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Article

Co-Designing the Kits of IoT Devices for Inquiry-Based Learning in STEM

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Abstract: The rapidly developing technological landscape challenges require educational institutions to constantly renew the school's digital infrastructure in order to keep students engaged in learning difficult subjects such as Science, Technology, Engineering, and Mathematics (STEM). The Internet of Things (IoT) is one of such new technology platforms that could help the schools enhance learning processes with innovative resources, and to increase students' motivation to learn. This paper summarizes the first stage of a design-based research focusing on introducing IoT technologies to secondary education. Five kits of IoT devices were co-designed by researchers, teachers, and students, to optimize their match with the curricular objectives, cost, learning curve, and re-usability in various educational contexts. The study included three steps: (1) mapping out the IoT devices on the basis of the desk research, (2) literature review on STEM education practices, and (3) two focus group interviews with teachers and students from different schools. As a result of the study, five different kits of IoT devices were purchased for schools and pilot-tested in real-life settings.

Keywords: Internet of Things (IoT); smart schoolhouse; inquiry-based learning; trialogical knowledge-creation

1. Introduction

In an era full of changes and technological opportunities, educational institutions must offer increasingly new and exciting options to involve and motivate students. Multiple studies indicate that [1–4], a lot of countries [5–9] consider STEM (Science, Technology, Engineering, and Mathematics) education to be the biggest challenge for students, and offer solutions to improve the situation. For example, [2–4,10] claim that STEM subjects are uninteresting, unpopular, and difficult to learn. Burns et al explain that "*The dramatic decline in youth interest in STEM during adolescence has been a phenomenon of societal concern for several decades.*" [2] "*Teaching of mathematics and science has been abstract, isolated from the real world problems, uninteresting, and without motivation in Estonia.*" points out Rüütmann. She continues that "*Students are often afraid of making mistakes and have started to be afraid of science and mathematics*" [3]. In 2016 reported English [10] that "*International concerns for advancing STEM education have escalated in recent years and show no signs of abating.*"

An analyses of the 2015 survey by the Estonian Ministry of Economic Affairs and Communications show that in the coming years approximately tens of thousands of people will need to leave the labor market due to their age, and thus new workers are needed in their place. Although Estonian students are consistently placed at the top in all three categories on the Program for International Student Assessment (PISA) [11] test, too few students choose to further their education in STEM fields (a little more than 30% in the higher education currently), yet at the same time the analyses show that knowing STEM fields gives better options when choosing an occupation. It is outlined in the annual report of The Committee on STEM Education 2013 that "*The jobs of the future are STEM jobs, with STEM competencies increasingly required not only within but also outside of specific STEM occupations*" [10–12].

An analysis of the 2015 survey by the Estonian Ministry of Economic Affairs and Communications pointed out that it is important to change the mind-set that science subjects are more of a topic for boys—that is a problem for in Europe [12] and in the USA [4], where girls choose to study sciences way less. "*Natural and exact sciences (STEM) are subjects that girls do not often feel interested in as these subjects are little affiliated with their every day lives and social environment*." In the analyses it is pointed out that "*it is important to create a notion that STEM field is not scary, to show that these subjects are interesting, and to explain that by learning natural and exact sciences the graduates do not necessarily become a scientist and teachers but sought-after specialists in businesses*" [13].

This article will give an overview of a project focusing on renewing STEM education through Internet of Things (IoT), the preparation for procuring IoT devices at the beginning of the project, the IoT device kits acquired for the test period, and the bottlenecks that emerged during the usage of IoT devices in the learning process, on the basis of which a final list of the devices needed was put together.

2. Smart Schoolhouse by Means of IoT

It is believed that problem-based learning (PBL) [14] and inquiry-based learning (IBL) [15,16], supported by trialogical approach (learning through pedagogical arrangements and supporting technology) [17,18], help students acquire, clarify, and apply understanding [19], to be engaged in real research in the way scientists do, and help them to build an understanding of science concepts [20].

