eROBSON

Teaching Educational Robotics Blended and Online with Augmented Reality

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Report

Teaching Educational Robotics blended and online with Augmented Reality

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Augmented Reality for Educational Robotics: A Group Concept Mapping study: Olga Firssova, Nardie Fanchamps, and Giel van Lankveld

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Summary

This report informs about the possibilities of using Augmented Reality to teach Educational Robotics and is based on primary and secondary research. The report aims to explore the existing knowledge and possibilities of supporting Educational Robotics methods with Augmented Reality in the online and blended formats, especially in the contexts of pandemic-related restrictions to laboratories and equipment.

The report describes the results of three studies, each providing a different perspective on the topic of using Augmented Reality to teach Educational Robotics.

The literature review *Teaching principles in Educational Robotics and Augmented Reality* presents the analysis of 65 research articles that cover both Educational Robotics and Augmented Reality identified from the literature. The results of the review covered the following five topics: learning theories and concepts, teaching principles in Augmented Reality, teaching principles of Educational Robotics, programming robots in education, and teaching principles of Robotics and Augmented Reality, combination of both.

The *Review of Educational Robotics platforms and literature* presents an in-depth analysis of 13 Educational Robotics platforms, exposing multiple indicators drawn from eight research articles identified from literature. The indicators we used in the analysis include cost, tangibility, durability, processor or microprocessor technology, software, hardware, available programming languages, support, community, available literature, fields of applications, and target age range. In particular, we suggest a complex indicator - friendliness to Augmented Reality, which consists of logical simulation-friendliness, visual simulation-friendliness, and selective exposure. The results of this review are concluded in a comparison matrix of the Educational Robotics platforms.

The *Group Concept Mapping study Augmented Reality for Educational Robotics* presents the primary research data collected and analyzed for this report. In this study, we used the Group Concept Mapping research approach to collect and prioritize ideas on the topic of designing Augmented Reality to support Educational Robotics from 40 experts. We used advanced statistical techniques of multidimensional scaling and hierarchical cluster analysis to analyze data. Collected ideas were grouped in six clusters: Educational ideas, Educational feedback, Requirements, modularity, and content, Hardware and design requirements, Educational Robotics platform selection, and Educational Robotics - Augmented Reality concept design. In addition, a list of ideas which were highly rated by the experts both in importance and feasibility is derived.

The report summarizes the work undertaken during the initial phase of the project Educational Robotics at Schools Online with Augmented Reality - eROBSON: in 2021-2023.

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1 Introduction

Teaching Educational Robotics blended and online with Augmented Reality is a report of three studies, each providing a different perspective on the topic of using Augmented Reality (AR) to teach Educational Robotics (ER). In Section 2, we present the results of the literature review on teaching principles in ER and AR. In Section 3, we present the results of our in-depth analysis of ER platforms and corresponding literature. In Section 4, we present the results of our primary research done following the Group Concept Mapping methodology. Finally in Section 5, we provide conclusions and general recommendations for the possibilities of teaching ER online or blended with AR.

1.1 Motivation

Educational Robotics (ER) is a term to describe educational approaches that use platforms such as Arduino, LittleBits and Mindstorms for STEM education, especially robotics, electronics, and programming.

ER, like many other laboratory-based educational approaches, has been greatly affected by COVID-19-restrictions as most of the methods require equipment and access to a lab. The COVID-19 pandemic highlighted the need for new technologies and methods that can allow laboratory-based educational approaches to work remotely, without access to the physical equipment and physical spaces.

The impact of COVID-19 on learning continuity has been nothing short of devastating. Due to global school closures, formal learning either stopped completely or was severely disrupted for the vast majority of the world's students, a situation without historical precedent. Alarmingly, breaks in learning continuity stemming from the pandemic are hardly resolved[1]. According to UNESCO, one and a half billion children and students (87%) were deprived of school worldwide due to the pandemic of COVID-19 pandemic[2].

In these new circumstances, teachers and students are at a distance and all the valuable knowledge that is usually created in the classroom remains unexploited transnationally. In the COVID-19 era, laboratory-dependent courses (such as engineering and robotics) suffer the most as the risk of spreading the virus increases significantly, due to the necessity of face to face (f2f) collaboration at a close distance within a lab and students' physical/haptic interaction with equipment devices. Moreover, COVID-19 can be contagious on specific surfaces vs the aerial environment.

1.2 Proposed approach

In this document, we explore a new possibility of delivering laboratory-dependent courses for the topic of ER, which is of low implementation cost, easy to adopt and of zero risk of transmitting COVID-19 or other viruses. The proposed educational approach, aims to amend the above described roadblocks, as it employs a risk free (of COVID-19 transmission), easy to use, and low cost use of technologies, available for free to any students and the instructors.

Our proposal is based on using Augmented Reality (AR) to simulate the necessary lab equipment and the interaction with it, while keeping the educational experience hands-on and tangible. AR is a technology that enhances human perception with additional, computer-generated sensorial input to create a new user experience.

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[1] S. Tawil, Six months into a crisis: Reflections on international efforts to harness technology to maintain the continuity of learning, UNESCO 2020 https://unesdoc.unesco.org/ark:/48223/pf0000374561

[2] UNESCO, Handbook on Facilitating Flexible Learning During Educational Disruption, 2020 https://iite.unesco.org/publications/handbook-on-facilitating-flexible-learning-during-educational-disruption/

1.3 Educational Robotics

Educational Robotics is an innovative interdisciplinary learning methodology which combines the elements of sciences (Physics, Mathematics, Engineering), new technologies (Information Technologies, Software / Coding, Artificial Intelligence) and social skills. The combination of sciences and project-based learning creates a creativity space in the classroom that has significant positive effects on the learning process. ER has gained ground in the last years and many approaches have been proposed and implemented in classrooms, providing to the students and teachers a variety of educational robotics platforms based on controversial educational approaches[3].

The ER platforms are designed following two approaches: Brick-based and Maker-based. The main difference between these approaches is that Brick-based robots (Figure 1a) are designed by educational/instructional designers keeping technology abstraction in higher levels and Maker-based (Figure 1b) educational robotic kits made by the practitioners/makers movement targeting the exposure of technology in lower levels.

Figure 1a: Brick-based ER platform

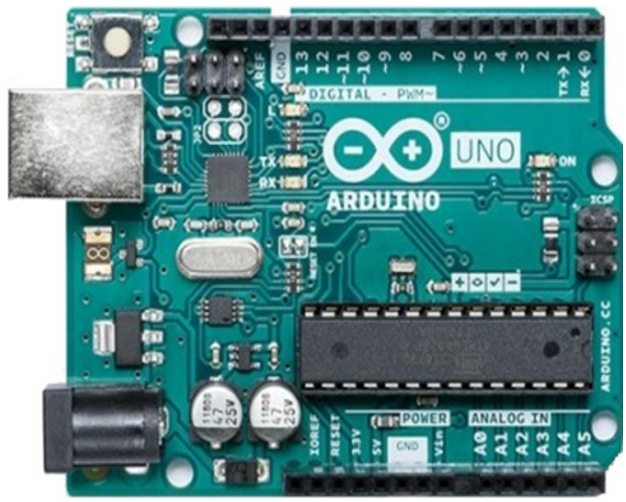

Figure 1b: Maker-based ER platform

In this report, we selected 13 ER platforms for in-depth evaluation using various indicators. The ER platforms selected are the following sorted by manufacturer name:

- Arduino Kit
- ESP32 Kit
- Lego Mindstorms EV3 Kit
- Lego Robot Inventor
- Lego Spike
- Lego Wedo 2.0 Kit
- Micro:bit Kit
- Raspberry Pi 4 Kit
- Raspberry RP2040 - RP Pico Kit
- Seeduino (Grove) Kit
- Sipeed Maixduino Kit for RISC-V AI + IoT
- Sphero - BOLT and SPKR+ Kits
- Sphero - littlebits

[3] Paulo Blikstein (2015), Computationally Enhanced Toolkits for Children: Historical Review and a Framework for Future Design, https://doi.org/10.1561/1100000057

1.4 Augmented Reality and its use in education

Augmented Reality (AR) is a technology that enhances human perception with additional, computer-generated sensorial input to create a new user experience. Most of the current AR systems provide visual experience, blending digital graphics with the features of the real physical space around the user. AR experience can be delivered to the users on mobile devices, smartphones and tablets, and on specialized smart glasses. AR applications for these devices use the camera of the device and other sensors to detect and track some features of the physical space around the user and use them as anchor points for the digital content.

Marker-based AR detects predefined image markers and tracks them in real time to provide such digital content anchors (Fig. 2a). Marker-less AR builds a so-called spatial map of the physical space around the user and uses its features as anchors (Fig. 2b). The visual effect of the AR experience is a seamless blending of the digital 3D content appearing and behaving as it belongs to the physical space. For example, 3D models of educational robotics components can be programmed to be displayed on image markers printed on paper cards. The user can print the cards, place them on a desk, and via the AR app see the 3D models of the educational robotics components (Fig. 2a). Another would be to program an AR app to detect the surface of the physical desk in front of the user and visualize the 3D models of the educational robotics components as if they were put on the desk (Fig. 2b).

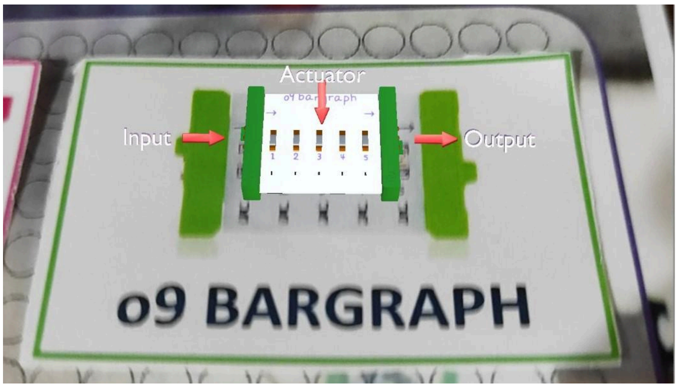

Figure 2a. Marker-based AR with AR Tutor

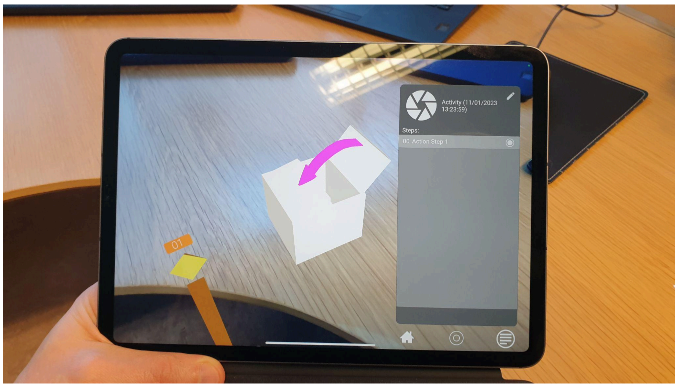

Figure 2b. Marker-less AR with MirageXR

Recent research studies reveal that AR-enhanced educational robotics is gaining interest and has created notable excitement in the school community[4].

[4] Chen C.-H., Yang C.-K., Huang K., & Yao K.-C. (2020) Augmented reality and competition in robotics education: Effects on 21st century competencies, group collaboration and learning motivation, https://doi.org/10.1111/jcal.12469

2 Teaching principles in educational robotics and augmented reality

Our in-depth theoretical exploration of *teaching principles in Educational Robotics and Augmented Reality* presents the analysis of 65 research articles that cover both ER and AR identified from the literature. The results of the review covered the following five topics: learning theories and concepts, teaching principles of ER, teaching principles in AR, programming robots in education, and teaching principles of Robotics and AR, the combination of both.

2.1 Method

In the literature review of the *teaching principles in educational robotics and augmented reality*, we first formulated and pre-compiled keywords related to the main topics of Educational Robotics and Augmented Reality. These keywords included (as a composite) some and amongst others the following terms: Robotics, Programming, Education, Teaching, Computational Thinking, Augmented Reality, Problem Solving, Development, Primary Education, Secondary Education, etc. This list of keywords was entered into search engines (Ebscohost #12, Scholar Google #60, ScienceDirect #38, Lecture Notes #5, Libsearch #42) and into available university libraries both individually and in clusters to retrieve suitable and applicable literature references in which we actively searched for: the application of ER and AR in education, the role of ER and AR in face to face, online and blended mode, the didactic components, the applications of ER/AR for relevant age groups, the outcomes/results of previous studies and the methodology used to embed ER/AR applications in education. This search yielded after removing all duplicates an initial result of in total 140 articles containing a combination of empirical and literature research papers.

After an initial cursory examination a total of 65 appropriate references were selected for the systematic literature review and analysis. The selected references were then assigned to five main categories. These main categories are: “Learning theories and concepts”, “Educational Robotics”, “Programming Robots in Education”, “ER Technologies”, and “Augmented Reality (and educational robotics)”. After an initial, global review of all selected references, and after assigning the references to these categories, a systematic analysis was performed. Information distilled from this analysis led to a subdivision, overview and representation of the following five subcategories: “Focus (general)”, “Study set-up”, “Study outcomes”, “Keywords” and “Limitations”. Based on the characteristics of these subcategories, all references were then systematically analyzed and described so that per reference detailed information was noted regarding these addressed subcategories.

The results of this literature review are presented below in section 2.2. All selected articles are included in Annex I of this report.

2.2 Results

The literature review results are presented first with a subject and content overview, followed by the results structured according to five groups of relevant literature:

- Learning theories and concepts
- Educational Robotics
- Augmented Reality
- Programming robots in education
- Combination of Robotics and Augmented Reality

For each of the main categories, we present the underlying characteristics and subcategories of information found in the literature.

2.2.1 Learning theories and concepts

A brief overview of learning theories and important concepts can be useful for context and further interpretation of specific didactics in either the domain of Robotics or of Augmented Reality. Here we provide an overview of important major concepts and theories.

1) Constructivism. Students build their own knowledge through interaction with their environment. Presented information is interpreted, modified, and absorbed into already gained knowledge and skills. How much a student learns and what, is therefore dependent on the student and on the amount of effort they invest during the learning process. The goal of didactics is to provide students with an environment in which the chances of learning are maximized and the possibility of misconceptions is reduced as much as possible[5].

2) Cumulative learning. The student builds on pre-existing knowledge but also on pre-existing informal knowledge and strategies of problem solving[6].

3) Self-directed learning. Students guard their own learning process. The more students control their own learning, the more they become independent of external guidance and regulation. They require less intervention by teachers. During the course of their studies, students learn to become more self-directed. Some examples of self-direction are: orienting on the learning task, reflecting on the learning process and progress, and maintaining motivation to learn[7].

4) Goal-directed learning. In goal directed learning, students are aware of a learning goal and formulate expectations on this goal. Education is more effective when clear goals are present. Learning is most effective when students set and follow their own goals. If the teacher or course has set goals, student conformation to these goals is essential for successful learning outcomes[8].

5) Situated learning. The learning process of students is interwoven with the context of learning and the learning materials. Cognitive- and learning processes are not solely internal but happen through continuous interaction with the social and cultural context in which the student learns. Learning is influenced in particular through situational and cultural activities and practices[9].

