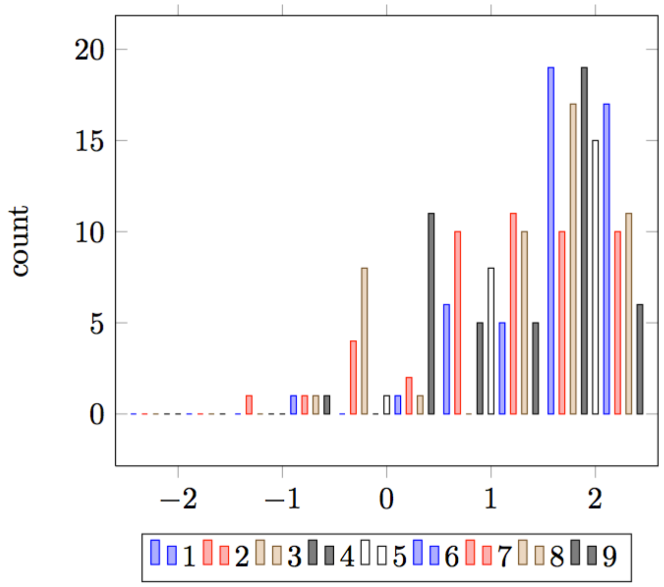

Fig. 5. Survey results of 25 attendees of the first and second workshop at the KinderUniversiteit in 2012.

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