Su et al. [21] stress that teachers and their chosen teaching methods play a crucial role when it comes to arousing interest in learners. As a result of the analysis, and comparison of the educational systems of four countries (Canada, Estonia, Singapore, and Finland—consistently at the top of the list in PISA tests), Su et al. have shown that problem-solving and inquiry-based projects in STEAM education related with other subjects that can foster curiosity and creativity of students, where the learning process becomes more personal. [21]. Rüütmann et al. suggest "just-in-time" teaching to encourage students to predict, apply, create, analyze, compare, evaluate, criticise, implement, and gain professional perfection [22], and He et al. adds that the new paradigm of learning in STEM is learning by doing [23,24].

In order to involve students in a more actively in the study process, to further motivate them and raise their interest in STEAM education through a trialogical approach and inquiry-based learning (IBL), a project called "Smart Schoolhouse by means of IoT" was launched [25]. The purpose of the project is to use IBL and PBL methods for solving every-day problems when teaching natural and exact sciences, and to create innovative teaching materials to support that.

We described the idea of Smart Schoolhouse as it is illustrated in Figure 1 in previous article [20]: "*Smart Schoolhouse" enables automatic data collection from physical learning environment so that this data could be integrated with the digital footprints of learners (in their own devices and online platforms) and its use for learning analytics purposes and ensuring students' and teachers' privacy using the data in STEM education.*"

The wider goal of the 3-year project is to: (1) increase the students' interest in technology and engineering; (2) to guide the learners to solve vital problems in their surrounding environments; (3) to change the natural and exact science's curriculum in schools to be more innovative; (4) to contribute in the effectiveness of engineer- and lifelong-learning; and (5) to create opportunities for engineering creativity. In addition, one of the goals is to support the cooperation and sharing of knowledge and experiences of STEAM education teachers. The project contributes to developing the digital competencies of teachers and learners using IoT technologies, while integrating different subject to better their analytical skills, i.e., analyzing the results of activities using different software.

In order to achieve the projects' goals one of the most important steps is procuring IoT devices (five different sensor kits: room sensor, smart clothes, research lab, digital arts, and body sensor kits), which is what the current article focuses on. In the project there are a total of 19 schools from different areas of Estonia, of which, only five Partner schools participated in the preparation and testing period, and 14 will join once the IoT devices kits have been acquired.

The project substantially supports the achievement of the curricular goals of natural sciences, and creates new and modern learning opportunities to practice with IoT devices during the learning process, where a trialogical approach is used with inquiry-based learning (IBL) and project-based learning. During the project, the learners involved must find solutions to vital problems with practical activities, create teaching materials in the course of active learning, and focus on team work (trialogical approach) to analyze, test, present, and judge.

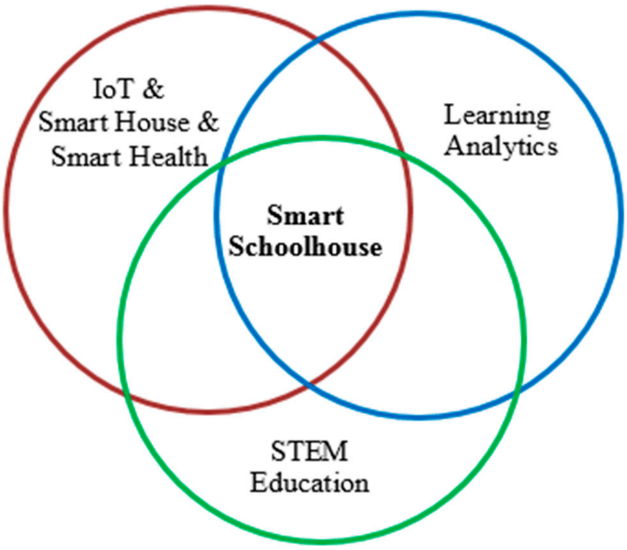

Figure 1. A Smart Schoolhouse—common core of Learning Analytics, STEM (Science, Technology, Engineering, and Mathematics) education and IoT (Internet of Things) [20].