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[5] Amineh, R.J., & Asl, H.D. (2015). Review of Constructivism and Social Constructivism. http://www.blue-ap.com/j/List/4/iss/volume%2001%20(2015)/issue%2001/2.pdf
[6] Thórisson, K.R., Bieger, J., Li, X., Wang, P. (2019). Cumulative Learning. https://doi.org/10.1007/978-3-030-27005-6_20
[7] Manning, G. (2007). Self-Directed Learning: A Key Component of Adult Learning Theory. https://www.bpastudies.org/index.php/bpastudies/article/view/38
[8] Boekaerts, M. (2009). Goal-directed behavior in the classroom. https://doi.org/10.4324/9780203879498
[9] Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated Learning and Education https://doi.org/10.3102/0013189X025004005

6) Cooperative learning. Learning is supported through interaction and cooperation with those that help the student. This principle is supported by Vygotsky's theory of zones of proximal development. The teacher's job includes guiding students in learning to start and maintain new zones of proximal development[10].

7) Scaffolding. Scaffolding refers to any form of support during the learning process. This includes practices such as providing appropriate levels of difficulty, providing "Just In Time" references to relevant information materials, and social learning opportunities e.g. those related to Vygotsky's zones of proximal development[11].

8) Individual differences. Because learning processes take place within individuals, they are influenced by indirect factors (like age, home situation, gender) as well as their psychological attributes (such as intelligence, fears, personality) and direct factors (pre-existing knowledge and skills, cognitive strategies, metacognitive knowledge and skills, perceptions, and motivation/interest). Every study trajectory differs per student based on the aforementioned factors[12].

2.2.2 Educational Robotics

ER can be found in various educational settings, including schools, after-school programmes, robotics clubs and competitions. It can range from simple robotics kits aimed at younger children to more advanced platforms. The application of ER can be used excellently to teach and learn the basics of programming and coding.

1) Educational robotics. Educational Robotics (ER) or pedagogical robotics, is a discipline designed to introduce students to robotics and programming interactively from a very early age. ER encompasses an interdisciplinary learning environment based on the use of robots and electronic components as the common thread to enhance the development of skills and competencies in students. It works specially on the STEAM disciplines, although it can also include other areas such as linguistics, geography and history.

The term "educational robotics" refers to a field of study that aims to improve student's learning experiences through the creation and implementation of activities, technologies, and artifacts related to robots. In practice, these activities can involve the use of a physical robot or robots specifically constructed for the designated activities. Such activities can be conceptualized for students from elementary to graduate levels and may include design, programming, application, or experimentation with robots. Educational robotics activities usually consist of the use of a robotics kit, with which students learn how to build and program the robots for a given task. These activities can take the form of interventions, after-school activities, voluntary classes, or an entire course module focusing on robotics.

Educational robotics can provide an engaging learning experience, particularly for students with special education needs. An educational robotics pedagogy needs to adapt to these specific learning challenges while maintaining an acceptable level of accessibility.

2) Computational Thinking. Wing characterizes Computational Thinking (CT) as thought process for formulating problems in such a way that they can be solved using a computer[13]. Tedre & Denning describe CT as mental skills needed to explain and interpret the world as is[14]. Brennan & Resnick analyzed how skills in CT are developed during programming[15]. Their Computational Thinking Framework describes three dimensions that together form a definition of CT: computational concepts (the concepts designers engage

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[10] Kagan, S., & Kagan, S. (1994). Cooperative learning. San Clemente: Kagan.
[11] Reiser B.J., Tabak I. (2014) Scaffolding. https://doi.org/10.1017/CBO9781139519526.005
[12] Snow R. E. (1986). Individual differences and the design of educational programs. https://doi.org/10.1037/0003-066X.41.10.1029
[13] Wing J. M. (2006). Computational Thinking. https://doi.org/10.1145/1118178.1118215
[14] Tedre M. & Denning P. J. (2016). The long quest for computational thinking. https://doi.org/10.1145/2999541.2999542
[15] Brennan K., & Resnick M. (2012). New Frameworks for Studying and Assessing the Development of Computational Thinking. http://scratched.gse.harvard.edu/ct/files/AERA2012.pdf

with while programming, such as iteration and parallelism, for example), computational methods (the methods designers develop while engaging with the concepts, such as debugging projects or remixing others' work), and computational perspectives (the perspectives designers form about the world around them and about themselves).

2) STEM education. Science, technology, engineering, and mathematics (STEM) is a broad term used to group together these academic disciplines. This term is typically used to address an education policy or curriculum choices in schools.

3) Skill development. Skill development is the process of identification of the skills gap. It identifies the shortcomings and develops the skills which enable a person to achieve goals. Both central & state governments are continuously making efforts to provide skill development to people with their skilling partners & schools around the country.

4) Teacher centered and student centered learning. Approaches to teaching can be broadly classified into teacher centered and student centered. In a teacher-centered approach to learning, teachers are the main authority figure in this model. Students are viewed as "empty vessels" whose primary role is to passively receive information (via lectures and direct instruction) with an end goal of testing and assessment. It is the primary role of teachers to pass knowledge and information onto their students. In this model, teaching and assessment are viewed as two separate entities. Student learning is measured through objectively scored tests and assessments. In student-centered approaches, while teachers remain the authority figure, teachers and students play equally active roles in the learning process. The teacher's primary role is to coach and facilitate student learning and support overall comprehension of material. Student learning is measured through both formal and informal forms of assessment, including group projects, student portfolios, and class participation. Teaching and assessments are connected; student learning is continuously measured during teacher instruction. Commonly used teaching strategies may include class participation, demonstration, recitation, memorization, or combinations of these.

5) Learning strategies and study skills. An array of generic skills which tackle the process of organizing and taking in new information, retaining information, or dealing with assessments can be seen as discrete techniques that can be learned, usually in a short time, and applied to all or most fields of study. More broadly, any skill which boosts a person's ability to study, retain and recall information which assists in and passing exams can be termed a study skill, and this could include time management and motivational techniques.

6) Human–robot interaction. Human–robot interaction is the study of interactions between humans and robots and a multidisciplinary field with contributions from human–computer interaction, artificial intelligence, robotics, natural language understanding, design, and psychology.

7) Visual programming. Visual programming environments come in different appearances. Characteristic for these kinds of environments (e.g., Lego Mindstorms NXT and EV-3, Robomind, Ardublock, Arduino, etc.) is that they enable novice programmers to gain a user-friendly experience and easy access to the programming paradigm because the programming syntax is already implemented in visual code blocks[16]. In primary schools these environments are used to introduce children into programming[17,18]. Their accessibility, simple

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[16] Jost B., Ketterl M., Budde R., & Leimbach T. (2014). Graphical Programming Environments for Educational Robots: Open Roberta - Yet Another One? https://doi.org/10.1109/ISM.2014.24

[17] Sáez-López J.-M., Román-González, M., & Vázquez-Cano, E. (2016). Visual programming languages integrated across the curriculum in elementary school: A two year case study using "Scratch" in five schools. https://doi.org/10.1016/j.compedu.2016.03.003

[18] Weintrop D. & Wilensky U. (2015). To block or not to block, that is the question: students' perceptions of blocks-based programming. https://doi.org/10.1145/2771839.2771860

availability and uncomplicated application is often the reason for using them in the classroom[19]. Visual programming environments are, due to their high imaginative power, ideally suited to teach pupils the underlying concepts of programming[20].

8) Tangible programming. Tangible, or graspable user interfaces help bridge the gap between the virtual world and the physical world by allowing us to manipulate digital information directly with our hands. Tangible Programming Bricks are physical building blocks for constructing simple programs. A tangible programming language is similar to a text-based or visual programming language. However, instead of using pictures and words on a computer screen, tangible languages use physical objects to represent various programming elements, commands, and flow-of-control structures.

9) Programming language. A programming language is a vocabulary and set of grammatical rules for instructing a computer or computing device to perform specific tasks. The term programming language usually refers to high-level languages, such as BASIC, C, C++, COBOL, Java, FORTRAN, Ada, and Pascal. A programming language is a formal language comprising a set of strings that produce various kinds of machine code output. Programming languages are one kind of computer language, and are used in computer programming to implement algorithms. Most programming languages consist of instructions for computers. There are programmable machines that use a set of specific instructions, rather than general programming languages.

10) Coding. Coding is the process of creating instructions for computers using programming languages. Electronic devices like cell phones, laptops, and tablets require code to function properly. Coding allows humans to communicate with these devices. Modern technology such as traffic lights, calculators, smart TVs, and cars use internal coding systems. Since computers do not communicate like humans, coding acts as a translator. Code converts human input into numerical sequences that computers understand. Once computers receive these messages, they complete assigned tasks such as changing font colors or centering an image.

11) Interventions. The act or fact of taking action about something in order to have an effect on its outcome. In general terms, classroom intervention is a set of steps a teacher takes to help a child improve in their area of need by removing educational barriers. There are four key components of classroom intervention:

- Proactive: Deals with areas of need before they become a larger obstacle to education
- Intentional: Specifically addresses an observed weakness
- Formal: Uses targeted methods for addressing specific needs and tracks progress
- Flexible: Adjusts methods based upon the needs of the student

In the classroom, teachers may observe and identify problems with a student's behavior or academic performance. Sometimes, the same child needs improvement in both areas. Although often connected, these issues are addressed using different types of interventions.

12) Self-efficacy. It appears that the level of self-efficacy of the learner plays a decisive role in learning how to program[21]. Bandura[22] and Zimmerman[23] describe self-efficacy as someone's belief in their own ability to complete a task successfully. The theory of self-efficacy comes from the field of psychology and has been

[19] Repenning A. (2017) Moving beyond syntax: Lessons from 20 years of blocks programing in AgentSheets. https://www.ksiresearch.org/vlss/journal/VLSS2017/vlss-2017-repenning.pdf

[20] Carlisle M. C. (2009). Raptor: a visual programming environment for teaching object-oriented programming. https://dl.acm.org/doi/10.5555/1516546.1516591

[21] Igbaria, M. & Iivari, J. (1995) The effects of self-efficacy on computer usage. https://ideas.repec.org/a/eee/jomega/v23y1995i6p587-605.html

[22] Bandura, A., & Walters, R. H. (1977). Social learning theory (Vol. 1). Englewood cliffs Prentice Hall.

[23] Zimmerman, B. J. (2000). Self-Efficacy: An Essential Motive to Learn. https://doi.org/10.1006/ceps.1999.1016

around for some time. It has been shown to be relevant today in many endeavors where technology interaction requires human skill and confidence[24]. Working autonomously and independent decision making contributes to the level of self-efficacy and self-effectiveness (Ramalingam and Wiedenbeck 1998).

2.2.3 Augmented reality

Akçayir et al. define AR as "a technology which overlays virtual objects into the real world"[25]. AR is used with increasing frequency in education due to recent hardware cost reduction. Particularly now that mobile devices can be used.

AR allows for authentic explorations of the real world and facilitates the observation of usually invisible processes such as the decision making behavior of robots. AR in education is not without its problems. Research has shown that (a) technical problems still occur often, (b) students find AR complicated to use without a well-designed interface, (c) a lot of traditional AR technology is bulky and hard to handle, and finally (d) extra instruction is necessary for students and teachers to be able to use AR efficiently in education.

1) Target students. According to literature research, AR in classrooms is mostly used with school students and university students. Akçayır et al. build on Piaget's stages of cognitive development[26] in explaining adolescents' interaction with AR. Early adolescence and elementary students must use their senses during a cognitive learning process which makes it harder for them to employ AR as a learning tool since many AR applications have a large amount of abstract information. According to that same study, adults (and elderly in particular) learn to use AR easier and receive much benefit from the technology. A neglected area in AR research is the question of whether students with special needs can benefit from AR.

2) Technologies. There are many technologies through which AR can be achieved. Commonly the focus lies on tablet PCs and head mounted displays. Mobile devices are another favorite, in particular in scenarios in which location data is incorporated into the AR. Slightly more dated examples of AR include the Xbox kinect and 3D vision glasses, which have become less popular recently.

3) Benefits of AR. Possible benefits of AR in education can be divided into four categories: learner outcomes, pedagogical contribution, interaction, and other[27].

- Learner outcomes: Most often, AR studies report increased learning achievement and increased learning performance. Students regard AR positively. Furthermore, AR facilitates learning through play, which enhances satisfaction and increases agency during the learning process. AR is also reported to decrease the cognitive load and to increase the spatial abilities of students[28].
- Pedagogical contributions: AR increases enjoyment and raises engagement. It is considered fun to use AR and AR increases student performance. AR supports student agency by allowing teachers to delegate tasks more easily to students. Students are reported to have higher levels of concentration while using AR.
- Interaction: A small percentage of studies reported higher levels of interaction between students when using AR. The primary other benefit of AR is its ability to improve visualization of abstract concepts for students.

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[24] Pan, X. (2020). Technology acceptance, technological self-efficacy, and attitude toward technology-based self-directed learning: learning motivation as a mediator. Frontiers in Psychology, https://doi.org/10.3389/fpsyg.2020.564294
[25] Akçayır M. & Akçayır G. (2017) Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. https://doi.org/10.1016/j.edurev.2016.11.002
[26] Piaget J. (1971) The theory of stages in cognitive development.
[27] Akçayır M. & Akçayır G. (2017) Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. https://doi.org/10.1016/j.edurev.2016.11.002
[28] Antonaci, A., Klemke, R., & Specht, M. (2015). Towards Design Patterns for Augmented Reality Serious Games. mLearn 2015. https://doi.org/10.1007/978-3-319-25684-9_20

4) Challenges of AR. As mentioned earlier, many studies report that AR is difficult for students to use[29]. A few different types of interaction problems have been mentioned:

- Well-designed interfaces may be essential to prevent usability issues.
- Students might require significantly longer training time for AR compared to other technologies.
- AR may result in cognitive overload due to its complexity.

Some proposed solutions are:

- Instant hints and learning guidance during usage.
- Required training time may be reduced naturally as users become more accustomed to AR technology in schools and in life in general.
- Solutions such as simplification may reduce cognitive overload. Additionally, increased experience with AR systems should naturally reduce their cognitive overload slightly.

Finally, a significant challenge is the prevailing technical problem. Often, problems stem from the use of GPS in AR applications. Additionally, problems still occur quite often when systems are trying to recognize glyphs (such as QR-codes) and other triggers. Finally, using AR in large groups can be prohibitive due to the cost of AR technology.

5) Hybrid learning environment. A hybrid learning environment is a learning environment in which augmented reality has been integrated and in which traditional education also takes place. Recent research has demonstrated that this type of environment has beneficial effects on skill learning, particularly in laboratory education[30].

6) Design patterns for AR. Design patterns are semi-formal interdependent descriptions of commonly recurring designs or design parts. This type of pattern is often used in game design, and Antonaci and colleagues suggest using a similar, pattern-based, approach for AR as well[31]. Antonaci and colleagues propose the following design patterns for use in AR:

- Localization: adding information related to users position and orientation.
- Video recording and sharing: sharing the users point of view with another user or with an expert.
- Synchronous communication: using communication features while performing a task.
- Contextualization: enriching the current view by providing contextual information (e.g. distance to specific points).
- Object recognition: enhancing on reaching an object in the field of vision of the user.

7) Design patterns for AR learning games. Emmerich at al. provide suggestions for game design patterns for sensor-based AR[32]. They identify 15 basic patterns and five patterns specific to AR learning games. Finally, they show the successful implementation of four patterns in their own WEKIT AR system.

8) Spatial mapping. Spatial mapping is a technique in which an AR system constructs a 3D model of its surroundings in real time, and then projects visual information onto the world[33].

