Open Source Hardware in PK-12 Education: A Literature Review

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Abstract- Open-source hardware (OSH) is a low-cost innovative alternative to commercial hardware technologies. Within the education system, these technologies are used to better students' learning without traditional costs. This literature review shows what, where, and how OSH is being used in PK-12 learning. The OSH technologies included in this review are robotics, science lab equipment, 3D printers, and e-textiles. It is concluded that these technologies are shown to further students' learning by enabling them to build the technologies themselves.

1. Introduction

Open-source hardware (OSH) is described by the Open Source Hardware Association as "hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design" [1]. Perceived advantages of using an open source approach to hardware include innovation and evolution of the hardware, ability to be scrutinized with helpful feedback for better engineering, a community that helps with troubleshooting, lowered barriers of entry so to increase competition for companies to improve their products, and the potential for personalization [2].

This literature review looks at how open-source hardware technologies are being used in PK-12 (pre-kindergarten through 12th grade) formal and informal education programs.

Each technology is given their own section, each being split further into school level (Multiple, Elementary, Middle, High) and split further yet by the intent of the reviewed literature (study/workshop, presenting a technology, or lesson plans/databases). Figures included are the school level at which these studies are conducted, nationalities from which these papers originate from, research questions of several studies, and various data collected, such as the duration of the studies, age of the participants, and number of participants. The research questions for this literature review are as follows:

1. What open-source hardware is being used in the PK-12 education system?
2. Where is open-source hardware being used in the PK-12 education system?
3. How is open-source hardware being used in the PK-12 education system?

This literature review was made from the contributions of student researchers at the Playful Learning Lab, thus different researchers researched a given topic in different ways, all using various keywords primarily in Google Scholar. The following sections are the result of their work.

2. Robotics

There are many open-source robots, including the Thymio [3-6], ProBot [9], Ottobot [10], AERobot [11], DuBot [13], EduBot[19], Neurorobot [20], and the 3D printable ArduSkybot [12] and Poppy [21].

2.1. Multiple Age Ranges

“A two years informal learning experience using the Thymio robot” is a workshop for the Thymio robot, where the goal was to promote creativity and understanding of the technology [3]. “How do teachers perceive educational robots in formal education? A study based on the Thymio robot*” is a study with Thymio robot, where it was found to have broad applicability in teaching [4]. “A sociological contribution to understanding the use of robots in schools: the Thymio robot” is a study of the sociological impact of the Thymio robot found that it "achieved a similar acceptance and diffusion to those of other tools such as the BeeBot or Mindstorms robots, which have fewer education-oriented technical features, are not open-source, [and] have fewer sensors" [5]. “Thymio II, a robot that grows wiser with children*” is a workshop that used Thymio II robots during the 2013 Robotics Festival where the participant's main goals were to have fun and learn new things [6]. “Piloting Diversity and Inclusion Workshops in Artificial Intelligence and Robotics for Children” is a workshop for AI and robotics for children that promotes diversity and inclusion in developing countries, including open-source hardware and software, educational resources, and alternative education programs [7]. “Open-source robotics: investigation on existing platforms and their application in education” is an overview of the available commercial open-source robotics platforms that can support education [8]. “Robotics Education Methodology for K-12 Students for Enhancing Skill Sets Prior to Entering University” is a study using ProBot, an open-source educational robot, and EDVON, an open-source software, found that the implementation of these technologies showed positive results in learning, performance, and communication [9].

2.1.1. Presents Technology

“Developing programmable robot for K12 STEAM education” presents the Ottobot, a low-cost open-source 3D printable robot as well as classroom guides [10]. “AERobot: An Affordable One-Robot-Per-Student System for Early Robotics Education” presents AERobot, a platform for early STEM education, with a study of one robot per student framework that allows personalization and increases engagement [11]. “Low Cost Educational Platform For Robotics, Using Open-Source 3D Printers and Open-Source Hardware” presents the ArduSkybot, its design process, and documents their performance during workshops [12]. “DuBot: An Open-Source, Low-Cost Robot for STEM and Educational Robotics” presents the DuBot, an open-source, low-cost robot for education [13].

2.1.2. Lesson Plans and Databases

“Technical Database on Robotics-based Educational Platforms for K-12 students” is a database of available educational robotic platforms and related learning material [14]. “Integrating Robotics in Education and Vice Versa; Shifting From Blackboard to Keyboard” is a "road map regarding commercial social robots and open-source robotic (OSR) platforms, currently available in education" [15]. “Overview of Technologies for Building Robots in the Classroom” is a "overview of technologies that can be used to implement robotics within an educational context" [16].

2.2. Elementary

“Motivating Future Engineers: Building Situation Sensing Mars Rover with Elementary School Students” is a study where participants attend weekly STEM Club sessions led by STEM professionals, found that an open-source Arduino-based robot will help participants learn the engineering process as well as potential careers [17].

2.2.1. Presents Technology

“AIR4 Children: Artificial Intelligence and Robotics for Children” presents AI and robotics for children, which is open-source hardware and software, that aim for minimal costs and are customisable for education [18]. “EduBot: An Educational Robot for Underprivileged Children” presents the EduBot, low-cost, customizable, block-based self-compiling education robot that uses the visual programming tool Blockly [19].