3. Materials and Methods

Before assembling the so called trunks, in several stages the mapping of different fields took place. To get an overview of the opportunities, the first mapping took place based on internet research, after that there was literature analysis, and two different interviews with the focus groups (teachers and students of different schools) took place with half a year difference.

3.1. Internet Research

In the field of IoT (1) answers to questions like (a) what kind of sensors are on offer in the market, (b) what can be measured with them, (c) from whom is it possible to procure them, and (d) for what price could they be purchased. After that, the results were analyzed and the first list of potential sensors to use in the research was put together. Since several sensors offered belonged in kits, it was needed to get an overview of (e) the environments that were created by the supplier for collecting the data, (f) the standards used for data transmission, and (g) the options for data export from these environments. As the final goal of the project was the use of sensors in the learning process, where the learners could use these sensors to measure and analyze themselves and the environment surrounding them, i.e., to raise questions and find answers to vital problems surrounding them, at this stage questions involving protection of personal data were accrued. Information needed included (h) what sensors are suitable to use in learning process, (i) what data could be collected from students and their surrounding environment, (j) what (personal) data needed extra security when collecting, and (k) what data must not be collected at all.

Results of the internet research were collected in a Google Sheet table, in which the measurable was noted down in rows (e.g., temperature, humidity, pulse, etc.), and the columns included the supplier names. In the cells where the rows and columns crossed was either simply a mark (x) to note that the supplier offers it or it was left empty to suggest the product is not offered by that specific supplier.

In the field of education (2) answers to questions like (a) how is the IoT technology used in the learning process, (b) what kind of teaching or learning methods have been so far found useful in technology enhanced learning process (TEL), that means success stories of TEL were sought, and (c) what kind of technology and use of it have been successful, are any examples of Bring Your Own Device (BYOD) and IoT opportunities were sought.

The platform (3) is needed in order to collect, process, analyze, visualizes, etc. data from different environments using different IoT technologies or BYOD. The internet research was used to find examples of environments used, and get an overview of (a) what kind of data were collected in that specific environment, (b) how these data were used, (c) what is the data processing, and (d) visualizing opportunities like, and (e) whether it is possible to export the data from the environment.

3.2. Literature Review

In the second stage we sought confirmation from articles to the information found in the internet research: whether, to what extent, and how were these topics covered in science articles. Article analysis was divided by fields and the questions requiring answers were: (1) which sensors and IoT devices, and how were they used in the learning process; and (2) which teaching–learning methods have given better results. As the Internet research did not give many answers about the platforms themselves, this field was not part of article analysis in this study, and will need to be dealt with on its own.

Literate review about sensors and IoT devices (from the major academic databases: IEEE Xplore, Springer digital library and Google Scholar) helped organize the list in a Google Sheet table that was created as a result of the Internet research. As the analysis of the articles showed that IoT devices were mainly used in STEM study, it was decided to divide the list of sensors and IoT devices in the learning process into four different kits (STEM), and to add a fifth kit (A) without sensors: room sensors, smart clothes sensors, science Labs sensors, body-sensors and digital art. A more thorough overview of these sensor kits is under the chapter Results.

3.3. The Focus Groups Interviews (FGI)

To finalize the IoT device kits list, interviews with the focus groups were conducted before and after the test period. The test period's purpose was to find bottlenecks in the list, and to make corrections and upgrades to it before ordering the kits for all the schools. Since during the testing period each school was given a different kit to experiment with, specific kit lists (smart clothes, and body sensors) were sent to the two schools two weeks prior to the interviews, so they could familiarize themselves with the list and make suggestions for corrections and changes. Table 1 includes information about the five schools participating in the pilot period, and the specific kit they were responsible for during the test period.

The first two FGI took place in January 2018 and were conducted as Skype sessions. At least two pupils, two teachers, and a project manager were present for the interview. The data were collected in the course of a semi-structured interview. On the basis of the additions and corrections made by the teachers to the list, the IoT kits were ordered for the schools for a 3-month testing period to try out their suitability in the learning process.