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[29] Akçayır M. & Akçayır G. (2017) Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. https://doi.org/10.1016/j.edurev.2016.11.002

[30] Akçayır M. & Akçayır G. (2017) Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. https://doi.org/10.1016/j.edurev.2016.11.002

[31] Antonaci, A., Klemke, R., & Specht, M. (2015). Towards Design Patterns for Augmented Reality Serious Games. mLearn 2015. https://doi.org/10.1007/978-3-319-25684-9_20

[32] Emmerich, F., Klemke, R., & Hummes, T. (2017). Design Patterns for Augmented Reality Learning Games. Games and Learning Alliance - GALA. https://doi.org/10.1007/978-3-319-71940-5_15

[33] Emmerich, F., Klemke, R., & Hummes, T. (2017). Design Patterns for Augmented Reality Learning Games. Games and Learning Alliance - GALA. https://doi.org/10.1007/978-3-319-71940-5_15

9) AR and Robotics in middle school classrooms. Chen and colleagues investigate the use and effectiveness of robotics and AR in a middle school in Taiwan[34]. In their study, AR was used to access information during task completion. This included visualization of abstract physics theories that could then be applied to a robotics building process. They show that AR provides benefits to learning 21st-century competencies as well as to motivation of learners.

10) AR for STEM learning. Ibáñez and Delgado-Kloos[35] review the work on augmented reality for STEM learning. According to their study, AR acceptance depends on: the availability of low-cost devices and the acceptance of AR by formal education institutions. The authors cite the following benefits of AR in education: increased motivation, collaboration, and the development of spatial abilities. Additionally, they conclude that most studies find improved performance in physical tasks. Usability problems are mentioned as the main blocking factor for the adoption of AR as educational support technology. This result is in line with other research.

11) AR building tools. Most studies present their own applications and use self-developed programs that include device sensors. About a third of the studies used tools developed by external companies (e.g. Vuforia, Metaio, Layar, and Aurasma)[36].

12) AR application types and features. The application types that were found in the literature are as follows: augmented books, augmented marks, point of interest (POI) triggers, simulation tools, and games[37].

The following features were included in the investigated AR applications: Images based on technology, location-based, digital information inclusion, digital element edition, text edition, 2D images, animations, 3D objects, video, audio information, and World Wide Web integration.

13) Instructional strategies in AR-based education. Ibáñez and Delgado-Kloos[38] elaborate on several instructional strategies supported by AR like presentation and discovery learning.

Presentation learning closely follows the model of traditional education. In this model a teacher provides learning materials and gives presentations, which students are expected to internalize themselves. The augmented reality part in this type of education comes in the form of augmented books and learning materials. Particularly three-dimensional interactive animations are popular.

In discovery learning, learning is mostly self-directed and constructive. AR is mostly used to enhance on-site information. Learning takes place in real world settings which students explore in order to build their knowledge. Of particular interest in this type of learning are blended learning environments in which learning takes place partially in the classroom and partially online.

2.2.4 Programming robots in education

The central objective regarding an integrating of ER into education is to provide students with an engaging and interactive learning experience that increases understanding of science and technology concepts,

[34] Chen, G., Shen, J., Barth-Cohen, L., Jiang, S., Huang, X., & Eltoukhy, M. (2017). Assessing elementary students' computational thinking in everyday reasoning and robotics programming. Computers & Education, https://doi.org/10.1016/j.compedu.2017.03.001

[35] Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education. https://doi.org/10.1016/j.compedu.2018.05.002

[36] Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education. https://doi.org/10.1016/j.compedu.2018.05.002

[37] Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education. https://doi.org/10.1016/j.compedu.2018.05.002

[38] Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education. https://doi.org/10.1016/j.compedu.2018.05.002

facilitates opportunities to learn programming and coding in an insightful way, and prepares them for future careers and challenges in a rapidly advancing technological world.

1) Cognitive skills. Cognitive skills, also called cognitive functions, cognitive abilities or cognitive capacities, are brain-based skills which are needed in acquisition of knowledge, manipulation of information, and reasoning. They have more to do with the mechanisms of how people learn, remember, problem-solve, and pay attention, rather than with actual knowledge. Cognitive skills or functions encompass the domains of perception, attention, memory, learning, decision making, and language abilities.

2) Learner centered education. Learner-centered education empowers the students to take ownership of what they learn by focusing on how the new knowledge solves a problem or adds value. It focuses on 3 key aspects about the learner. First, each learner is seen as being unique in meaningful ways. They have unique backgrounds, circumstances, and starting points with unique strengths, challenges, interests, and aspirations. All of these unique attributes call for unique responses from their learning system. Second, each learner is seen as having unbounded potential—potential that will unfold at its own pace and in its own way. Every single learner is a wonder to behold. And, finally, each learner is seen as having an innate desire to learn.

3) SRA-programming. When programming following a SRA-approach users need to explicitly link the relationship between observations based on sensor use (sense), with a logic reasoning component which infers actions based on these observations and comparison of internal and external conditions (reason) and the process of acting based on the given inferences (act)[39]. SRA-programming has been identified as an instrumental way of thinking for learning to program robots and encourages the development of complex concepts of programming[40].

4) Kindergarten. Kindergarten in the United States is a program generally for 5-year-olds, but sometimes includes 4-to-6-year-olds, that offers developmentally appropriate learning opportunities to build the child's social and academic skills and to prepare them for the transition into first grade, and for school in general.

5) Proportional reasoning. Proportional reasoning involves thinking about relationships and making comparisons of quantities or values. Proportional reasoning is sometimes perceived as only being the study of ratios, rates and rational numbers such as fractions, decimals and percents, but it actually permeates all strands of mathematics. Proportional reasoning takes fractions, decimals, ratios or percentages and places them in a problem solving context. It can present a different way of approaching some problems rather than immediately leaping to or looking for a formula that numbers can be plugged into without a real consideration for the relationships between quantities.

6) Special education. Special education (known as special-needs education, aided education, exceptional education, exceptional student education, special ed., SEN, or SPED) is the practice of educating students in a way that provides accommodations that address their individual differences, disabilities, and special needs. Ideally, this process involves the individually planned and systematically monitored arrangement of teaching procedures, adapted equipment and materials, and accessible settings. These interventions are designed to help individuals with special needs achieve a higher level of personal self-sufficiency and success in school and in their community, which may not be available if the student were only given access to a typical classroom education.

7) Making centered learning. Making centered learning[41] is closely associated with STEM learning. It is an approach to problem-based and project-based learning that relies upon hands-on, often collaborative,

[39] Slangen, L. A. M. P. (2016). Teaching robotics in primary school. Technische Universiteit Eindhoven. https://pure.tue.nl/ws/files/25754482/20160630_CO_Slangen.pdf

[40] Fanchamps, N. (2021). The influence of sense-reason-act programming on computational thinking. Open Universiteit. https://research.ou.nl/en/publications/the-influence-of-sense-reason-act-programming-on-computational-th

[41] Dougherty, D. (2013). The Maker Mindset. https://doi.org/10.4324/9780203108352

learning experiences as a method for solving authentic problems. People who participate in making often call themselves "makers" of the maker movement and develop their projects in makerspaces, or development studios which emphasize prototyping and the repurposing of found objects in service of creating new inventions or innovations. Culturally, makerspaces, both inside and outside of schools, are associated with collaboration and the free flow of ideas. In schools, maker education stresses the importance of learner-driven experience, interdisciplinary learning, peer-to-peer teaching, iteration, and the notion of "failing forward", or the idea that mistake-based learning is crucial to the learning process and eventual success of a project.

8) Active learning. Active learning is an approach to instruction that involves actively engaging students with the course material through discussions, problem solving, case studies, role plays and other methods. Active learning is a special case of machine learning in which a learning algorithm can interactively query a user (or some other information source) to label new data points with the desired outputs. In statistics literature, it is sometimes also called optimal experimental design. The information source is also called teacher or oracle.

2.2.5 Combination of Robotics and Augmented Reality

The application of ER provides opportunities for hands-on learning, where students can build, program and control robots. AR can further enhance learning by superimposing virtual parts or instructions on a physical robot, providing real-time feedback and making programming and assembly insightful and more meaningful.

1) Educational materials. The combination of ER and AR provides various novel options with regards to educational materials. It becomes possible to use robot centric challenges to teach and extend skills through focused reasoning tasks within a game. Furthermore, it enables the use of individualized tutorials for robotics[42]. One example of the combination between robotics and AR is the application of Lego Mindstorms based teaching of robotics principles[43]. Within this combination (ER-AR) there are various technology types that are commonly used for the application of AR (tablets, mobile devices, head-mounted displays) and these are commonly considered in relation to their costs[44].

2) Pedagogical activities/instruction. AR is already used to provide instructional opportunities within educational robotics-defined problems[45]. AR is an interactive experience of a real-world environment in which the real world is complemented and enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, and sensory-motor and olfactory. AR can be defined as a system that contains three basic features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects. The overlapping sensory information can be complementary and constructive, seamlessly intertwining this experience with the physical world so that it is perceived as an immersive aspect of the real environment.

The primary value of AR is the way components of the digital world merge into a person's perception of the real world. Not as a simple representation of data, but through the integration of immersive experiences and perceptions that are perceived as natural components of an environment. AR applications can make content accessible in education by scanning or viewing an image with a mobile device or by using markerless AR techniques such as QR code. They can also provide just-in-time information on tasks due to the interface always being available to the learner.

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[42] Alfieri L., Higashi R., Shoop R., & Schunn, C. D. (2015). Case studies of a robot-based game to shape interests and hone proportional reasoning skills. International Journal of STEM Education. https://doi.org/10.1186/s40594-015-0017-9

[43] Slangen, L. A. M. P. (2016). Teaching robotics in primary school. Technische Universiteit Eindhoven. https://pure.tue.nl/ws/files/25754482/20160630_CO_Slangen.pdf

[44] Alfieri L., Higashi R., Shoop R., & Schunn, C. D. (2015). Case studies of a robot-based game to shape interests and hone proportional reasoning skills. International Journal of STEM Education. https://doi.org/10.1186/s40594-015-0017-9

[45] Alfieri L., Higashi R., Shoop R., & Schunn, C. D. (2015). Case studies of a robot-based game to shape interests and hone proportional reasoning skills. International Journal of STEM Education. https://doi.org/10.1186/s40594-015-0017-9

AR is used to enhance natural environments or situations and provide perceptually enriched experiences. AR can support play-based learning, can facilitate group discussions, can be applied as part of regular/other learning activities to reduce cognitive load by giving students agency in when they receive information, can increase motivation and engagement during learning activities and can promote student interaction[46]. Using advanced AR technologies (e.g., adding computer vision, embedding AR cameras in smartphone applications and object recognition), information about the user's surrounding real world is interactively and digitally manipulated. In other words, the information about the environment and its objects is superimposed on the real, physical world. This information can be virtual. AR is any experience that is artificial and adds something to the already existing reality, e.g. seeing other real-world perceived or measured information such as chemical compounds and elements, electromagnetic radio waves or overlays in exact alignment with where objects actually are in space.

AR also has great potential in gathering and sharing tacit knowledge. Augmentation techniques are usually performed in real time and in semantic contexts with environmental elements. Immersive perceptual information is sometimes combined with additional information such as scores from a live video feed of a sporting event. This combines the advantages of both augmented reality technology and heads up display technology (HUD).

3) Guidance and supervision. Various papers have reviewed the importance and subjects regarding guidance and supervision in relation to educational robotics. A close examination reveals that there is a particular focus on learning process support by teachers through scaffolding and interactive learning dialogue in education[47] [48]. It also appears that a well-balanced classroom management and pedagogical forms of adaptive pacing can properly support and facilitate learning in robotics-based education[49]. Also, the questioning strategies used by teachers can support learning in robotics-based education to make students more aware of what they learn, how they learn and thus bring them in their further development[50]. Furthermore, the type of guidance can help, for example, in understanding and debugging robot behavior (including by visualizing robot sensor data such as touch sensors, ultrasonic and infrared readings, sonar cones, color measurements, and distance to object measurements)[51], and how to intervene by programming actions by visualizing real-time robotic decision-making[52].

4) Limitations to usage of AR-technology. A meta-study by Akçayır and Akçayır revealed three common challenges that may occur when using AR systems[53]. They identified (a) usability challenges, (b) cognitive overload risk, and (c) low sensitivity in trigger recognition. Usability challenges refer to difficulties for students in learning and using the AR interface. In the cases where the interface and its usability are not

[46] Alfieri L., Higashi R., Shoop R., & Schunn, C. D. (2015). Case studies of a robot-based game to shape interests and hone proportional reasoning skills. International Journal of STEM Education. https://doi.org/10.1186/s40594-015-0017-9
[47] Slangen L. A. M. P. (2016) Teaching robotics in primary school. Technische Universiteit Eindhoven. https://pure.tue.nl/ws/files/25754482/20160630_CO_Slangen.pdf
[48] Fanchamps N., Slangen L., Hennissen P., & Specht M. (2019) The Influence of SRA Programming on Algorithmic Thinking and Self-Efficacy Using Lego Robotics in Two Types of Instruction. International Journal of Technology and Design Education, https://doi.org/10.1007/s10798-019-09559-9
[49] Sentance S., & Csizmadia A. (2017) Computing in the curriculum: Challenges and strategies from a teacher's perspective. Education and Information Technologies. https://doi.org/10.1007/s10639-016-9482-0
[50] Slangen L. A. M. P. (2016). Teaching robotics in primary school. Technische Universiteit Eindhoven. https://pure.tue.nl/ws/files/25754482/20160630_CO_Slangen.pdf
[51] Cheli M., Sinapov J., Danahy E.E., & Rogers C (2018) Towards an augmented reality framework for k-12 robotics education. 1st International Workshop on Virtual, Augmented, and Mixed Reality for HRI. https://interactive.holoniq.com/reports/Towards_an_Augmented_Reality_Framework_for_K-12_Robotics_Education.pdf
[52] Magnenat S., Ben-Ari M., Klinger S., & Sumner R.W. (2015) Enhancing Robot Programming with Visual Feedback and Augmented Reality. ACM Conference on Innovation and Technology in Computer Science Education https://doi.org/10.1145/2729094.2742585
[53] Akçayır M. & Akçayır G. (2017) Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review. https://doi.org/10.1016/j.edurev.2016.11.002

carefully designed, students require additional course time to learn how to use the system. Cognitive overload refers to the additional mental effort required to attend to AR systems during learning tasks. Whenever cognitive load is too high the actual learning contents may no longer be stored in long-term memory and learning may become ineffective[54]. Low sensitivity in trigger recognition refers to the AR software being unable to determine at which position it is and which direction it is oriented. This problem occurs most frequently with GPS based AR applications. According to the authors it is expected to be resolved as part of ongoing developments in device technology.

2.2.6 Discussion points and conclusions of the literature review

In our literature review, we report on the current state-of–the-art in didactical techniques and outcomes in the fields of Augmented Reality, Educational Robotics, and the combination of both. We observe several trends and can formulate conclusions that provide a broad overview of the current state of research and that are relevant to consider for this and future work.

Educational Robotics. ER has been shown to be particularly effective in the domain of STEM education. The visual programming methodology is an often used approach to code robots and during this process students improve their programming skills, proportional reasoning skills, and analysis skills. As part of Educational Robotics, teachers develop classroom interventions that rely on robotics.

Teachers look for educational strategies that are particularly effective in the domain of ER. In this process they can benefit from insights in the domain of Human-Robot Interaction. Several approaches have been found to facilitate programming ER robots, such as the visual programming (as mentioned before) and tangible programming. Teaching approaches are intended to increase skills and knowledge, but also to improve the form of confidence that is known as "self-efficacy" – the confidence that the student is able to perform the intended action or to use the intended skill.