2.3. High

“Neurorobotics Workshop for High School Students Promotes Competence and Confidence in Computational Neuroscience '' is a workshop for Neurorobot to teach computational neuroscience [20].

2.3.1. Presents Technology

“Poppy: open-source, 3D printed and fully-modular robotic platform for science, art and education” presents the Poppy, a open-source, 3D printable, robotic platform for education [21]. “Bridging Robotics Education between High School and University: RoboCup@Home Education” presents the RoboCup@Home, an open-source, low-cost, large community support for novice teams [22].

2.4. Tables and Figures

Paper	School Level	Age of Participants	Duration	# of Participants	Location	#
Developing programmable robot for K12 STEAM education	Elementary, Middle, High				Taiwan	10
A two years informal learning experience using the Thymio robot	Elementary, Middle, High		1 session	50		3
AERobot: An Affordable One-Robot-Per-Student System for Early Robotics Education	Elementary, Middle, High		3 sessions	41		11
How do teachers perceive educational robots in formal education? A study based on the Thymio robot*	Elementary, Middle, High					4
A sociological contribution to understanding the use of robots in schools: the Thymio robot	Elementary. Middle, High					5
Thymio II, a robot that grows wiser with children*	Elementary, Middle, High					6
Low Cost Educational Platform For Robotics, Using Open-Source 3D Printers and Open-Source Hardware	Elementary, Middle, High				Spain	12
AIR4 Children: Artificial Intelligence and Robotics for Children	Elementary				Canada, Mexico, US, UK	18

Piloting Diversity and Inclusion Workshops in Artificial Intelligence and Robotics for Children	Elementary, Middle, High	average of 7.64 years old		14	Mexico	7
Open-source robotics: investigation on existing platforms and their application in education	Elementary, Middle, High				Greece	8
Motivating Future Engineers: Building Situation Sensing Mars Rover with Elementary School Students	Elementary	4th grade		40	US	17
Robotics Education Methodology for K-12 Students for Enhancing Skill Sets Prior to Entering University	Elementary, Middle, High			17 schools	Pakistan	9
EduBot: An Educational Robot for Underprivileged Children	Elementary				Bangladesh	19
Technical Database on Robotics-based Educational Platforms for K-12 students	Elementary, Middle, High				Portugal	14
Integrating Robotics in Education and Vice Versa; Shifting From Blackboard to Keyboard.	Elementary, Middle, High				Greece, Bulgaria, Croatia	15
DuBot: An Open-Source, Low-Cost Robot for STEM and Educational Robotics	Elementary, Middle, High				Greece, Canada	13
Overview of Technologies for Building Robots in the Classroom	Elementary, Middle, High				Belgium	16
Poppy: open-source, 3D printed and fully-modular robotic platform for science, art and education	High					21
Neurorobotics Workshop for High School Students Promotes Competence and Confidence in Computational Neuroscience	High		1 week		US	20
Bridging Robotics Education between High School and University: RoboCup@Home Education	High				China, Italy, US, Japan	22

Table 1c: Robotics Data

Paper	Research Questions	#
How do teachers perceive educational robots in formal education? A study based on the Thymio robot*	1. What do they perceive as the robots' main utility? 2.What kind of knowledge do they target in robot-based activities? In which school subjects are involved? 3. What professional skills are required to use the device? How is the use of robots facilitated? 4. What is the perceived usability of the device? Can it be easily handled by the pupils? 5. What is the perceived acceptability of integrating this type of device in teachers' practice? What are the constraints of the device in classroom use?	4
Motivating Future Engineers: Building Situation Sensing Mars Rover with Elementary School Students	1. What types of perceptual changes result from participation in an after-school STEM activity? 2. What types of attitudinal effects result from participation in an after-school STEM activity? 3. What types of changes in affect toward engineering result from participation in an after-school STEM activity?	17