The next FGI took place in June 2018 where representatives from all schools involved in the pilot period participated. The interview was held face-to-face and was joined by 14 teachers and three headmasters, from five different schools. Two weeks before the meeting all the participants were sent questions to which answers were sought after during the interview. Using the questions sent to them, the schools presented the positive and negative sides of the kits used by them, and made suggestions for changes in the kit list. The following half-structured interview was used to figure out the final list of necessary kits and the number of components to be ordered for the next period. The improved list was available to all the participants in the Google Drive folder. Only a few slight details (e.g., the number of Breadboards suitable for the room sensors, etc.) were confirmed in a later phone call or via e-mail instead.

Table 1. Schools in the pilot project.

Type of School	Pupils in School	Form Participating	Pupils in the Project	Teachers in the Project	Participants (Teachers) in the Second Interviews	Sensor Set	Subject
Lower secondary school	137	7	18	4	4	Science Lab	Maths, Life Science
Secondary school	1043	6; 10; 11	76+186	3	3	Smart clothes	Biology, Art
Lower secondary school	125	7; 8; 9	41	2	2	Smart classroom	Physics, Technology Education
Upper secondary school	152	10; 11	106	3	3	Body sensors	Chemistry, Physical Education
Secondary school	1221	8; 9; 10	114+104	4	5	Digital Art	Maths, Art

4. Results

4.1. Internet Research

The list of found IoT devices based on the preliminary Internet research was too long to be pointed out in its entirety. In total, 20 products (supplier/manufacturer) were found, and a total of 133 rows with different sensors were charted (Table 2). As the whole table is less important compared to the end results, only the standpoints used to form the list of IoT devices will be presented.

Table 2. An extract of the table of IoT devices charted on the basis of the Internet research.

IoT device	PocketLab Weather	PocketLab Voyager	LabDisc	Garden Hydroponics	eHealth V2.0	MySignals SW	Kinect Sensor for Xbox One	iBeacon	Vernier Sensor	Fourier Sensors	Q Sensor	iMotions	Headsets	Zephyr BioHarness	eMwave2
Colorimeter			x						x						
Conductivity			x	x					x						
Dissolved oxygen			x						x						
Drop counter									x						
Ecologxl Distance										x					
Facial expressions												x			
Flow rate									x	x					
Force									x	x					
Galvanic skin response (gsr)					x	x					x	x			
Gestures							x								
GPS			x												
Heart rate			x						x	x			x	x	x
Humidity	x	x	x	x						x					
Light	x	x	x	x					x	x					
Magnetic field		x							x	x					
Motion		x					x		x						

An extract of the table gives an insight to how many different products (in rows) included different sensors, which is why one device could measure many different physical, chemical, physiological, and other kinds of processes. Therefore, it was decided to create product groups (kits) that could be used in different subjects, and thus sensor kits supporting STEM study were created, the kits being: room sensors, smart clothes sensors, research labs sensors, body-sensors, and digital art.

One of the goals when choosing the contents of the kits was to give the learners an opportunity to use their previously acquired skills using inquiry-based learning methods, i.e., to give the learners an opportunity to find an everyday problem for which a solution could be found by using smaller kits or a single sensor. For this purpose they had to first create an actual device usable for measuring data during the learning process. This kind of research would direct students to first deal with the problem—they would have to understand the nature of the problem—and only then would it be possible to start looking for solutions.

The criteria for choosing the IoT devices were as follows: (1) the data collected must be available for and processable by the learners, (2) they must promote inquiry-based learning, (3) must support the achievement of the learning outcomes described by the national curriculum, and (4) must be acquirable with the project's limited resources.

This is why many well-known products with lots of different options, e.g., the LabDisc [26] kits, Vernier sensors [27], etc., that were found as a result of the internet research, were excluded.