Augmented Reality. The pace of innovation and research in AR has increased with the arrival of affordable mobile technologies that are capable of providing the required interfaces and sensors for AR. Particularly, hand-held mobile devices and head mounted devices have become much more pervasive in the educational landscape in recent years due to their reduction in cost.

In the recent processes of innovation there have been influences from both fields, including in particular the fields of computer science and educational science. From the field of computer science we see major influences from computer vision and gaming. We conclude that several research groups are considering design pattern based approaches as promising candidates for solving recurring design and development challenges.

From the domain of educational sciences we see the merging of previously existing didactical approaches with the affordances provided by AR. AR has been applied in three domains of teaching and learning: presentation learning, discovery learning, and collaborative learning. In each of these domains, AR adds the ability to provide information in a Just-In-Time fashion and is able to visualize previously invisible processes of the topic of study. Additionally, adding AR to educational practice almost universally enhances student agency and motivation.

Many benefits to using AR in education have been reported. Research findings indicate that AR can boost learning outcomes, reduce learning task complexity, facilitating insight into otherwise invisible processes. AR is also reported as being beneficial to motivation and learning achievement.

However, there are also several "wicked" problems that provide barriers to AR adoption that have not yet been tackled sufficiently. Technical difficulties in the AR process provide important barriers to adoption.

[54] Sweller J., van Merrienboer J.J.G. & Paas F.G.W.C. (1998) Cognitive Architecture and Instructional Design. https://doi.org/10.1023/A:1022193728205

Multiple studies report that students and teachers consider AR difficult to interact with. Particularly the design of clear and uncomplicated user interfaces is cited as a major potential solution.

Another often encountered problem relates to the ability of AR devices to accurately and effectively scan visual symbols (glyphs) and to recognize objects. These issues are exacerbated by changes in light circumstances, dynamic environments with moving participants or objects, and the process of moving AR devices around in unexpected angles. There have also been reports of positioning problems and of AR sensors losing tracking (in both room tracking and GPS tracking).

A factor of consideration is the age group of participants using AR. The information added by AR to learning processes is often particularly abstract in nature. This caters to the cognitive processes of school and university students but may not provide as much benefit to younger students due to their more activity based learning process (for which Akçayır et al. refer to Piaget's stages of cognitive development[55]). More work remains to be done in this area. Finally, the area of AR for disabled students has received very little attention so far.

Combination of Robotics and Augmented Reality. In order to explore the possibilities for an in-depth connection between ER and AR, a systematic literature review was conducted. This theoretical review revealed to what extent such a connection already exists, which robotics platforms have been applied in this respect and what application possibility, functionality and added value can be attributed to AR in this respect. The literature analysis shows that a connectivity between ER and AR is not entirely new, but often involves combinations of specific robotics platforms, with AR applications developed specifically for this connection. The application in education takes place mainly for topic explicit and focused forms of explanation, instruction and/or assessment, and to a lesser extent for methodological study lesson design in relation to inquiry and design-based learning.

[55] Piaget J. (1971) The theory of stages in cognitive development.

3 Review of Educational Robotics platforms and literature

3.1 Method

In the literature review of the technological platforms in educational robotics and augmented reality, we first formulated and pre-compiled keywords related to the main topics of supporting technology and their use in educational robotics learning environments. These keywords included (as a composite) some and amongst others the following terms: STEM, Applications in STEM education, AR, interactive learning environments.

This list of keywords was entered into search engines Scopus and Google Scholar in which we actively searched for: ER technologies and kits used in ER/AR educational courses and the applications of ER/AR for relevant age groups, and the outcomes/results of previous studies. This search yielded after removing all duplicates an initial result of in total 215 articles containing a combination of STEM and AR, and only three articles combining STEM, AR and Systematic review.

After an initial cursory examination a total of 21 appropriate references were selected for the systematic literature review and analysis. After the processing of abstracts of the papers we studied in detail the following seven documents:

1. Chen, C.-H., Yang, C.-K., Huang, K., & Yao, K.-C. (2020). Augmented reality and competition in robotics education: Effects on 21st century competencies, group collaboration and learning motivation. Journal of Computer Assisted Learning, 36(6), 1052–1062. https://doi.org/10.1111/jcal.12469
2. Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education, 123, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002
3. Jung, S. E., & Won, E. (2018). Systematic Review of Research Trends in Robotics Education for Young Children. Sustainability, 10(4). https://doi.org/10.3390/su10040905
4. Sapounidis, T., & Alimisis, D. (2020). Educational robotics for STEM: A review of technologies and some educational considerations, 167–190. https://novapublishers.com/shop/science-and-mathematics-education-for-21st-century-citizens-challenges-and-ways-forwards/
5. Schad, M., & Jones, W. M. (2020). The Maker Movement and Education: A Systematic Review of the Literature. Journal of Research on Technology in Education, 52(1), 65–78. https://doi.org/10.1080/15391523.2019.1688739
6. Sırakaya, M., & Sırakaya, D. A. (2020). Augmented reality in STEM education: A systematic review. Interactive Learning Environments, 1–14. https://doi.org/10.1080/10494820.2020.1722713
7. Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive science, 12(2), 257-285. https://doi.org/10.1207/s15516709cog1202_4

Additionally, we studied one exceptional monograph:

8. Paulo Blikstein (2015), "Computationally Enhanced Toolkits for Children: Historical Review and a Framework for Future Design", Foundations and Trends in Human–Computer Interaction: 9(1), 1–68. https://doi.org/10.1561/1100000057

3.2 Results of the review of Educational Robotics platforms and literature

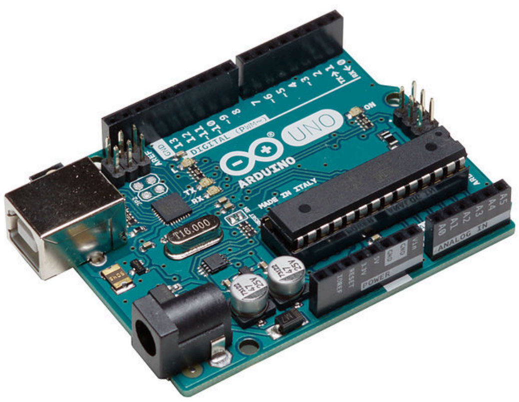
In this section, we present the results of the review of ER platforms based on a literature review and expert evaluation. We present an in-depth review of 13 ER platforms exposing various indicators from literature and the experience of the involved experts with the ER platforms. The results are concluded in a comparison matrix of the ER platforms under evaluation.

There is a plethora of robots in education which can be categorized in three main categories:

- Social robots
- Telepresence robots
- Educational robotics

Within the scope of our research, we delved into the educational robotics category which includes pieces of hardware modules that can be used by students for creating and/or programming robots and they are the most effective solution in teaching robotics itself as well as other subjects. The ER kits based on their main characteristics are categorized in:

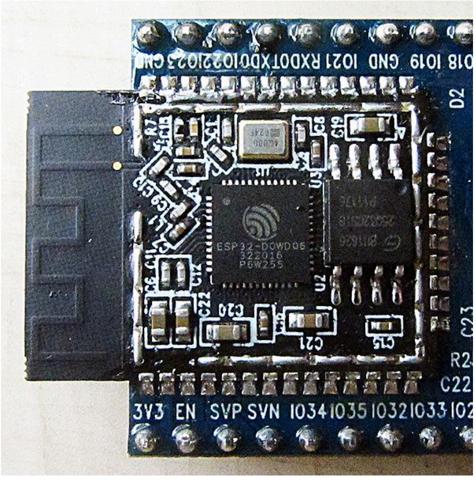
- Board based (e.g., Arduino, RPi Pico)
- Robot based (e.g., Sphero BOLT, Ozobot)
- Brick/module based (e.g., Lego, littleBits)
- Computer based (e.g., RPi 4/5 based platforms)



[56]

Auduino kit

[56] Image without modifications, CC BY-SA, https://commons.wikimedia.org/wiki/File:Arduino_Uno_dllu.jpg

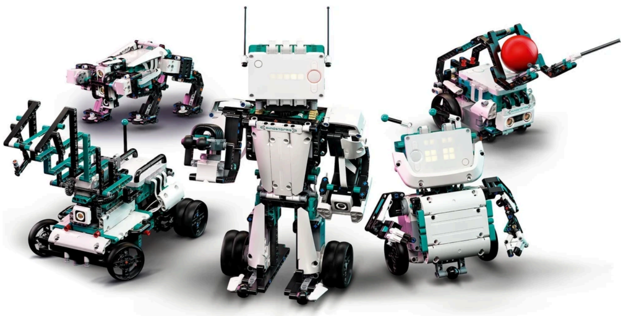


[57]

ESP32 Kit

[58]

Lego Mindstorms EV3 Kit


[59]

Lego Robot Inventor

[57] Image without modifications, CC BY-SA, https://en.wikipedia.org/wiki/File:Espressif_ESP-WROOM-32_Wi-Fi_%26_Bluetooth_Module.jpg
[58] Image without modifications, https://brickipedia.fandom.com/wiki/45500_EV3_Intelligent_Brick
[59] Image without modifications, https://brickipedia.fandom.com/wiki/51515_Robot_Inventor


[60]

Lego Spike

[61]

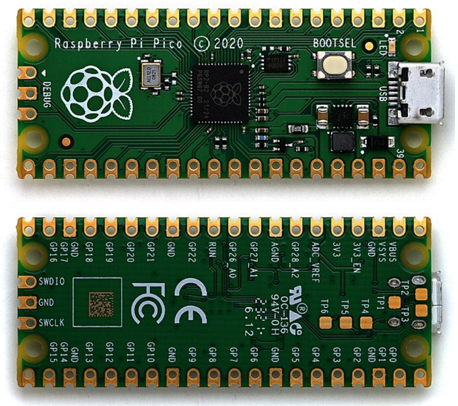
Micro:bit Kit


[62]

Raspberry Pi 4 Kit

[60] Image without modifications, https://brickipedia.fandom.com/wiki/45678_SPIKE_Prime_Set
[61] Image without modifications, CC0, https://en.wikipedia.org/wiki/File:Micro-bit_v2.JPG
[62] Image without modifications, CC0, https://en.wikipedia.org/wiki/File:Micro-bit_v2.JPG

Raspberry RP2040 - RP Pico Kit



[63]

Seeduino (Grove) Kit

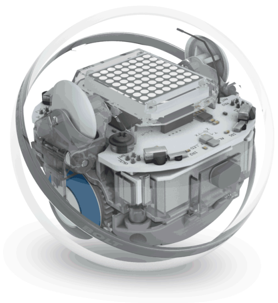
[64]

Sipeed Maixduino Kit for RISC-V AI + IoT

[65]

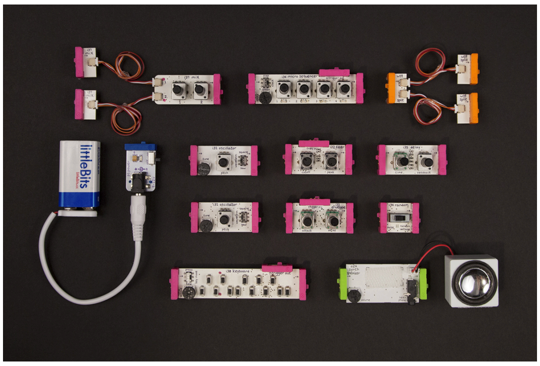
[63] Image without modifications, https://en.wikipedia.org/wiki/File:Raspberry_Pi_Pico_top_and_bottom_composite.jpg
[64] Image without modifications, https://www.seeedstudio.com/Grove-Starter-Kit-for-Raspberry-Pi-Pico-p-4851.html
[65] Image without modifications, CC BY-SA, https://commons.wikimedia.org/wiki/File:Maixduino.SipeedM1.jpg

Sphero - BOLT and SPKR+ Kits



[66]

Sphero - Littlebits Kit



[67]

3.2.1 ER Platform Evaluation Indicators

Recently, Sapounidis & Alimisis suggested that designers of ER systems appear to be guided by four basic requirements: Low-Cost, Appeal, Simplicity (Assembly, Operation - Programming, Maintenance), and Open source[68].

General comparison indicators for the Educational Robotics platforms. In this context and building upon our literature study, our expert team (three in ER and four in the AR domain respectively) prepared an enhanced comparison matrix with additional indicators for ER platform evaluation. The indicators of this comparison matrix are presented below. Some of the indicators assume an expert evaluation, using a 1-5 Likert scale[69].

- *Cost*: The initial cost to buy the ER Kit.
- *CPU/MCU Technology*: The technology of the embedded CPU/MCU chip.
- *Software*: Openness of the platform's software (Open or Proprietary)
- *Hardware*: Openness of the platform's hardware (Open or Proprietary)
- *Programming tools and languages*:
    - Visual Programming Language (Yes or No)
    - Python (Yes or No)
    - C/C++ (Yes or No)
- *Support*: The support from the manufacturer (Likert scale 1 to 5)
- *Community*: The support from the community (Likert scale 1 to 5)

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[66] Image without modifications, https://robotics.fandom.com/wiki/Sphero
[67] Image without modifications, CC BY-SA, https://www.flickr.com/photos/130557019@N06/15898282384/
[68] Sapounidis, T., & Alimisis, D. (2020). Educational robotics for STEM: A review of technologies and some educational considerations.https://novapublishers.com/shop/science-and-mathematics-education-for-21st-century-citizens-challenges-and-ways-forwards/
[69] The five points of the Likert scale are (1) Very poor; (2) Poor; (3) Average; (4) Good; and (5) Excellent.

- *Literature*: The use of the platform in research works and publications
- *Field of Applications*: The suitability of the ER platform in application domains like ER, STEM, IoT, AI
- *Age Range*: Age ranges in typical education: Early 4-6, Primary 7-11, Secondary 12-17
- *Maker's Box*: If the ER technology is Black or White box from a makers' perspective.

As the next step, to address the challenges of creating AR content for educational robotics, we extended this matrix by incorporating additional indicators such as Tangibility, Durability, and Selective exposure, based on the approach presented in by Blikstein [70].

Special comparison indicators for Educational Robotics platforms. In addition, we proposed a new specialized indicator called Augmented Reality friendliness. In detail, the proposed indicators are:

- *Tangibility*: How tangible are the parts and in total the ER Kit (Likert scale 1 to 5)
- *Durability*: How much durable (in use) are the parts and in total the ER Kit (Likert scale 1 to 5)
- *Selective exposure:* Includes selective exposure for usability and selective exposure for power.
- *AR friendliness**: How easy is it to create AR supporting material for an ER Kit (Likert scale 1 to 5)

Augmented Reality friendliness comparison indicators for Educational Robotics platforms. AR friendliness is a complex original indicator we introduced in this work. It takes into account how easy it is to create AR supporting material for an ER platform. AR-friendliness consists of two components with their respective indicators:

- Logical simulation friendliness and
- Visual simulation friendliness.

Logical simulation-friendliness:

- *Modularity*. The more modular an ER kit is, the easier it is to program the interaction in AR because it is possible to program the behavior of each module separately.
- *Complexity in assembly*. How much functionality/programmability the ER Kit offers.
- *Selective Exposure for Usability*. How does the material communicate rules for its use (embedded error correction).
- *Availability of Open source simulators*

Visual simulation-friendliness:

- *Size of components*. If an ER kit has small parts or components, it is more difficult to display and interact with them in AR (low/high precision/resolution)
- *Plethora of components*. The quantity of parts or components the ER kit contains. How much effort is needed to create AR material/content.
- *Selective Exposure for Usability*. How does the material communicate rules for its use (embedded error correction).
- *Selective Exposure for Power.* How are cognitive and physical operations mapped to each other ("tangibility mapping"), and how can the design make them more explicit?
- *Standardized ports and connections*
- *Open source resources*. Availability of libraries of 3D models/assets for ER Kits.