Table 2c: Robotics Research Questions

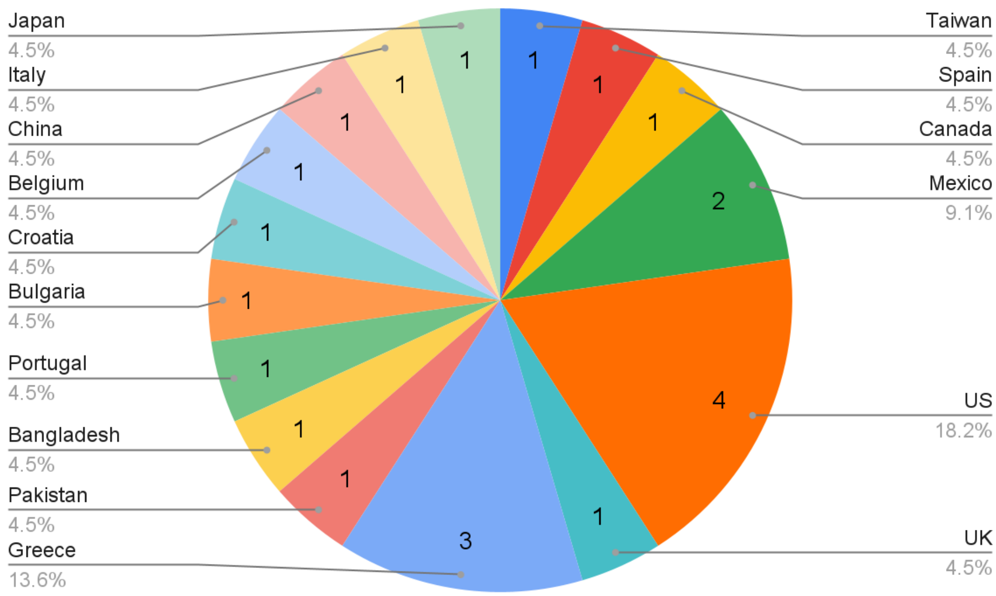

Figure 1c: Robotics Paper Origins

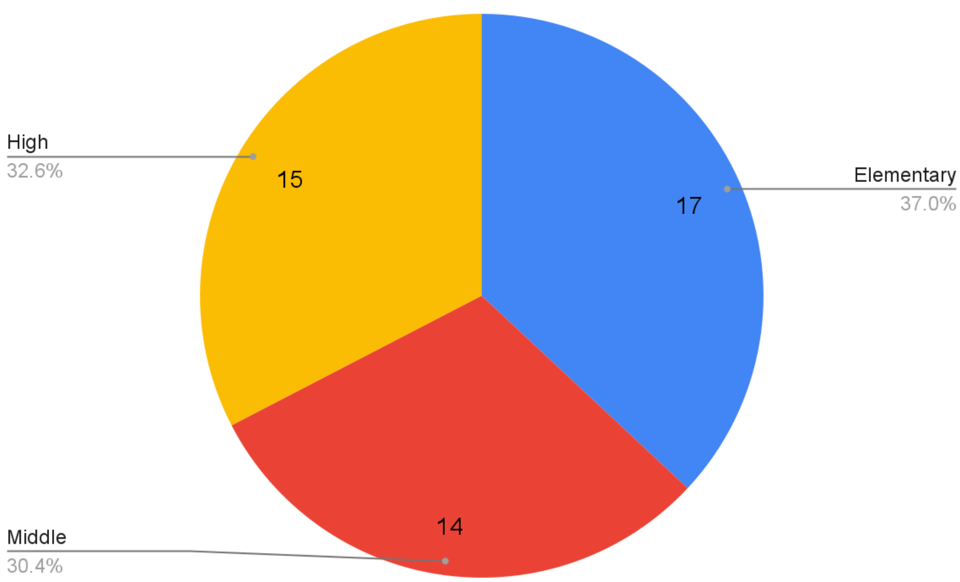

Figure 2c: Robotics School Level

2.5. Analysis

A majority of open-source hardware robotics papers focused on all school levels, with a majority of the papers being from outside the US, which is to be expected because of the outreach of many of the robots.

3. Science Lab Equipment

Open-source science lab equipment, known as OSSLE, makes the otherwise expensive lab-grade measuring equipment more affordable and customizable. Some popular OSSLE products are Paperfuge and Foldscope [29-30]. Many OSSLEs include an Arduino [23,25-28,33,34-37].

3.1. Multiple Age Ranges

"Teaching Chemistry with Arduino Experiments in a Mixed Virtual-Physical Learning Environment" is a study where Arduino experiments were incorporated into Chemistry Education, and found that the experiments may bridge virtual and physical instruments as tools in a mixed learning environment [23].

3.1.1. Presents Technology

"A low-cost do-it-yourself microscope kit for hands-on science education" presents a low-cost, DIY, 3D printable microscope for education [24].

3.2. Elementary

3.2.1. Lesson Plans and Databases

"Effect of Gases in Temperature Change In the Atmosphere: A Stem Activity" is a lesson plan for an Earth Science class where a new prototype measuring technique using Arduino is used [25].

3.3. Middle

"Low-cost emerging technologies as a tool to support informal environmental education in children from vulnerable public schools of southern Chile" is a study using Arduino technology to address current environmental problems, global change, and anthropization [26].

3.3.1. Presents Technology

"Arduino-Assisted robotic and coding applications in science teaching: Pulsometer activity in compliance with the 5E learning model" presents an Arduino-assisted robotic and coding activity that aligns with the 5E learning model for the circulatory system [27].

3.4. High

"Learning about UV radiation and sustainability with arduino and sensors" is a study using Arduino and a UV radiation sensor to measure the effectiveness of sunblocks, where the participants developed interdisciplinary skills [28]. "The effective affordances of frugal science using foldscopes during a life sciences water quality practical" is a study where the participants, teachers, used a Foldscope, an open-source microscope, and developed practical activities to be used in their own classrooms [29]. "'Foldscope'- A simple and economical microscope" is a study using Foldscope, an open-source microscope, where participants made and use slides to be tested under the Foldscope, found that the conventional microscope was less efficient for learning as the Foldscope [30].