4.2. Literate Review

The literature review brought out the fact that there are not many articles regarding the use of IoT technologies in the learning process of general education schools (primary schools, and secondary schools). Many articles in Google Scholar and IEEE Xplore Digital Library's covered the use of Vernier sensors (in total over 3000, of which more than 1500 were conducted in schools), and LabDisc (approximately 1600, but only in Google Scholar), yet if the keywords IoT or Internet of Things were used, most of the educational articles focused on higher education.

In general education schools, the most frequently used IoT devices were wristbands to collect a students' vital data, their temperature, sleep, and stress indicators, which may be used to predict students' learning activities, or room temperature, humidity, light, etc. It can be concluded that while there are many articles exploring ready-made wearables in education, only a small proportion of the possibilities has been covered, mainly concerning closed systems. The most important aspect of the literature review was that it acknowledged the lack of articles regarding the use of IoT devices in the study process of general education schools.

4.3. The Focus Groups Interviews (FGI)

Two weeks before the first interviews with the focus groups, both schools were sent a final list of the kits they were responsible for using during the test period. These lists were improved during the literature review: (1) smart clothes (Adarfuit Gemma, Flora and different sensors, NeoPixels, Matrix Creator, different Arduino sensors: speed, acceleration, flexibility, pressure, gps), and (2) body sensors (eyetracker, Kinect, EEG headset, activity tracker, fingerprint reader, pulse sensor). The lists were available to them in Google Sheets.

4.3.1. The First Stage: Two Focus Groups Interviews (FGI)

The Robotics teacher of the school participating in the interview suggested replacing cables with some sensors, and an Adafruit Flora Bluefruit LE to transmit the data of the smart clothes kit via Bluetooth. In the body-sensor kit, however, more radical changes were suggested: the participants wished to leave only the brainwaves starter kit, replacing everything else with the eHealth kit (MySignals SW Complete Kit) [28].

After the first two interviews with the focus groups, the following IoT devices were obtained: (1) room sensors: Proximity Beacons, Xiaomi Mijia 6 in 1 Smart Home Security Kit, 45 different sensors– temperature, humidity, capacity, six axis sensor accelerometer, gyroscope, 3-axis gyroscope, 3-axis accelerometer, IR motion sensors etc. LED Kit, Raspberry Pi 3 Sets, Z-Wave.Me RaZberry2, and accessories; (2) smart clothes sensors: Wearable electronic platforms Flora and Gemma, Bluefruit LE Module, NeoPixels, Force-Sensitive Resistor, UV Index, Light, Accelerometer/Compass, GPS, temperature, Flex Sensor, Conductive Thread, Knit Conductive Fabric; (3) research labs sensors:

Teslong Portable Waterproof USB Microscope with 10-200 Magnification camera for Android, Mac and Windows PC, Open Garden Indoor Hydroponics kit from Libelium, Ozobot Bit Coding Robot, and PocketLab Voyager; (4) body-sensors: NeuroSky MindWave EEG Headset, MySignals SW Complete Kit; and (5) digital art: Action camera Samsung Gear 360°, 3D printer Prusa i3 MK2S, Photo Studio set with Continuous Lighting Softboxes, Daylight Sets and Tripods, Google Home Speaker, SmartPhone Galaxy 6, Wacom Intuos Pro Small Graphics Tablet, and VR virtual reality Headset.

4.3.2. The Second Stage: Focus Group Interview (FGI)

The schools were given three months to test these kits in the study process, after which, a meeting between the teams took place. During this meeting, the groups presented the positive and negative aspects of the kits they used, and during an interview with the focus group consisting mainly of half-structured questions, additions and corrections were made for the final procurement of the IoT kits. The changes resulting from the interview are shown (in boldface) in Table 3.

Table 3. The list of IoT kits based on the interviews with the focus groups.