3.2.2 ER Platform Comparison Matrix

The comparison of the selected ER platforms has been done by our expert team.

Comparison of the Educational Robotics platforms using general indicators. Some of the general indicators allowed for an objective comparison (e.g., cost, openness of software and hardware, programming languages,

[70] Paulo Blikstein (2015), Computationally Enhanced Toolkits for Children: Historical Review and a Framework for Future Design, https://doi.org/10.1561/1100000057

Maker's box), while for some other indicators we made informed choices based on the literature and expertise (e.g., field of application, support, community, literature). The comparison itself is presented below (Table 1, 2, and 3).

Table 1. Comparison of ER platforms using general indicators, part A

ER platform name	Cost	Software	Hardware	Field of Applications	Age Range	Maker's Box
Lego Mindstorms EV3	400 €	Proprietary	Proprietary	ER	7-11, 12-17	Black
Lego Wedo 2.0	220 €	Proprietary	Proprietary	ER	7-11	Black
Arduino	50 €	Open	Open	Generally STEM	12-17	White
Sphero - littlebits	400 €	Open	Open	Generally STEM	7-11	White
Sphero - BOLT - SPKR+	150 €	Proprietary	Proprietary	ER	7-11	Black
ESP32	50 €	Open	No	Generally STEM	12-17	White
micro:bit	30 €	Open	No	Generally STEM	12-17	White
Raspberry RP2040 - RP Pico	25 €	Open	No	Generally STEM	12-17	White
Seeduino (Grove)	80 €	Open	No	Generally STEM	12-17	White
Raspberry Pi 4	120 €	Open	No	Generally STEM	12-17	White
Lego Robot Inventor	360 €	Proprietary	Proprietary	ER	12-17	Black
Lego Spike	480 €	Proprietary	Proprietary	ER	7-11, 12-17	Black
Sipeed Maixduino	50 €	Open	Proprietary	Generally STEM, IoT, AI	12-17	White

Table 2. Comparison of ER platforms using general indicators, part B

ER platform name	CPU/MCU Technology	Programming		
		VPL	Python	C/C++
Lego Mindstorms EV3	ARM/AVR based	Yes	Yes	Yes
ARM	ARM	Yes	Yes	</>
Arduino	ARM/AVR based	Yes	Yes/32bit	Yes
Sphero - littlebits	ARM/AVR based	Yes	via microbit	</>
Sphero - BOLT - SPKR+	ARM based	Yes	Yes	Yes
ESP32	Tensilica Xtensa LX6	Yes	Yes	Yes
micro:bit	Nordic nRF51822, ARM Cortex-M0	Yes	Yes	</>
Raspberry RP2040 - RP Pico	ARM based	Yes	Yes	Yes
Seeduino (Grove)	ARM/AVR based	Yes	Yes	Yes
Raspberry Pi 4	ARM based	Yes	Yes	Yes
Lego Robot Inventor	No source of data	Yes	Yes	</>
Lego Spike	No source of data	Yes	Yes	</>
Sipeed Maixduino	RISC-V, NPU	No	Yes	Yes

Table 3. Comparison of ER platforms using general indicators, part C

ER platform name	Support	Community	Literature
Lego Mindstorms EV3	4	4	Yes
Lego Wedo 2.0	4	4	Yes
Arduino	5	5	Yes
Sphero - littlebits	3	3	No
Sphero - BOLT - SPKR+	3	2	Partial
ESP32	4	4	Partial
micro:bit	4	5	No
Raspberry RP2040 - RP Pico	4	3	New
Seeduino (Grove)	3	2	No
Raspberry Pi 4	5	5	Yes
Lego Robot Inventor	2	2	New
Lego Spike	2	2	New
Sipeed Maixduino	3	3	No

Special comparison indicators for Educational Robotics platforms. Our experts team conducted an intensive task to evaluate the selected ER Kits for the additional ER-AR indicators. The results of this evaluation are presented in Tables 4, 5, 6 and 7 with a summary in Table 8. The data presented in this matrix inform the ER designer about valuable ER kit characteristics and the ratings of AR friendliness of each kit. In the case of littleBits, we have an ER Kit with average to good ratings related to appeal and simplicity, and also an average grade regarding AR friendliness. These indications qualified the selection of littleBits kit as the most suitable for an AR enhancement.

Table 4. Comparison of ER platforms using ER-AR special indicators Tangibility and Durability

ER platform name	Tangibility	Durability
Lego Mindstorms EV3	5	5
Lego Wedo 2.0	5	5
Arduino	2	3
Sphero - littlebits	4	3
Sphero - BOLT - SPKR+	5	5
ESP32	2	3
micro:bit	3	3
Raspberry RP2040 - RP Pico	2	3
Seeduino (Grove)	4	3
Raspberry Pi 4	3	3
Lego Robot Inventor	5	5
Lego Spike	5	5
Sipeed Maixduino	3	3

Table 5. Comparison of ER platforms using ER-AR special indicators of Selective exposure

ER platform name	Selective exposure for Usability	Selective exposure for Power
Lego Mindstorms EV3	4	3
Lego Wedo 2.0	4	3
Arduino	1	5
Sphero - littlebits	3	3
Sphero - BOLT - SPKR+	5	2
ESP32	1	5
micro:bit	3	4
Raspberry RP2040 - RP Pico	1	5
Seeduino (Grove)	2	4
Raspberry Pi 4	1	5
Lego Robot Inventor	4	3
Lego Spike	4	3
Sipeed Maixduino	1	5

Table 6. Comparison of ER platforms using ER-AR special indicators of the Logical simulation friendliness

ER platform name	Logical simulation friendliness	Modularity	Complexity	Availability of Open source simulators
Lego Mindstorms EV3	3.3	4	4	1
Lego Wedo 2.0	3.3	4	4	1
Arduino	1.8	1	1	4
Sphero - littlebits	3.5	4	4	3
Sphero - BOLT - SPKR+	4.0	5	5	1
ESP32	1.8	1	1	4
micro:bit	3.3	3	3	4
Raspberry RP2040 - RP Pico	1.8	1	1	4
Seeduino (Grove)	2.8	2	3	4
Raspberry Pi 4	1.5	1	1	3
Lego Robot Inventor	3.3	4	4	1
Lego Spike	3.3	4	4	1
Sipeed Maixduino	1.0	1	1	1

Table 7. Comparison of ER platforms using ER-AR special indicators of the Visual simulation friendliness

ER platform name	Visual simulation friendliness	Size	Plethora/Quantity	Standardized ports and connections	Open source libraries of 3D models for ER Kits
Lego Mindstorms EV3	3.7	5	2	5	3
Lego Wedo 2.0	3.5	5	2	5	2
Arduino	2.5	1	3	2	3
Sphero - littlebits	3.5	5	4	5	1
Sphero - BOLT - SPKR+	4.0	5	5	5	2
ESP32	2.5	1	3	2	3
micro:bit	2.8	3	3	2	2
Raspberry RP2040 - RP Pico	2.5	1	3	2	3
Seeduino (Grove)	2.7	1	3	5	1
Raspberry Pi 4	2.3	1	3	2	2
Lego Robot Inventor	3.2	5	1	5	1
Lego Spike	3.2	5	1	5	1
Sipeed Maixduino	2.2	1	3	2	1

Table 8. Summary of the ER platform comparison using ER-AR special indicators

ER platform name	AR friendlines	Visual simulation friendliness	Logical simulation friendliness
Lego Mindstorms EV3	3.5	3.7	3.3
Lego Wedo 2.0	3.4	3.5	3.3
Arduino	2.1	2.5	1.8
Sphero - littlebits	3.5	3.5	3.5
Sphero - BOLT - SPKR+	4.0	4.0	4.0
ESP32	2.1	2.5	1.8
micro:bit	3.0	2.8	3.3
Raspberry RP2040 - RP Pico	2.1	2.5	1.8
Seeduino (Grove)	2.7	2.7	2.8
Raspberry Pi 4	1.9	2.3	1.5
Lego Robot Inventor	3.2	3.2	3.3
Lego Spike	3.2	3.2	3.3
Sipeed Maixduino	1.6	2.2	1.0

3.2.3. Availability of open-licensed libraries of 3D models and assets for ER Kits

We evaluated the availability of the open-licensed libraries of 3D models and assets for ER Kits by searching in several search engines and analyzing the results. We searched for information for each ER kit in the different engines. In each search engine, we used different search queries (Table 9).

Table 9. Search engines and queries used in identifying available 3D models and assets for ER kits

Search engine	Search query	Search query example
Google https://www.google.com/	<ER kit name> + 3D models	Lego Mindstorms EV3 kit 3D models
Sketchfab https://sketchfab.com/	<ER kit name>	Lego Wedo 2.0 Kit
Turbosquid	<ER kit name>	Arduino Kit

The results demonstrate that it is challenging to find open-licensed libraries of 3D models or other 3D assets for the ER platforms we selected (Table 10). For five (5) ER platforms we could find any 3D models available (Sphero - littlebits, Seeduino (Grove), Lego Robot Inventor, Lego Spike, and Sipeed Maixduino).

Table 10. Availability of 3D models and assets for ER kits

#	ER Platform name	Search engine		
		Sketchfab	Turbosquid	Google
1	Lego Mindstorms EV3	No results	No results	Grabcad community [71] (Not complete and game-ready format)
2	Lego Wedo 2.0	3dwarehouse[72]	No results	No results
3	Arduino	(Multiple results) e.q., by kakaeka [73]	(Multiple results, not optimized), e.g., Ruslan812 at turbosquid.com[74]	No results
4	Sphero - littlebits	No results	No results	No results
5	Sphero - BOLT - SPKR+	By gbourel[75] (Without textures)	No results	No results
6	ESP32	Multiple Results, E.g., By gsaurabhr[76]	No results	Grabcad[77] (Not complete and game-ready format)

[71] https://grabcad.com/library/lego-mindstorms-ev3-1

[72] https://3dwarehouse.sketchup.com/model/346b2728-06a8-4328-a257-e29ccd3e1e2a/Lego-WeDo-20-Bricks-Components-inc

[73] https://sketchfab.com/3d-models/arduino-uno-775a2bf901a74fd190f175f5f0dcf2d0

[74] https://www.turbosquid.com/3d-models/arduino-mega-leonardo-3d-1196985

[75] https://skfb.ly/otCpr

[76] https://sketchfab.com/search?q=esp32

[77] https://grabcad.com/library/esp-32-1

#	ER Platform name	Search engine		
		Sketchfab	Turbosquid	Google
7	micro:bit	(Not optimized) By Sitetechno.fr[78]	No results	(Multiple Results), e.g., kitronik[79] (Not Optimized)
8	Raspberry RP2040 - RP Pico	By Abdoubouam [80]	by Raihanali (Not free)[81]	(Multiple Results) e.g., by “Evil Genius Laboratory” at thangs.com[82]
9	Seeduino (Grove)	No results	No results	No results
10	Raspberry Pi 4	By F2A[83] (Not Free)	No results	(Multiple Results, Not Optimized, No Textures) e.g., by M3chTroniC at thangs.com[84]
11	Lego Robot Inventor	No results	No results	No results
12	Lego Spike	No results	No results	No results
13	Sipeed Maixduino	No results	No results	No results

3.3 Existing Augmented Reality solutions for Educational Robotics platforms

3.3.1 Literature on in-depth connection between ER and AR

A significant part of our literature review was conducted in order to explore the possibilities for an in-depth connection between ER and AR. This effort revealed to what extent such a connection already exists, which robotics platforms have been applied in this respect and what application possibility, functionality and added value can be attributed to AR in this respect. The literature analysis shows that connectivity between ER and AR is not entirely new, but often involves combinations of specific robotics platforms, with AR applications developed specifically for this connection. The application in education takes place mainly for topic explicit and focused forms of explanation, instruction and/or assessment, and to a lesser extent for methodological study lesson design in relation to inquiry and design-based learning.

78 https://skfb.ly/o6wRn
79 https://kitronik.co.uk/blogs/resources/bbc-microbit-cad-resources
80 https://skfb.ly/6Ywsu
81 https://www.turbosquid.com/3d-models/3d-raspberry-pi-pico-1779544
82 https://thangs.com/designer/Evil%20Genius%20Laboratory/3d-model/Raspberry%20Pi%20Pico-12567
83 https://skfb.ly/6QXSV
84 https://thangs.com/designer/M3chTroniC/3d-model/Raspberry%20Pi%204%20Model%20B.SLDPRT-22465

Pasalidou and Fachantidis[85], presented their mobile AR learning environment and research findings in a primary school setup. During the research, two experiments were conducted using the EV3 Lego robot. The first experiment used tangible objects and robots to program and the second was supported by the AR application. Based on their results, the second approach gained students' attention; the augmented reality app was an engaging and user-friendly tool for students, improved their robotics programming performance, and encouraged active engagement in the learning process.

Yang et al.[86] focuses on the effect of augmented reality-based virtual educational robotics on enhancing computational thinking skills. The authors implemented an augmented reality virtual educational robotic system (AR Bot). They examined the impact of AR Bot on programming learning in a university classroom, conducting the research with an experimental group of students utilizing AR Bot and a control group programming with Scratch. The results showed that the AR bot group had comparatively improved performance related to enjoyment of learning, algorithm design skills, and algorithm efficiency skills. However, they lagged behind in problem decomposition skills and academic achievement than students who used Scratch.

3.3.2 Ozobot

There are very few solutions available in the market that offer AR-enhanced ER platforms to support their products and to enrich user experience. As a representative example, it is important to mention a remarkable commercial product named MetaBot™ extended reality (XR) application provided by Ozo EDU Inc. This application (launched 2021[87]) gives a user the ability to play with Ozobot (a desk-friendly coding robot) in AR (Figure 3) or VR (Figure 4) modes[88]. The user can choose different costumes, place tiles, backgrounds, point of view, and edit blockly code (Figure 5) all in the same mobile app. MetaBot is a valuable tool to work and write code for a robot in an XR environment, and could support teachers and students to work in pandemic-like circumstances.