3.4.1. Presents Technology

"LudusScope: Accessible Interactive Smartphone Microscopy for Life-Science Education" presents the LudusScope, an accessible smartphone microscope platform that "promotes exploratory stimulation and observation of microscopic organisms" [31].

“A remote-controlled detector system with Geiger–Müller counter” presents a system of remote-controlled detectors that detects radiation so teachers can conduct radioactive experiments safely [32]. “Working in a Team: Development of a Device for Water Hardness Sensing Based on an Arduino−Nanoparticle System” presents an Arduino-based device that automatically measures water hardness, which involves chemistry, electronics, and IT experience [33]. “Friction coefficient determination by electrical resistance measurements” presents a low-cost, DIY, Arduino-based experiment for the study of friction and measuring the friction coefficient [34]. “AIRduino: On-Demand Atmospheric Secondary Organic Aerosol Measurements with a Mobile Arduino Multisensor" presents the AIRduino, a handheld multisensor device used to record atmospheric measurements of ozone, volatile organic compounds, and aerosol particulate matter [35]. “ChemDuino: Adapting Arduino for Low-Cost Chemical Measurements in Lecture and Laboratory” presents the ChemDuino, where the microprocessor board can be used with measuring devices in a chemistry lab to be more adaptable for classroom use [36]. “Learning Laboratory Chemistry through Electronic Sensors, a Microprocessor, and Student Enabling Software: A Preliminary Demonstration” presents a way to adapt Arduino for low-cost data collection in laboratory classes [37]. “3D-Printable Model of a Particle Trap: Development and Use in the Physics Classroom” presents a 3D printable model of a quadrupole ion trap for classroom use, and can be used to levitate lycopodium spores [38].

3.5. Tables and FIgures

Paper	School Level	Age of Participants	Duration	# of Participants	Location	#
Teaching Chemistry with Arduino Experiments in a Mixed Virtual‑Physical Learning Environment	Elementary, Middle, High	14-15 years old			Greece	23
Effect of Gases in Temperature Change In the Atmosphere: A Stem Activity.	Elementary	5th grade			Turkey	25
A low-cost do-it-yourself microscope kit for hands-on science education	Elementary, Middle				US	24
Arduino-Assisted robotic and coding applications in science teaching: Pulsometer activity in compliance with the 5E learning model	Middle	6th grade		10	Turkey	27
Low-cost emerging technologies as a tool to support informal environmental education in children from vulnerable public schools of southern Chile	Middle	7th grade	5 week	115	Chile	26
A remote-controlled detector system with Geiger–Müller counter	High				Vietnam	32
Working in a Team: Development of a Device for Water Hardness Sensing Based on an Arduino−Nanoparticle System	High			20	Italy	33
Friction coefficient determination by electrical resistance measurements	High				Romania	34
Learning about UV radiation and sustainability with arduino and sensors	High	9th grade			Romania	28
ARduino: On-Demand Atmospheric Secondary Organic Aerosol Measurements with a Mobile Arduino Multisensor	High					35
ChemDuino: Adapting Arduino for Low-Cost Chemical Measurements in Lecture and Laboratory	High				Czech Republic	36

Learning Laboratory Chemistry through Electronic Sensors, a Microprocessor, and Student Enabling Software: A Preliminary Demonstration	High				US	37
3D-Printable Model of a Particle Trap: Development and Use in the Physics Classroom	High					38
The affective affordances of frugal science using foldscopes during a life sciences water quality practical	High				South Africa	29
'Foldscope'- A simple and economical microscope	High	9th and 10th grade			India	30
LudusScope:Accessible Interactive Smartphone Microscopy for Life-Science Education	High				US	31

Table 1d: Science Lab Equipment Data

Paper	Research Questions	#
Teaching Chemistry with Arduino Experiments in a Mixed Virtual‐Physical Learning Environment	1. By using IB(Interactive Board), is there a difference in declarative knowledge acquisition when teaching with a mixed virtual-physical environment vs. teaching with VL(Virtual Labs)? 2. By using IB, is there a difference in declarative knowledge acquisition when teaching with a mixed virtual-physical environment vs. teaching with no experiments at all? 3. By using IB, is there a difference in declarative knowledge acquisition when teaching with VLs vs. teaching with no experiments at all?	23
Low-cost emerging technologies as a tool to support informal environmental education in children from vulnerable public schools of southern Chile	1. whether these new, low-cost technologies can be used to change perspectives in learning STEM and in what context we can use these tools to help students be more enthusiastic about STEM subjects.	26
Learning about UV radiation and sustainability with arduino and sensors	1. How can the use of Arduino develop students' epistemic practices and interdisciplinary skills? 2. How can the use of Arduino help in understanding the concept of UV radiation and prevent risk behaviors?	28
The affective affordances of frugal science using foldscopes during a life sciences water quality practical	1. What are the affordances of utilizing foldscope microscopes in promoting affective outcomes in the Life Sciences classroom? 2. What are teachers' experiences of engaging in classroom action research (CAR) on foldscopes, and what are the effective affordances of such CAR?	29