Before Test Period, after First FGI	After Test Period, after Second FGI
Room sensors:	
Estimote Proximity Beacons Xiaomi Mijia 6 in 1 Smart Home Security Kit 45 different sensors—temperature, humidity, capacity, six axis sensor accelerometer, gyroscope, 3-axis gyroscope, 3-axis accelerometer, IR motion sensors etc. LED Kits Raspberry Pi 3 Sets Z-Wave.Me RaZberry2 Accessories	Estimote Proximity Beacons Xiaomi Mijia 6 in 1 Smart Home Security Kit 45 different sensors—temperature, humidity, capacity, six axis sensor accelerometer, gyroscope, 3-axis gyroscope, 3-axis accelerometer, IR motion sensors etc. LED Kits Raspberry Pi 3 Sets **with keyboards** Z-Wave.Me RaZberry2 accessories **ZigBee addon for Raspberry Pi**
Smart clothes sensors:	
Wearable electronic platforms Flora and Gemma Bluefruit LE Module different NeoPixels 8 different sensors: Force-Sensitive Resistor, **UV Index**, Light, Color, Accelerometer/Compass, GPS, Temperature, Flex Sensor, Conductive Thread, Knit Conductive Fabric	Wearable electronic platforms Flora and Gemma Bluefruit LE Module different NeoPixels 12 different sensors: Force-Sensitive Resistor, Light, Color, Accelerometer/Compass, GPS, Temperature, Flex Sensor, Fast Vibration, **MyoWare Muscle, Pulse Sensor, Capacitive Touch Shield, Triple-Axis Accelerometer** Conductive Thread, Knit Conductive Fabric
Research Labs sensors:	
Teslong Portable Waterproof USB Microscope with 10-200 Magnification camera **Open Garden Indoor Hydroponics kit from Libelium** Ozobot Bit Coding Robot PocketLab Voyager	Teslong Portable Waterproof USB Microscope with 10-200 Magnification camera Ozobot Bit Coding Robot PocketLab Voyager
Body-sensors:	
NeuroSky MindWave EEG Headset **MySignals SW Complete Kit**	NeuroSky MindWave EEG Headset **MySignals HW BLE Complete Kit** **eHealth Medical Development Shield for Arduino** **Arduino UNO Rev.3** **The Puzzlebox Orbit—a brain-controlled helicopter** **Mini-Wireless-Camera for Puzzlebox Orbit**
Digital art:	
Action camera Samsung Gear 360° 3D printer Prusa i3 MK2S Photo Studio set with Continuous Lighting Softboxes, Daylight Sets and Tripods **Google Home Speaker** SmartPhone Galaxy 6s Wacom Intuos Pro Small Graphics Tablet VR virtual reality Headset	Action camera Samsung Gear 360° 3D printer Prusa i3 MK2S Photo Studio set with Continuous Lighting Softboxes, Daylight Sets and Tripods SmartPhone Galaxy 6s Wacom Intuos Pro Small Graphics Tablet VR virtual reality Headset **Educational license for Agisoft PhotoScan software**

5. Discussion

Table 2 shows that changes were made to all the IoT kits after the test period. Some changes were (1) less important, but there were also (2) radical changes.

(1) Less important changes: some boards, based on different standards of data transmissions, were added to the room sensor kits, sensors used in sports were added to the smart clothes kit, in the digital arts kit the Google Home speaker was replaced with a license for a software to create 3D models based on photographs. In the body sensor kit a model helicopter, that could be flown using a NeuroSky MindWave EEG Headset that was put on the market during the testing period was added.

(2) Radical changes: were related to body sensor and science lab kits, where during the testing period Libelium products (Open Garden Indoor Hydroponics kit, MySignals SW Complete KIT) were used. This change was made due to the fact that Libelium changed the conditions of use for their cloud platform during the IoT kits procurement period (February 2018) for the project's test period, which made platform use a paid service. Unfortunately, the changes were revealed only after the kits had arrived, and as we had not ordered any cloud service the data collected were unusable. For this reason, it was decided that a replacement platform for the body-sensor kits was needed. Eventually, the most suitable option seemed to be an open-source platform allowing data processing, and the previously ordered complete biometrical platform was abandoned. This was done so it would be possible for the students to use the data collected from their surrounding environments and their own digital footprint in the learning process. As the research lab kit also contained a closed system (Open Garden Indoor Hydroponics kit), and in order to use it, it would have been necessary to purchase additional cloud service without the opportunity to export the data, therefore, it was decided not to use this devices.