[85] C. Pasalidou and N. Fachantidis, “Contextualizing educational robotics programming with augmented reality,” in 2022 8th International Conference of the Immersive Learning Research Network (iLRN), May 2022, pp. 1–5. https://doi.org/10.23919/iLRN55037.2022.9815969

[86] Fang-Chuan Ou Yang, Hui-Min Lai, Yen-Wen Wang. Effect of augmented reality-based virtual educational robotics on programming students’ enjoyment of learning, computational thinking skills, and academic achievement, Computers & Education, Volume 195, 202. https://doi.org/10.1016/j.compedu.2022.104721

[87] Ozobot Launches MetaBot, the Free AR Robot for Education (2021) https://arpost.co/2021/12/14/ozobot-metabot-ar-robot-education/

[88] N. Nevrelova, L. Korenova (2022) Usage of Augmented Reality App to Develop the Mathematical Competences of Children in Primary Education, ICERI2022 Proceedings, pp. 7553-7560. https://doi.org/10.21125/iceri.2022.1924

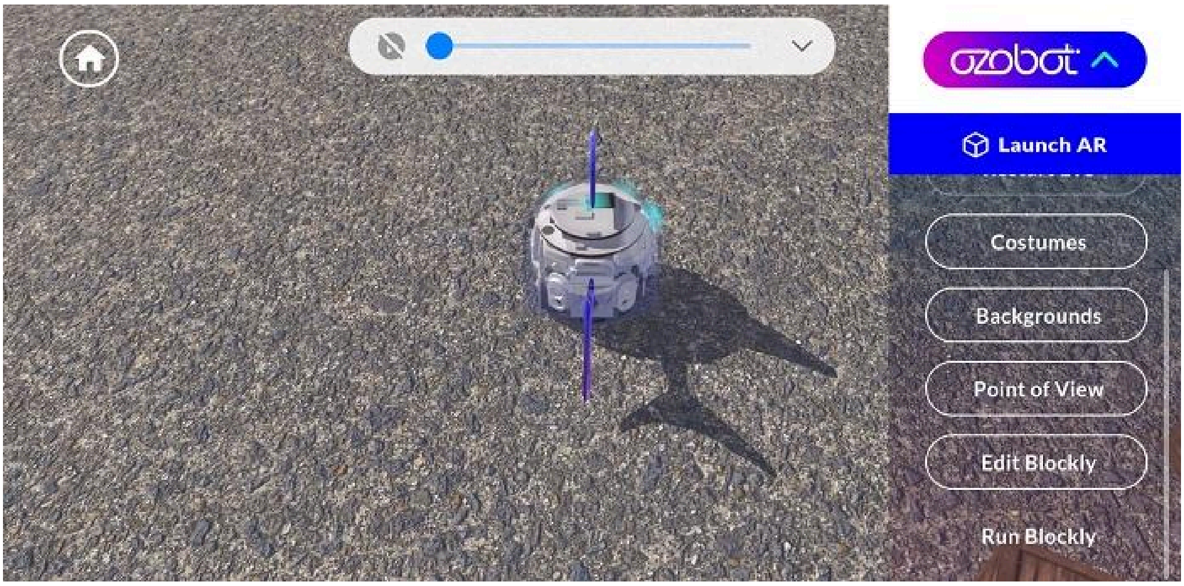

Figure 3. Metabot AR mobile app view

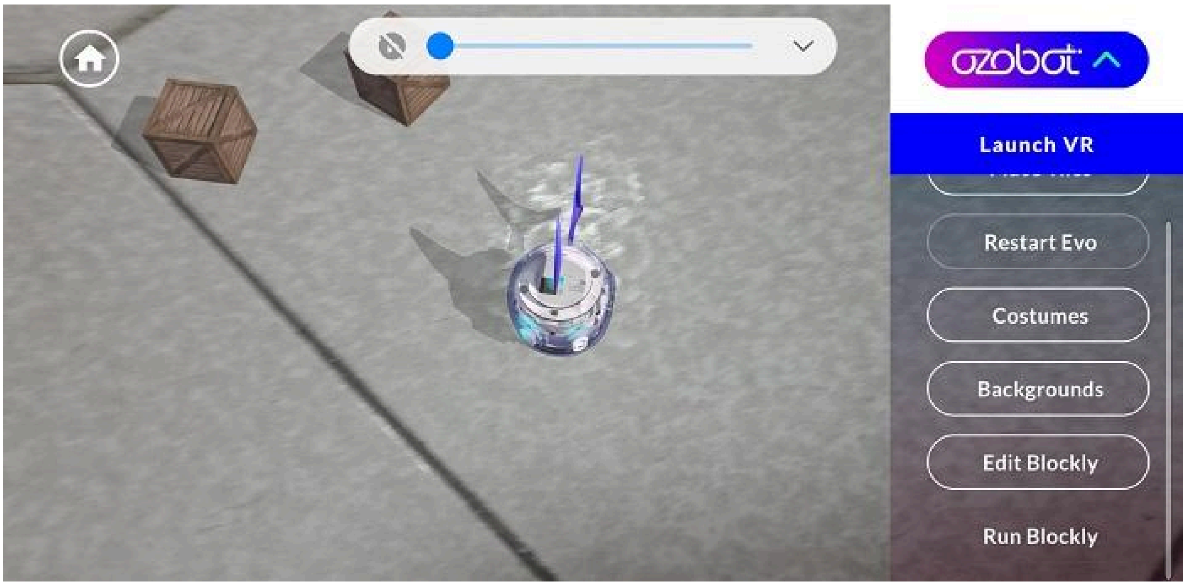

Figure 4. Metabot VR mobile app view

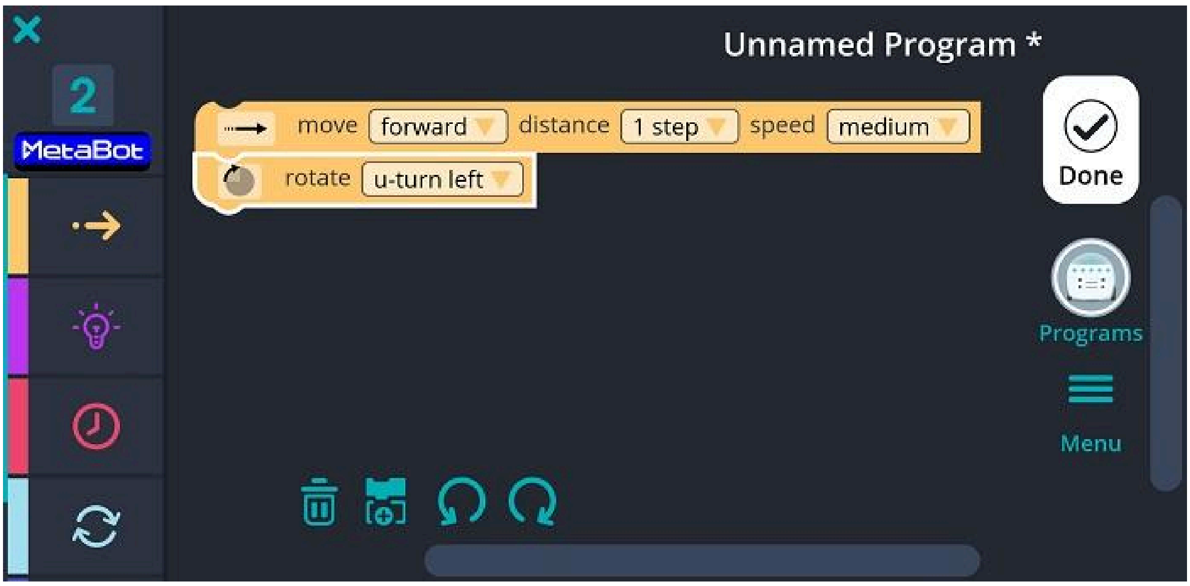

Figure 5. Metabot bloclky mobile app view

3.3.3 Arlektra

Arlektra[89] is an Augmented Reality app that supports the Arlektra ER kit, developed by AR STEM LABS[90]. Arlektra can be used to teach electronics and circuits with real hands-on projects, merged with AR instructions and animations available on phones and tablets. Arlektra contains 85 lessons and 370 electrical parts, with hands-on projects using real-world parts and materials (Figure 6).

Arlektra allows us to visualize and comprehend electrical concepts and theories. The AR app uses step-by-step AR instructions, teaching to build electrical circuits. The VR app allows you to see real electrical parts in detailed 3D-exploded and 360 views.

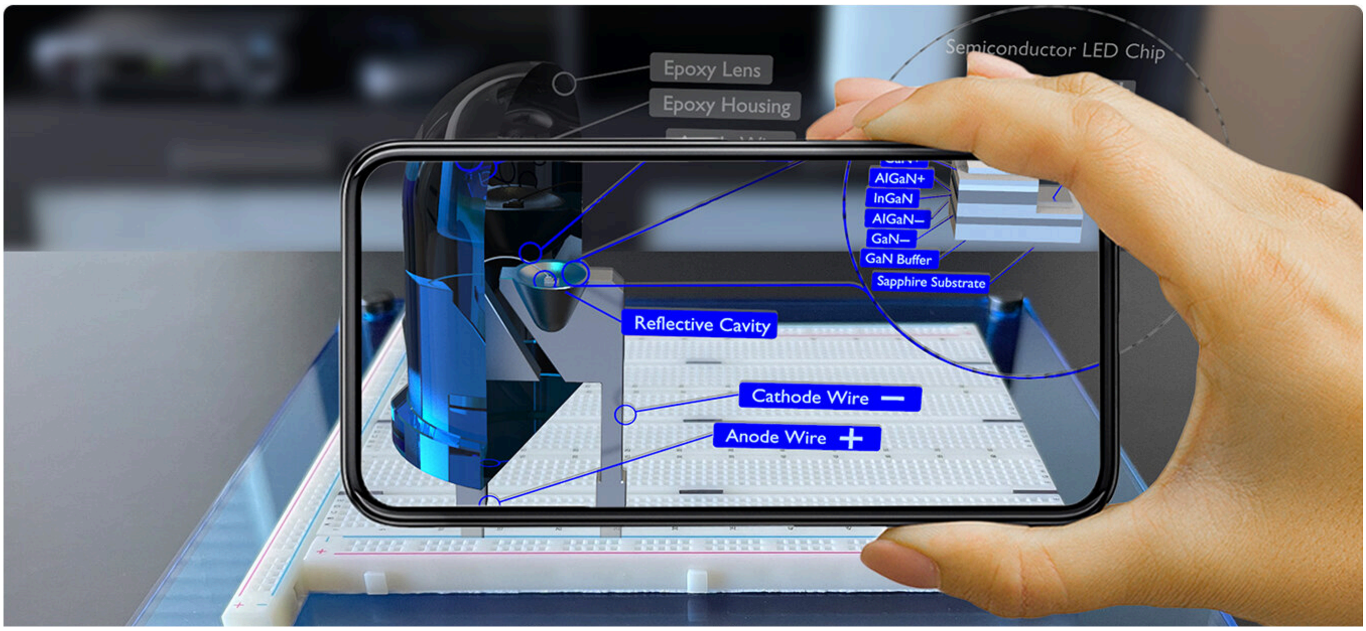

Figure 6. Arlektra app. Image from https://www.arstemlabs.com/arlektra

[89] https://www.arstemlabs.com/arlektra
[90] AR STEM LABS Inc https://www.arstemlabs.com/

4 Augmented Reality for Educational Robotics: A Group Concept Mapping study

In order to gather insights into both added value and possible challenges of using AR in teaching ER and to inform design, a research study was conducted among stakeholders and problem-owners as potential users of AR enhanced ER in teaching, namely STEM primary and secondary school teachers, educational researchers, designers and developers.

The following questions were posed:

- How do STEM teachers, educational researchers and educational technologists conceptualize using AR for teaching ER and teaching STEM with ER in online or blended formats?
- What pedagogical and technical affordances do they consider vital for the design of AR enhanced ER?

In this section, we introduce the Group Concept Mapping methodology, describe how we applied it in our study, and then present and discuss the results.

4.1 Introduction to the Group Concept Mapping methodology

Group Concept Mapping (GCM) is a consensus driven research approach that combines qualitative data collection with advanced quantitative data analysis techniques to support stakeholders and problem owners in constructing and refining deep understandings of a problem[91]. GCM provides visual support to idea generation and joint deep discussions of ideas and standpoints that serve to underpin design choices, to support decision making, guide educational design decisions or to reach consensus in a complex matter[92],[93],[94].

GCM methodology involves organizing and performing a fixed set of activities, each involving a particular category of stakeholders or several stakeholder categories. Firstly, stakeholder representatives are invited to generate their individual answers to a provided prompt. After this brainstorm activity and the subsequent removal of duplicates and textual editing of collected input, participants are asked to arrange or sort generated ideas in a meaningful way and to evaluate (rate) them on relevant dimensions. Collection, sorting and rating of input as well as data analysis is performed by Groupwisdom® Global MAX™ online application[95]. Advanced multivariate statistical techniques of multidimensional scaling (MDS) and hierarchical cluster analysis (HCA) are used to generate visual representations of shared collective perspectives in Groupwisdom to support data interpretation. Outcomes of analyses and visual

[91] Kane, M & Trochim, W. (2007). *Concept Mapping for Planning and Evaluation*. Thousand Oaks, CA, Sage Publications https://us.sagepub.com/en-us/nam/concept-mapping-for-planning-and-evaluation/book229728

[92] Kane, M., & Rosas, S. (2017). *Conversations about group concept mapping. Applications, examples and enhancements.* https://us.sagepub.com/en-us/nam/conversations-about-group-concept-mapping/book248804

[93] Rajagopal, K., Firssova, O., op de Beeck, I., van Stappen, E., Stoyanov, S. T., Henderikx, P., & Buchem, I. (2020). Learner skills in open virtual mobility. *Research in Learning Technology, 28*. https://doi.org/10.25304/rlt.v28.2254

[94] Schophuizen, M., Kreijns, K., Stoyanov, S., & Kalz, M. (2018). Eliciting the challenges and opportunities organizations face when delivering open online education: A group-concept mapping study. *The Internet and Higher Education, 36*, 1-12. https://doi.org/10.1016/j.iheduc.2017.08.002

[95] Groupwisdom® Global MAX™ https://groupwisdom.com

representations become points of departure in design activities and decision making. Figure 7 illustrates the order of these activities as GCM phases in which different actors are involved.

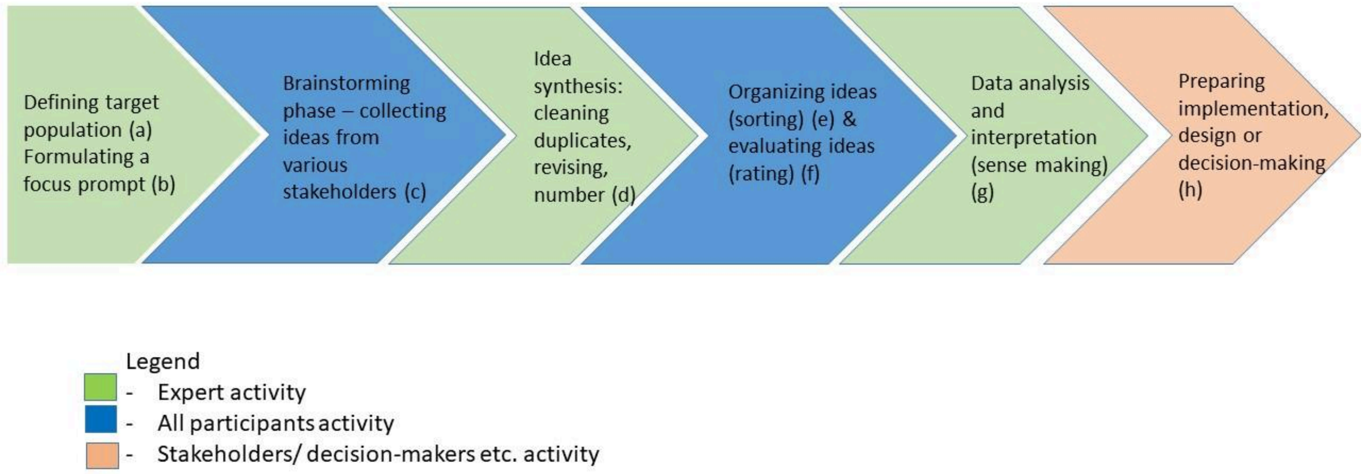

Figure 7. A visual representation of a GCM phases and actors per phase

GCM data analysis outcomes are accompanied by a variety of visual representations of shared collective perspectives in the form of point and cluster maps. These maps show how the statements and groups of statements are plotted on an x–y graph and how they are related to each other. Graphs such as ladder graphs or pattern matches and four quadrant Go zone graphs support understanding of the problem under study and provide insights into the differences in the perspectives of the participants. To help determine best-fitting solutions of a problem under study GCM provides a number of statistical indices that support participants in selecting such solutions. Table 11 provides an overview of these statistics.