Table 2d: Science Lab Equipment Research Questions

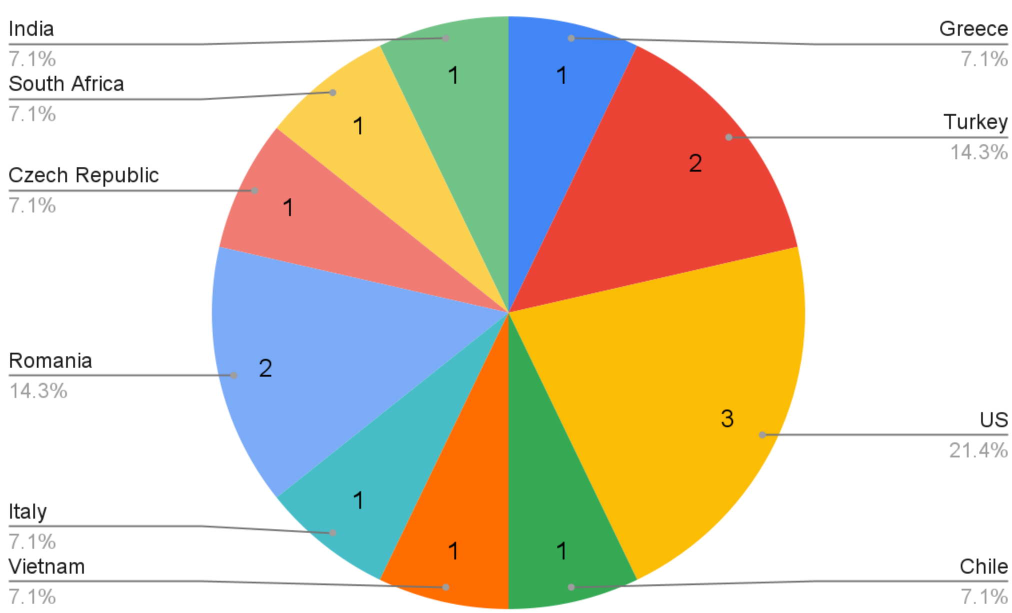

Figure 1d: Science Lab Equipment Paper Origins

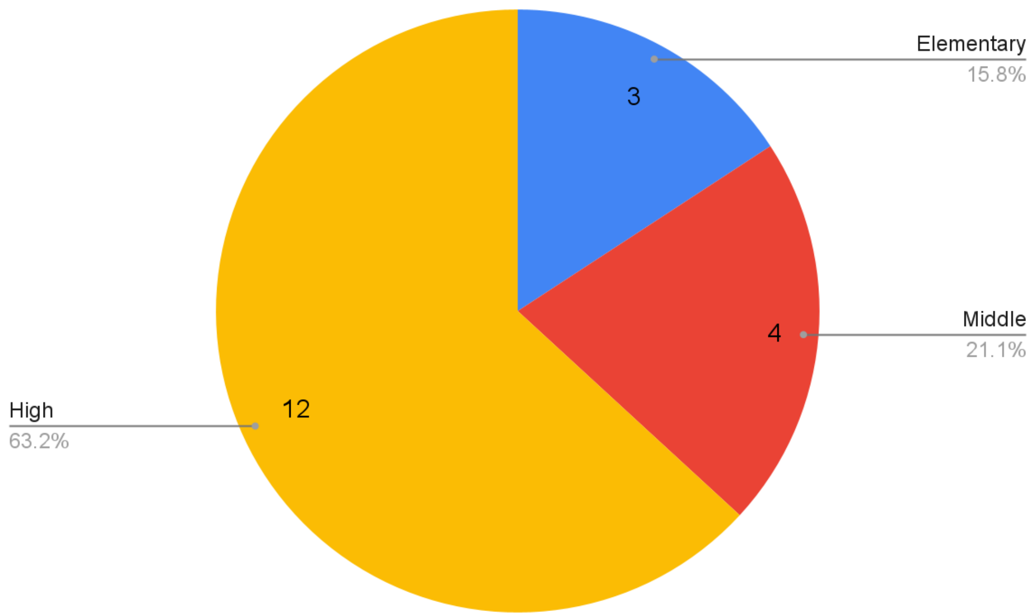

Figure 2d: Science Lab Equipment School Levels

3.6. Analysis

A majority of the open-source science lab equipment takes place in high school, which is to be expected due to the need for more and unique measuring equipment in higher level science classes. A majority of the papers originate from outside the US, which is to be expected due to the widespread use and need of lab equipment. The research questions were mainly the effectiveness of OSSLE within the classroom as well as its effectiveness against standard lab-grade equipment.

4. 3D Printing

Open-source hardware 3D printers, known as OSH3DP, are extremely cost effective, compared to their commercial counterparts. The most popular OSH3DP is the RepRap [39-40], which many of the following papers use. This section also includes several papers on open source 3D printable objects used in various classrooms including chemistry [46].