6. Conclusions

In order to popularize the natural- and exact-sciences, and to motivate and arouse interest in the students towards STEM education, a project called "Smart Schoolhouse by means of IoT" was launched. The ultimate goal of the project is using inquiry- and project-based learning methods when teaching natural- and exact-sciences to find solutions to real life problems, and through trialogical approach creating innovative teaching materials that would support these methods.

To achieve these goals, the schools participating in the test period were given IoT device kits specifically procured for them. In this article, a short overview of the preparations for obtaining IoT devices, IoT device kits procured for the test period, and the bottlenecks which occured while using them were given. This was used as a basis for creating a final list of IoT device kits needed and later purchased. In following articles there will be an introduction of adopted kits and approaches.

To ensure that the best suitable IoT devices having the option to use the data collected in the learning process were obtained, a multi-staged research approach was conducted: (1) mapping out the IoT devices that are going to be used on the basis of the internet research, (2) literature review, and (3) two different interviews conducted with the focus groups (teachers and students from different schools) with half a year difference. As a result of these interviews, a list of IoT device kits to be obtained was created.

Students were actively involved in introducing IoT devices to the learning process through trialogical approach and IBL. There have already been scenario-based participatory-design research sessions to ascertain the readiness of learners to create learning materials using the standpoints of IBL and trialogical approach, to find solutions to real-life problems, and to share acquired knowledge with schools joining the project.