Table 11. Basic statistical indices in GCM[96]

Statistic	Explanatory note
Kruskal Stress value statistic	Stress value is an index between 0 and 1 that indicates how good the data is represented by the generated point map. The accepted range that corresponds to goodness of fit is between 0.2 and 0.37.
Bridging value (BV) statistic	MDS assigns each idea a value between 0 and 1 as an indicator of the extent to which a statement was sorted with its neighboring ideas. A lower BV indicates that more participants grouped a particular idea with ideas close to it, a higher BV means that participants sorted the statements with ideas further on the map. Thus, the BV statistics provides an indication of differences in standpoints of the participants.
Cluster bridging value	Cluster bridging value is an average of BV indicators of all ideas within a cluster. A lower cluster BV is an indicator of a consistent cluster

4.2 Applying GCM methodology in Augmented reality for Educational Robotics (AR4ER) study

In the reported study the GCM was used to involve potential end users and stakeholders in the design of AR-enhanced support for teaching ER by collecting their ideas and views on it.

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[96] Note: this overview is based on Kane & Rosas (2017) and Kane & Trochim (2007)

4.2.1 Participants

Teams of experts on ER and AR from three European universities and representatives of their respective networks of teachers of ER and other STEM subjects took part in the study with circa 30 participants contributing to one or more phases of the reported GCM study. According to the information provided in Groupwisdom, among the study participants were university professors, teachers, teacher educators, educational designers, researchers, software developers, managers in education, representing the educational domains of primary, secondary, tertiary vocational and higher education. Participants indicated their fields of expertise, such as teaching STEM, ER and AR, online teaching, design of school and out of school learning.

4.2.2 Instruments and materials

All data collection activities (brainstorming, sorting, rating and collection of participant background information) and analyses with MDS and HCA are facilitated by Groupwisdom® Global MAX™ (2021) online environment.

During debriefing online sessions in team 1 and team 2 evaluation remarks were collected in padlets (padlet.com).

4.2.3 Procedure

(a, b) Selecting participants and formulating the focus prompt. The GCM was conducted online through partially separate data collection trajectories per national team. The focus prompt was formulated in conformity with the objective "to identify approaches best suited for online and blended learning enhanced by AR as one of the solutions for the pandemic restrictions in teaching Educational Robotics".

In order to speed up data collection it was decided to limit participation in the idea generation (brainstorm) activity to three teams, each from a university in Norway, Greece and the Netherlands respectively. The ethical approval requests were filed separately by each team with their respective ethical boards. Two teams received full ethical approval for data collection and one team did not receive ethical approval for collecting personal data.

(c) Brainstorming / collecting ideas. Ideas were collected through Groupwisdom online tool. The participants were requested to share ideas as an answer to the following trigger (focus prompt with an explanation):

> The e-ROBSON project aims to design solutions that would enable teaching Educational Robotics (ER) with the help of augmented reality and/or online. The ambition is also to demonstrate to teachers of STEM on how ER (combined with augmented reality / online solutions) can enrich teaching of STEM subjects. What are the solutions that you can think of in this context? You can share as many ideas as you wish. Try to formulate them in a compact way. You can indicate a specific perspective (for example, with AR this or that might be possible…. ; to teach ER through online learning we could develop this or that …. : ... or to teach STEM with ER we can ....). You can see what others write and can build on and use already available statements as inspiration. Feel also free to suggest something completely different…

Collection of ideas lasted for approximately a month. Reminders were sent out twice.

(d) Idea synthesis. A total of 61 ideas were collected and analyzed by three project members statement by statement in order to avoid repetition and ambiguous statements that could be interpreted in different ways. Ideas were edited to be formulated as design requirements. Several statements were split in the process. The final set included 72 unique statements upon which full agreement was reached.

(e, f) Sorting and rating. 72 ideas formulated as an answer to the focus prompt were arranged in meaningful piles (sorted) and evaluated (rated) on a scale from 1 to 5 on dimensions of importance and feasibility by the participants of each team.

Team 1 organized three small scale online sessions of 1,5 hour. Each session was designed to provide an introduction in the project, a demonstration of a prototypical AR4ER application, to introduce and give instruction on the Groupwisdom tool and the task. Then a 45 min individual activity (sorting and rating in Groupwisdom) took place to be followed by de-briefing. Participants who ran out of time while completing sorting and rating during the session were requested to complete it afterwards. Reminders were sent a week after the session. In the debriefing part participants shared their impressions on the activity and commented on the choices they made. Online sessions were recorded and a summary of points in the debriefing was made with the help of the padlet tool. Thus, team 1 provided initial input to the joint outcomes.

Team 2 collected data through a series of activities starting with an introductory online session about the AR4ER approach and the Groupwisdom tool. Sorting and rating activities were organized as individual online activities at participants' convenience to be completed within a week after the online introduction. Another synchronous online event was conducted as an interpretation and meaning making activity based on the accumulated outcomes of sorting and rating by teams 1 and 2.

Team 3 conducted a single two hour online session with a short introduction and the focus on the individual sorting and rating activity. Participants who did not complete sorting and rating during the synchronous session were invited to complete the task within a week after the session.

One participant generated 36 clusters with one or two statements per cluster. Input of this participant was excluded from the analysis during the data validation procedure.

(g) Discussion and selection of the best fit solution. After the three teams finalized sorting and rating, collected data were validated manually according to the Groupwisdom procedure. Then, analyses were run and the outcomes in the form of provisional cluster maps were presented for discussion at an online cross-team meeting. The outcomes of Meaning making by team 2 were also taken into account in this discussion. A six cluster solution was found most appropriate as a representation of all statements in the respective clusters. Agreement was reached on meaningful labels. After that analyses were run again based on the best-fit solution drawn collectively and visual representations of the outcomes were produced and standpoints of participants could be analyzed and described. The following Results section describes these outcomes.

4.3 Results of the AR4ER GCM study

This section presents and discusses the outcomes of the AR4ER GCM study.

4.3.1 Point map

The first outcome of the GCM analysis is a point map representing each idea (answer to the focus prompt trigger) as a separate point on a two-dimensional space and the distance between each individual idea and all other ideas. The point map generated by Groupwisdom in the AR4ER study consists of 72 ideas.

Stress value statistic of 0.254 indicates that the map is a reliable representation of the collected data with ideas that are closer to each other in meaning being located close to each other on the pointmap and ideas that do not belong together being located further from each other. Figure 8 illustrates this outcome and presents some exemplary statements. The complete list of statements is provided in Annex II of this report.

As shown at Figure 8, idea 66 has the bridging value (bv) of 0.00 which indicates that all participants sorted it together with ideas that are positioned near it on the point map and are in complete agreement as to where this idea belongs. Ideas 5 and 17 have a relatively high bridging value of respectively 0.45 and 0.53

which are indications of less agreement between participants on the extent these ideas belong together with other ideas nearby. Idea 42 has a bridging value of 1 which is an indication that it is sorted by participants in different ways. Participants are not in agreement about where this idea belongs.

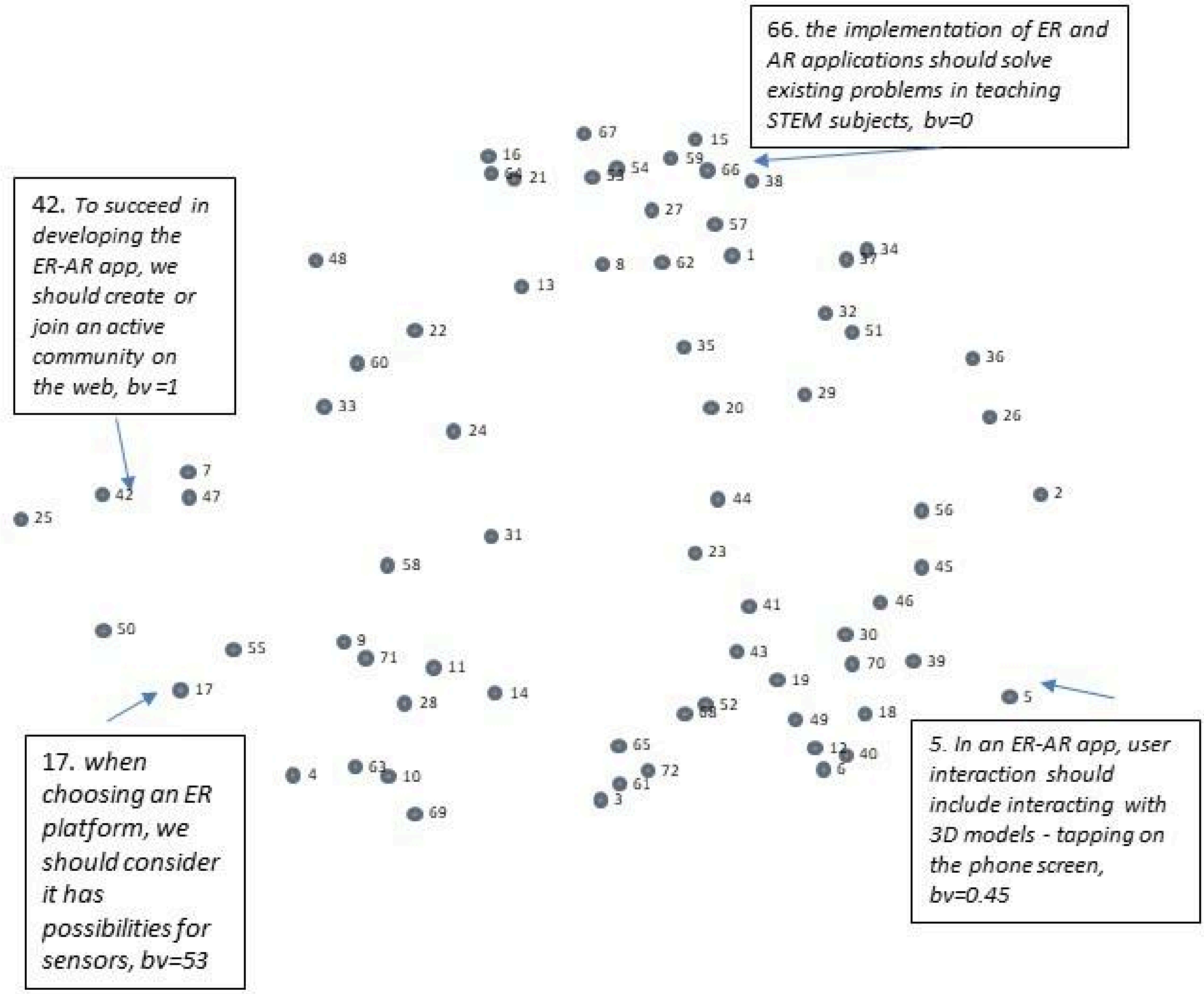

Figure 8. AR4ER GCM study results: a point map of generated ideas with some examples

4.3.2 Meaningful clusters of ideas and cluster maps

MDS and HCA analysis provide a variety of possible groupings of collected ideas. It is up to the participants to decide upon the meaningfulness of ideas that are grouped together.

In AR4ER GCM study, six thematic groupings or clusters of ideas of using AR and online learning to enhance ER and experiments in STEM were distinguished. These clusters are: Generic educational ideas, Feedback design ideas, Interaction design ideas, Hardware design ideas, ER platform selection ideas and ideas on Framing AR4ER concept.

Generic educational design ideas cluster consists of 17 ideas with 7 ideas listing possible general educational benefits or potential added value of using AR to teach ER, for example, "support of crossing boundaries between primary education and secondary education" (idea 16), or being "beneficial for all students" (idea 27). In this thematic cluster, 10 ideas dwell on possible educational scenario guidelines, such as idea 54 ("ER-AR educational scenarios can be designed as a sequence of steps to be done, which will reduce the time commitment of a teacher because instructions and feedback are provided through AR"). All items in the cluster have a low bringing value, indicating that most participants agree with each other that these ideas belong together in this cluster.

Cluster *Feedback design ideas* includes 9 ideas on the way learning and feedback are conceptualized in the context of AR use for teaching ER and on feedback related affordances such as feedback visualization. An exemplary idea on the function of feedback visualization is idea 37: “with AR, students can see consequences of their actions (i.e. if one makes coding mistakes or wrong assumptions)”. Agreement between participants on cluster composition is relatively high with a cluster bv of 0.32. However, there seems to be less agreement on two ideas on feedback visualization in the cluster, namely ideas 2 and 26.

Interaction design ideas cluster contains 22 ideas that are formulated as requirements for AR-ER app functionalities or can be translated into such, f.e., idea 3: “The AR-ER app should use modularity to allow working with more than one ER platform” or idea 40: “In the AR-ER app, user interaction should include moving the physical ER cards”. The average bv is 0.24, most items have the bv statistic between 0.2 and 0.3, indicating that agreement between participants and hence cluster consistency is relatively high.

The 11-idea cluster on *Hardware design ideas* combines ideas on requirements for mobile devices for the AR-ER app, ideas on wireless connectivity and requirements for ER hardware components. BV statistics for individual items lie in the range between 0.25 and 0.36 with one exception of idea 4: “We need to use real ER hardware components and augment them with AR”, bv=0.53.

The 7-idea cluster ER platform selection ideas includes ideas on selection criteria such as costs, f.e., idea 50, specific functionalities or affordances like idea 17 and the ease of use (idea 47). Furthermore, this cluster includes generic recommendations on building an expert community, such as idea 42: “To succeed in developing the AR-ER app, we should create or join an active community on the web”. High average bv statistic of 0.69 points to a low level of cluster consistency and low agreement between participants on whether the ideas actually belong together. Idea 42, is, for example, sorted with different ideas by all participants, which explains bv statistic of 1.

Last but not least, cluster *Framing AR-ER concept* contains five generic ideas related to framing AR use for ER conceptually (idea 24), from the technology point of view (idea 33), and from the design process point of view (idea 48). Average bv statistic is 0.42, the level of agreement between participants relatively low.

Figure 9 shows these clusters at the cluster map, together with a visualization of the outcomes of the bridging analysis - less layers point to a higher level of cluster consistency, indicators per cluster are also provided.