Desktop 3D Printer	DIY Open Source	Fully Assembled Open Source	Commercial	Approximate Cost
Prusa Mendel RepRap	X			$550
Delta RepRap	X			$400
Trinity Labs		X		$2,199
Aleph Objects		X		$1,725
Type A Machines		X		$1,400
Printrbot LC		X		$799
Makerbot Replicator			X	$2,800
Statasys Mojo			X	$10,000

Table 3: 3D Desktop Printers [69].

4.1. Multiple Age Ranges

“The RepRap 3D Printer Revolution in STEM Education” is a study of how and where the 3D printer RepRap is being used in STEM education. [39] “Evaluation of RepRap 3D Printer Workshops in K-12 STEM” is a workshop teaching high school science and technology teachers, where participants built their own RepRap printers in order to take them back to use in their classrooms [40].

4.1.1. Lesson Plans and Databases

“3D printing in education: a literature review” is a literature review of how 3D printing is being used in education (not necessarily open-source) [41]. “Purposes, Limitations, and Applications of 3D Printing in Minnesota Public Schools” is a literature review of how 3D printing in K-12 education in Minnesota public schools includes open-source 3D printers [42].

4.2. Elementary

“Using 3D Printing in Science for Elementary Teachers” is a study of the application of 3D printing in elementary science education (not necessarily open-source) [43].

4.3. High

“Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece” is a study where participants collaboratively design and create 3D artifacts using an open-source 3D printer and a 3D design platform [44]. “3D printing as a means of learning and communication: The 3Ducation project revisited” is a study into how open-source 3D printers and 3D design software are being used for learning and communication. Participants designed and manufactured natural and cultural heritage artifacts with messages in Braille [45].

4.3.1. Lesson Plans and Databases

“Printing 3D Models for Chemistry: A Step-by-Step Open-Source Guide for Hobbyists, Corporate Professionals, and Educators and Students in K-12 and Higher Education” is a guide for 3D printing open-source chemistry models [46].

“An Educational Framework for Digital Manufacturing in Schools” is a guide to how digital manufacturing programs using open-source 3D printers and other tools were made [47].

4.4. Tables and Figures

Paper	School Level	Age of Participants	Duration	# of Participants	Location	#
3D printing in education: a literature review	Elementary. Middle, High				US	41
Using 3D Printing in Science for Elementary Teachers	Elementary				US	43
Purposes, Limitations, and Applications of 3D Printing in Minnesota Public Schools	Elementary, Middle, High				US	42
The RepRap 3D Printer Revolution in STEM Education	Middle, High					39
Evaluation of RepRap 3D Printer Workshops in K-12 STEM	Middle, High				US	40
Printing 3D Models for Chemistry: A Step-by-Step Open-Source Guide for Hobbyists, Corporate Professionals, and Educators and Students in K-12 and Higher Education	High					46
Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece	High		3 months	33	Greece	44
An Educational Framework for Digital Manufacturing in Schools	High					47
3D printing as a means of learning and communication: The 3Ducation project revisited	High			11	Greece, Portugal	45

Table 1e: 3D Print Data

Paper	Research Questions	#
Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece	1. What role could 3D printing and design, along with the modern ICT, play in developing and implementing new educational ideas based on the principles of constructionism?	44