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References

1. Kusmin, M.; Kusmin, K.-L.; Laanpere, M.; Tomberg, V. Engaging Students in Co-Designing Wearable Enhanced Learning Kit for Schools. In *Springer Book Perspectives on Wearable Enhanced Learning: Current Trends, Research and Practice*; Springer: New York, NY, USA, 2019; in press.
2. Burns, H.D.; Lesseig, K.; Staus, N. Girls' interest in STEM. In Proceedings of the Frontiers in Education Conference (FIE), Erie, PA, USA, 12–15 October 2016; pp. 1–5.
3. Rüütmann, T. Optional STEM courses for secondary schools designed and implemented for enhancement of K-12 technology education in order to excite students' interest in technology and engineering education. In Proceedings of the 2014 International Conference on Interactive Collaborative Learning (ICL), Dubai, UAE, 3–6 December 2014; pp. 144–150.
4. National Research Council. *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*; National Academies Press: Washington, DC, USA, 2011; ISBN 978-0-309-21296-0.
5. Global STEM Alliance. Available online: https://www.nyas.org/programs/global-stem-alliance/ (accessed on 16 January 2019).
6. LUMA Centre Finland. Available online: https://www.luma.fi/en/centre/ (accessed on 16 January 2019).
7. NTNU's Resource Centre for STEM-Education. Available online: https://www.ntnu.edu/skolelab (accessed on 16 January 2019).
8. Estonian Centre for Engineering Pedagogy. Available online: https://www.ttu.ee/en/?id=150200 (accessed on 16 January 2019).
9. NSTC. Available online: https://www.whitehouse.gov/ostp/nstc/ (accessed on 16 January 2019).
10. English, L.D. STEM education K-12: Perspectives on integration. *Int. J. STEM Educ.* 2016. [CrossRef]
11. Organisation for Economic Co-Operation and Development. *PISA 2012 Assessment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy*; OECD Publishing: Paris, France, 2013.
12. European Schoolnet 2015 Report. Available online: http://www.eun.org/resources/country-reports (accessed on 1 December 2018).
13. *Haridus-ja Teadusministeeriumi Aasta-Analüüs*; HTM: Tartu, Estonia, 2015; Available online: https://www.hm.ee/sites/default/files/aastaanalyys2015_kokkuvote_16sept.pdf (accessed on 16 January 2019).
14. Kamal, N.; Saad, M.M.; Kok, C.S.; Hussain, A. Towards revolutionizing stem education via IoT and blockchain technology. *Int. J. Eng. Technol.* **2018**, *7*, 189–192. [CrossRef]
15. Hoić-Božić, N.; Laanpere, M.; Pata, K.; Franković, I.; Teder, S. Introducing inquiry-based learning to Estonian teachers: Experiences from the Creative Classroom project. In Proceedings of the 2016 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, 30 May–3 June 2016; pp. 1010–1015.
16. Şimşek, P.; Kabapınar, F. The effects of inquiry-based learning on elementary students' conceptual understanding of matter, scientific process skills and science attitudes. *Procedia-Soc. Behav. Sci.* **2010**, *2*, 1190–1194. [CrossRef]
17. Lakkala, M.; Muukkonen, H.; Paavola, S.; Rämö, E. Pedagogical Design for Trialogical Approach on Learning. In Proceedings of the Symposium Conducted at the 12th Biennial Conference for Research on Learning and Instruction (EARLI), Budapest, Hungary, 28 August–1 September 2007.
18. Paavola, S.; Lakkala, M.; Muukkonen, H.; Kosonen, K.; Kalgren, K. The roles and uses of design principles in a project on trialogical learning. *Res. Learn. Technol.* **2011**, *19*, 233–246. [CrossRef]
19. Andy, F.C.W. To arouse students' interest in learning: Does inquiry based learning make a difference. In Proceedings of the IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Zhuhai, China, 10–12 December 2015; pp. 295–300.
20. Kusmin, M.; Laanpere, M.; Saar, M.; Rodríguez-Triana, M.J. Work in Progress—Smart Schoolhouse as a Data-Driven Inquiry Learning Space for the Next Generation of Engineers. In Proceedings of the Global Engineering Education Conference (EDUCON), Athens, Greece, 25–28 April 2017; pp. 1667–1670.
21. Su, H.F.A.; Ledbetter, N.; Ferguson, J.; Timmons, L.T. Finland: An Exemplary STEM Educational System. *Transformations* **2017**, *3*, 4. Available online: https://nsuworks.nova.edu/transformations/vol3/iss1/4 (accessed on 1 December 2018).

22. Rüütmann, T.; Saar, M. Scholarly teaching and scholarship of teaching and learning in teaching engineering. In Proceedings of the Global Engineering Education Conference (EDUCON), Athens, Greece, 25–28 April 2017; pp. 213–218.
23. He, J.S.; Ji, S.; Bobbie, P.O. Internet of things (iot)-based learning framework to facilitate stem undergraduate education. In Proceedings of the SouthEast Conference, Kennesaw, GA, USA, 13 April 2017; ACM: New York, NY, USA, 2017; pp. 88–94.
24. He, J.; Lo, D.C.T.; Xie, Y.; Lartigue, J. Integrating Internet of Things (IoT) into STEM undergraduate education: Case study of a modern technology infused courseware for embedded system course. In Proceedings of the IEEE Frontiers in Education Conference (FIE), Erie, PA, USA, 12–15 October 2016; pp. 1–9.
25. Kusmin, M.; Saar, M.; Laanpere, M. Smart schoolhouse—Designing IoT study kits for project-based learning in STEM subjects. In Proceedings of the Global Engineering Education Conference (EDUCON), Tenerife, Spain, 17–20 April 2018; pp. 1514–1517.
26. Labdisc Portable STEM Lab. Available online: https://mimio.boxlight.com/labdisc-portable-stem-lab/ (accessed on 16 January 2019).
27. LabQuest®2. Available online: https://www.vernier.com/products/interfaces/labq2/ (accessed on 16 January 2019).
28. Cooking Hacks by Libelium. Available online: https://www.cooking-hacks.com/mysignals-sw-ehealth-medical-biometric-complete-kit (accessed on 16 January 2019).