Table 2e: 3d Print Research Questions

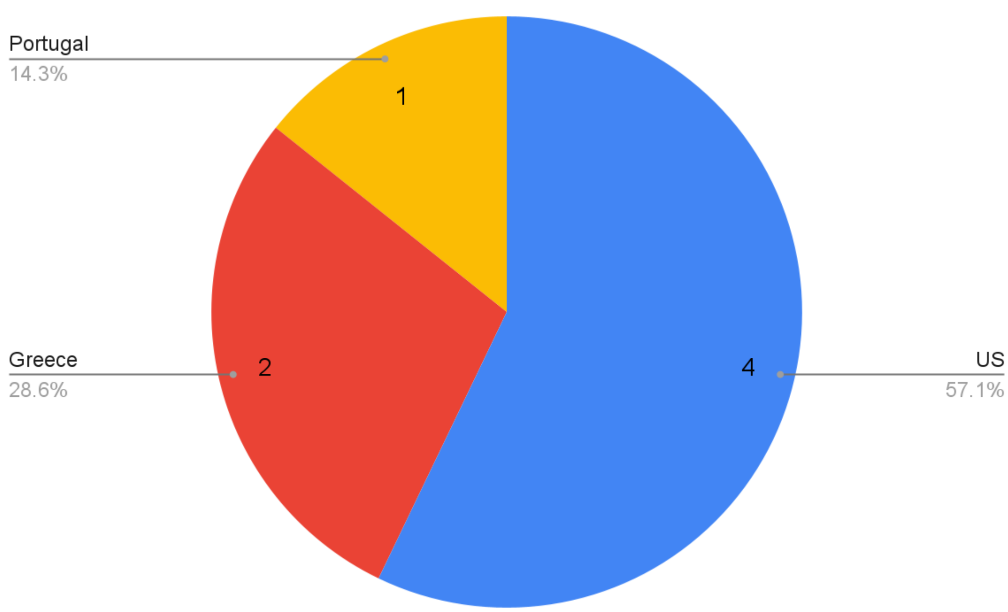

Figure 1e: 3D Printing Paper Origins

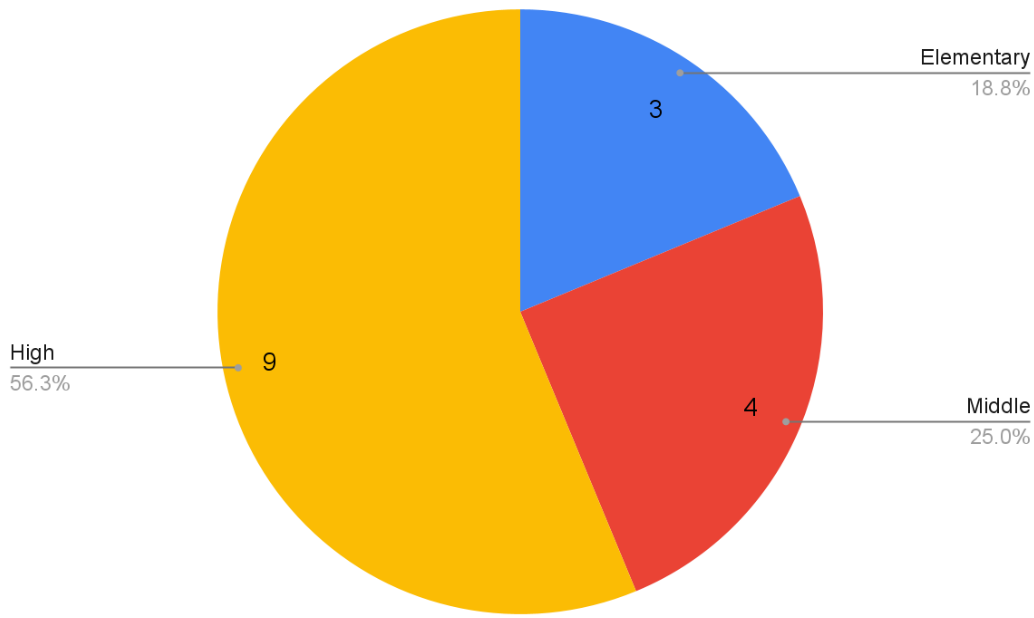

Figure 2e: 3D Printing School Levels

4.5. Analysis

The RepRap is by far the most popular OSH 3D printer. A large majority of the papers take place in high school, with most of the papers originating from the US. RepRap is a 3D printer that can print the parts to build more 3D printers. It is because of the replicability that much of this literature is using RepRap.

5. E-textiles

Electronic textiles, known as e-textiles, are open-source sewable electronic components to be sewed onto clothing and other fabric. The leading hardware options are Lilypad components, which are usable with an Arduino board.

5.1. Multiple Age Ranges

“Implementing and Evaluating An E-Textile Curriculum In an Engineering Summer Program for Girls (Evaluation)” is a study of the implementation and assessment of e-textiles curriculum for participants in a summer STEM program for girls [48]. “MOTIVATE: Bringing Out the Fun with 3D Printing and E-Textiles for Middle- and High-School Girls” is a paper describing the MOTIVATE framework using 3D printing and e-textiles to expose African American girls to computer science [49].

5.2. Elementary

“Exploring Early Designs for Teaching Anatomy and Physiology to Children Using Wearable E-Textiles” is a study where participants use e-textiles to create a shirt to teach anatomy and physiology [50].

5.3. Middle

“Equitable Engagement in STEM: Using E-textiles to Challenge the Positioning of Non-dominant Girls in School Science” is a study of how e-textiles impact the self-perceptions and actions of participants from non-dominant communities in science education [51].

5.4. High

“Diversifying High School Students’ Views About Computing with Electronic Textiles” is a study of an implemented e-textiles unit where participants practice, design, and program electronic artifacts, and found that the participants created a link between e-textiles and coding [52]. “Making Physical and Digital Games with E-Textiles: A Workshop for Youth Making Responsive Wearable Games and Controllers” is a study where participants coded and created their own Scratch games and created controllers using e-textiles [53]. “Towards a Curriculum for Electronic Textiles in the High School Classroom” is a study with a proposed curriculum of an e-textiles course and its implementation [54]. “Electronic Textiles as Disruptive Designs: Supporting and Challenging Maker Activities in Schools” is a study of e-textiles workshops and how participant experiences making e-textiles affect themes of transparency, aesthetics, and gender [55]. “Sustaining Making in the Era of Accountability: STEM Integration Using E-Textiles Materials in a High School Physics Class” is a study of how the addition of e-textiles in the science curriculum deepens the understanding of science, technology, engineering, design, and physics using hands-on experiences [56].

5.5. Tables and Figures

Paper	School Level	Age of Participants	Duration	# of Participants	Location	#
Exploring Early Designs for Teaching Anatomy and Physiology to Children Using Wearable E-Textiles	Elementary				US	50
Implementing and Evaluating An E-Textile Curriculum In an Engineering Summer Program for Girls (Evaluation)	Middle, High				US	48
MOTIVATE: Bringing Out the Fun with 3D Printing and E-Textiles for Middle- and High-School Girls	Middle, High				US	49
Equitable Engagement in STEM: Using E-textiles to Challenge the Positioning of Non-dominant Girls in School Science	Middle				US	51
Diversifying High School Students’ Views About Computing with Electronic Textiles	High	16-18 years old	10 week	27	US	52
Making Physical and Digital Games with E-Textiles: A Workshop for Youth Making Responsive Wearable Games and Controllers	High	14-15 years old	8 sessions		US	53
Towards a Curriculum for Electronic Textiles in the High School Classroom	High	14-17 years old			US	54
Electronic Textiles as Disruptive Designs: Supporting and Challenging Maker Activities in Schools	High	high	3 sessions		US	55
Sustaining Making in the Era of Accountability: STEM Integration Using E-Textiles Materials in a High School Physics Class	High				US	56

Table 1f: E-textiles

Paper	Research Questions	#
Equitable Engagement in STEM: Using E-textiles	1. How do non-dominant female students engage with e-textiles projects and materials in science	51

to Challenge the Positioning of Non-dominant Girls in School Science	classrooms? 2. How do such engagements shift their perceptions and their teachers' perceptions of what STEM is and who can do it?	
Sustaining Making in the Era of Accountability: STEM Integration Using E-Textiles Materials in a High School Physics Class	1. Can e-textiles making activities serve as a useful and sustainable approach to teach core science curriculum as outlined by national and state standards? 2. Can written code be used with students to model electric potential as they learn physics?	56

Table 2f: eTextiles Research Questions

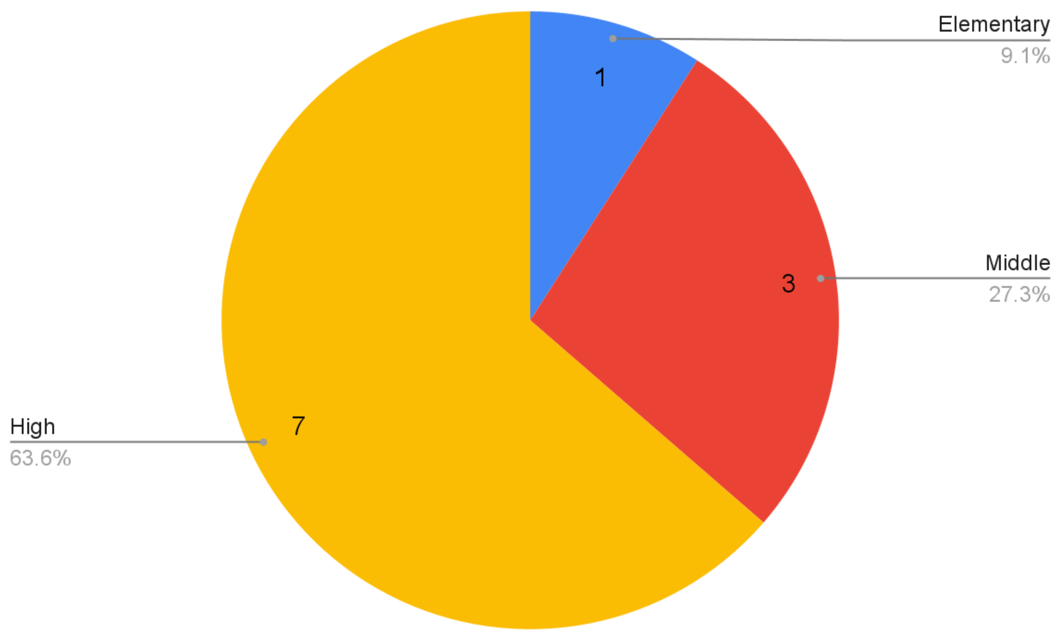

Figure 2f: eTextiles School Levels.

5.6. Analysis

All of the OSH e-textiles originate from the US, with a majority taking place in high school. Many of these papers were also gender-focused.

7. Conclusion

A total of 54 papers were used for the literature review, and an additional 2 papers were used for background information. The final tallies are: 20 robotics papers, 16 science lab equipment papers, 9 3D Printing papers, and 9 eTextiles papers.

The reasons for this literature review are as follows:

- Raise awareness of open-source hardware in PK-12, STEAM, STEM, and art programs.
- Inform educational researchers and rates at which, as reasons why, open-source hardware is being used in such programs.
- Provide examples for academics for incorporating open-source hardware for PK-12 related work into their academic scholarly engagement portfolio.
- Raise awareness of open-source hardware among faculty.

This literature review shows how these open-source technologies: robotics, science lab equipment, 3D printers, and e-textiles, are currently being used in PK-12 programs. This literature review includes various figures and tables showing where and how these technologies are being used. With all this information in one place, any academic, researcher, or PK-12 teacher, can find what they are looking for. Open-source hardware are technologies built to be adaptable, so that they may continue to grow and change. With their significantly lower cost compared to their commercial counterparts, open source hardware are optimal tools for education.

Works Cited

[1] “Definition (English).” Open Source Hardware Association, 14 May 2021, www.oshwa.org/-definition/.

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