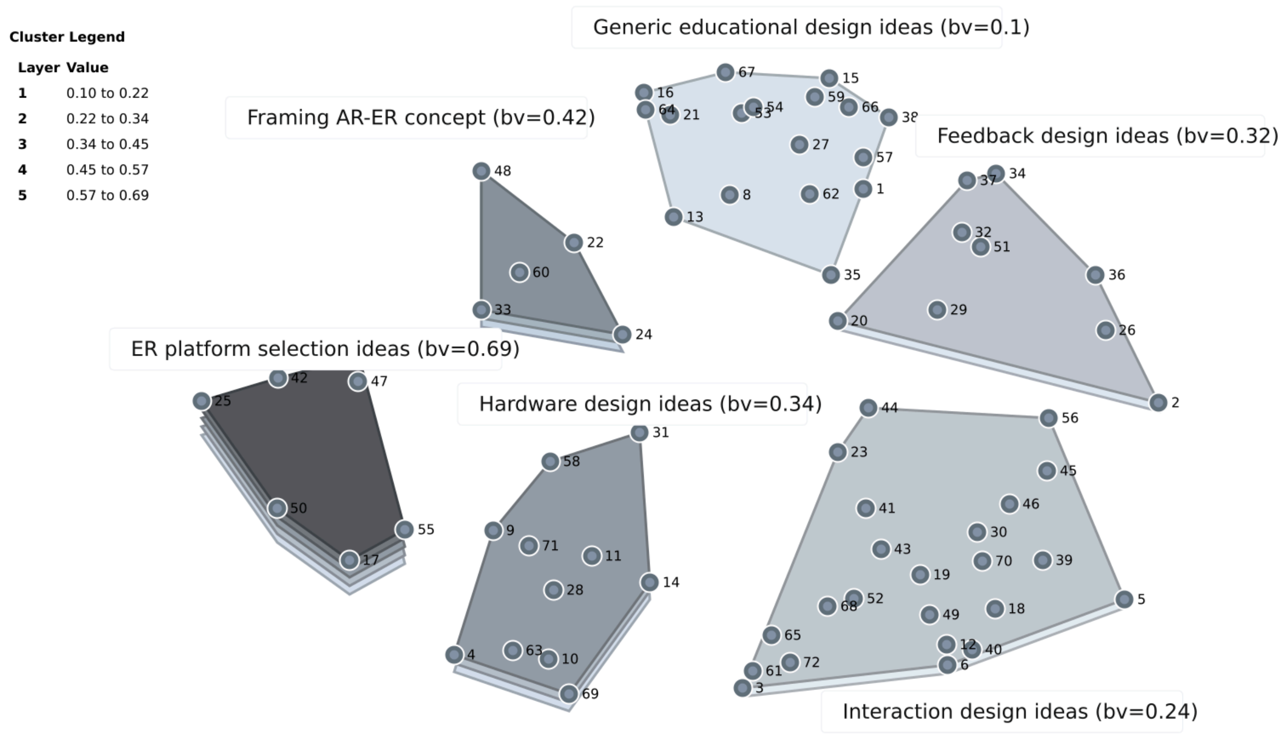

Figure 9. AR4ER GCM study: Clusters of ideas with cluster bridging value levels

As Figure 9 illustrates, agreement between participants and cluster consistency are higher for the clusters *Generic educational design ideas*, *Interaction design ideas* and *Feedback design ideas* and lower for the remaining three clusters. The agreement is the lowest on the cluster *ER platform selection ideas*.

4.3.3 Evaluation of ideas in clusters: rating on two dimensions

Additional information on the thematic groupings of collected ideas is generated by evaluating (rating) ideas on dimensions of importance and feasibility on a scale from 1 to 5. The pattern match graph on Figure 10 illustrates these ratings at cluster level with thematic clusters related to educational design (*Generic educational* and *Feedback design ideas*) scoring highest on both dimensions compared to clusters on technological design aspects (clusters *Interaction design ideas* and *Hardware design ideas*). Differences in ratings of perceived importance of ideas versus perceived feasibility are significant for all clusters but one (*ER platform selection ideas*). Ratings of perceived importance also differ significantly between the educational design related ideas (clusters *Generic educational ideas* and *Feedback design ideas)* and technology oriented ideas (*Hardware design, ER platform selection* and *Interaction design ideas*).

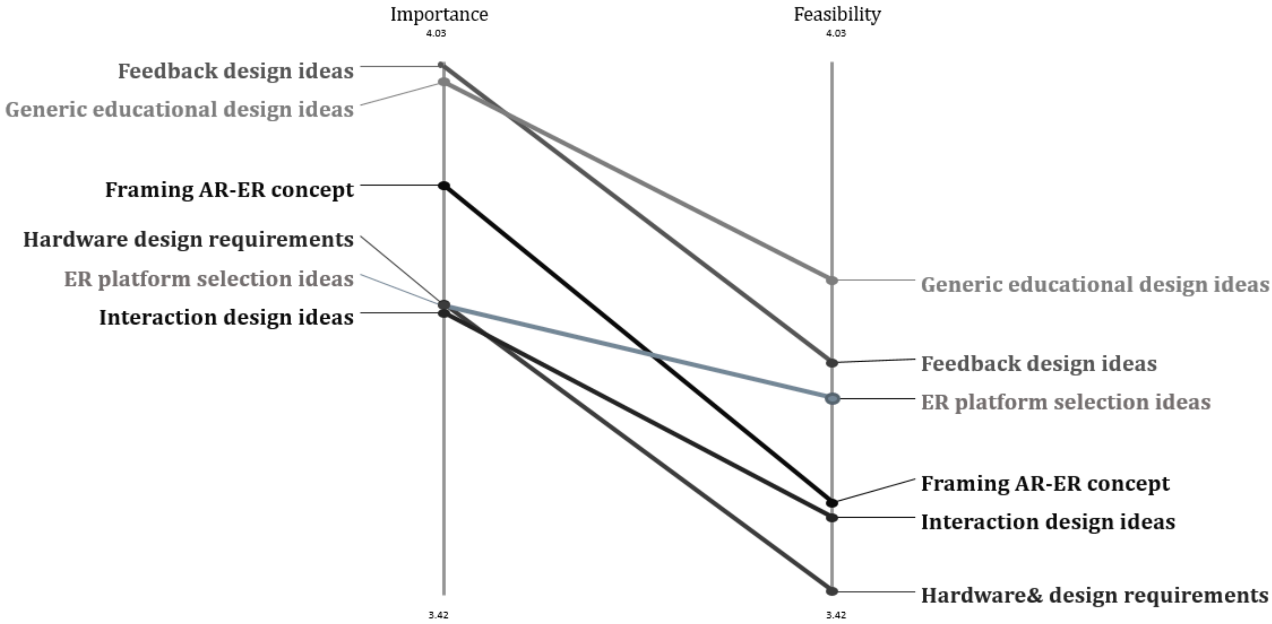

Figure 10. AR4ER GCM study: Importance and Feasibility

4.3.5 Directions for implementation: Go-zone overviews

Ideas that are evaluated above average on both importance and feasibility form the so-called Go Zone and are considered first when results of a GCM are used for design, decision making or policy making process. Go-zone overviews provide additional support to idea discussions and joint searching for solutions[97] as these graphs visualize ideas as points which are found both highly important and highly feasible (above average on both dimensions) in contrast with ideas that are found less/least feasible and important by the participants. The resulting Go-zone overview for the GCM outcomes in the AR4ER GCM study, with the Go-Zone kwadrant marked (Figure 11) illustrates the spread in the standpoints of the participants.

[97] Schophuizen, M., Kreijns, K., Stoyanov, S., & Kalz, M. (2018). Eliciting the challenges and opportunities organizations face when delivering open online education: A group-concept mapping study. The Internet and Higher Education, 36, 1-12. https://doi.org/10.1016/j.iheduc.2017.08.002

Figure 11. Go zone graph in AR4ER GCM study (x-importance, n=29; y=feasibility, n=23)

In Annex II of this report, all ideas in the Go-zone idea (i.a. ideas that score higher than average on the two dimensions) are highlighted. Based on the Go-zone overviews and statistics a priority list for design requirements can be generated.

4.4 Outcomes of the AR4ER GCM study: points for discussion

The outcomes of a GCM study are meant to steer further exchange of standpoints as a roadmap to shared understanding and knowledge construction through discussion and collaboration. The outcomes offer food for thought and a point of departure for further elaborating on design requirements and scenario development on ER-AR applications at both conceptual and more applied level. The GCM approach prescribes intensive discussion and interpretation of results[98] which in the context of this study can be done throughout and in the frame of the planned design iterations and pilot evaluations. Together with the literature study, AR4ER GCM study can be seen as a zero-measurement point in this process.

The study aimed at getting insights and expert opinions on the question how teaching ER and experimental part of STEM subjects in general can be supported by online learning and AR.

GCM outcomes confirm full agreement between the study participants on the educational goals AR4ER GCM study and on the general ideas for designing educational solutions (providing support to learning STEM, learning through the power of concrete imagination, support to a broad range of pedagogical approaches that involve learning by doing). There are some guidelines for scenario development: development of pedagogical scenarios for different pedagogical approaches, some specific points for feedback design (i.e., making consequences of learners' actions visible). Furthermore, a number of concrete technical and

[98] Kane, M., & Rosas, S. (2017). Conversations about group concept mapping. Applications, examples and enhancements. https://us.sagepub.com/en-us/nam/conversations-about-group-concept-mapping/book248804

functional requirements for hardware and ER-AR app design are formulated. It is clear that the issue of selection of ER-AR platform is an important one but that opinions on this issue differ. Differences in the way participants from different teams view the requirements need to be taken into consideration in the design process. Comparison of patterns in evaluating the ideas suggests that the differences are related with expertise backgrounds and possibly, also with task division within the project.

The GCM outcomes can be used as a scaffold in further idea development and translation of these ideas in design requirements, on the one hand. On the other hand, interpretation and discussion of the outcomes in the next iterations of the design process can serve to add relevant, yet missing aspects to these outcomes.

5 Conclusions

This report on Teaching Educational Robotics (ER) blended and online with Augmented Reality (AR) consists of three studies, each providing a different perspective on the topic of using AR to enable the methods of ER in an online or blended mode. In these studies, we explored a possibility of delivering laboratory-dependent courses for the topic of ER, which is of low implementation cost, easy to adopt, and possible to be implemented remotely. The original motivation for the proposed idea was finding a way to run such laboratory-dependent courses in the context of the COVID-19 pandemic.

Our proposal is based on using AR to simulate the necessary lab equipment and the interaction with it, while keeping the educational experience hands-on and tangible. AR is a technology that enhances human perception with additional, computer-generated sensorial input to create a new user experience.

In our literature review Teaching principles in ER and AR, we presented the analysis of 65 research articles that cover the topics of ER and AR as well as the efforts of integrating both. The results of the literature review cover five topics: learning theories and concepts, teaching principles in AR, teaching principles of ER, programming robots in education, and teaching principles of Robotics and AR, combination of both. For each of these topics, we presented the underlying characteristics and subcategories of information found in the literature.

ER has been shown to be particularly effective in the domain of STEM education. The visual programming methodology is an often used approach to code robots and during this process students improve their programming skills, proportional reasoning skills, and analysis skills. As part of ER, teachers develop classroom interventions that rely on robotics. Teachers look for educational strategies that are particularly effective in the domain of ER, for example, from Human-Robot Interaction. Several approaches have been found to facilitate programming robots in ER, such as visual and tangible programming. Teaching approaches are intended to increase skills and knowledge, but also to improve self-efficacy.

The pace of innovation and research in AR has increased with the arrival of affordable mobile technologies that are capable of providing the required interfaces and sensors for AR. Several research groups in computer vision and gaming are considering design pattern based approaches as promising candidates for solving recurring design and development challenges. We can also see that educational scientists merge existing didactical approaches with the affordances provided by AR. The application domains of AR are still limited to presentation learning, discovery learning, and collaborative learning with only a few notable exceptions. In each of these domains, AR adds the ability to provide information just-in-time and to visualize invisible processes. Studies often conclude that AR can boost learning outcomes, reduce learning task complexity, and that AR is beneficial to motivation. Several barriers to AR adoption still exist, such as difficulty in interaction, unstable recognition of images and objects by AR devices. AR for disabled students has received very little attention so far.

Our review revealed to what extent the connection of ER and AR already exists. The literature analysis shows that it is not entirely new, but often involves combinations of specific robotics platforms, with AR applications developed specifically for this connection. The application in education takes place mainly for topic explicit and focused forms of explanation, instruction and/or assessment, and to a lesser extent for methodological study lesson design in relation to inquiry and design-based learning.

Our Review of ER platforms and literature presents an in-depth analysis of 13 such platforms, exposing multiple indicators drawn from eight research articles. The indicators we used in the analysis include cost, tangibility, durability, processor or microprocessor technology, software, hardware, available programming languages, support, community, available literature, fields of applications, and target age range. Based on our analysis, we suggest a new complex indicator - AR friendliness, which consists of logical simulation-friendliness, visual simulation-friendliness, and selective exposure. This system of generic and new specialized indicators can be used to analyze any ER platform for its potential of being simulated with AR, and possible with other simulation technologies. Another result of this review is the expert comparison of the 13 ER platforms and a conclusion that the littleBits ER platform has the best potential for AR simulation. Other ER platforms that were also evaluated highly are Sphero - BOLT - SPKR+, Lego Mindstorms EV3, and Lego Wedo 2.0.

Our Group Concept Mapping study AR for ER presented an analysis of primary research data on the topic of designing AR to support ER systematically collected from 40 experts. We used the Group Concept Mapping approach to collect and prioritize ideas and advanced statistical techniques of multidimensional scaling and hierarchical cluster analysis to analyze the data. The ideas suggested by the experts were grouped in six clusters: Educational ideas, Educational feedback, Requirements, modularity, and content, Hardware and design requirements, Educational Robotics platform selection, and Educational Robotics - Augmented Reality concept design. In addition, a list of ideas which were highly rated by the experts both in importance and feasibility is derived. The outcomes of this study are meant to be a point of departure for further elaborating on design requirements and scenario development on ER-AR applications.

The outcomes confirm full agreement between the experts on the general concept for designing educational solutions, such as providing support to learning STEM, learning through the power of concrete imagination, support to a broad range of pedagogical approaches that involve learning by doing. There are some guidelines for scenario development: development of pedagogical scenarios for different pedagogical approaches, some specific points for feedback design. Furthermore, a number of concrete technical and functional requirements for AR hardware and ER-AR application design are formulated. It is clear that the issue of selection of an ER-AR platform is important, but it has been approached differently by different expert groups.

Annex I. List of article on teaching principles in educational robotics and augmented reality

List composed by Nardie Fanchamps & Corrie Urlings

Educational robotics

Angeli, C., & Valanides, N. (2020). Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy. Computers in Human Behavior, 105, 105954. https://doi.org/10.1016/j.chb.2019.03.018

Abstract: The study examined the effects of learning with the Bee-Bot on young boys' and girls' computational thinking within the context of two scaffolding techniques. The study reports statistically significant learning gains between the initial and final assessment of children's computational thinking skills. Also, according to the findings, while both boys and girls benefited from the scaffolding techniques, a statistically significant interaction effect was detected between gender and scaffolding strategy showing that boys benefited more from the individualistic, kinesthetic, spatially-oriented, and manipulative-based activity with the cards, while girls benefited more from the collaborative writing activity. In regards to the children's problem-solving strategies during debugging, the results showed that the majority of them used decomposition as a strategy to deal with the complexity of the task. These results are important, because they show that children at this very young age are able to cope with the complexity of a learning task by decomposing it into a number of subtasks that are easier for them to tackle. The research contributes to the body of knowledge about the teaching of computational thinking. In addition, the study has practical significance for curriculum developers, instructional leaders, and classroom teachers, as they can use the results of this study to design curricula and classroom activities with a focus on the broader set of computational thinking skills, and not only coding

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. Robotics and Autonomous Systems, 75, 661-670. https://doi.org/10.1016/j.robot.2015.10.008

Abstract: This work investigates the development of students' computational thinking (CT) skills in the context of educational robotics (ER) learning activity. The study employs an appropriate CT model for operationalising and exploring students' CT skills development in two different age groups (15 and 18 years old) and across gender. 164 students of different education levels (Junior high: 89; High vocational: 75) engaged in ER learning activities (2 hours per week, 11 weeks totally) and their CT skills were evaluated at different phases during the activity, using different modality (written and oral) assessment tools. The results suggest that: (a) students reach eventually the same level of CT skills development independent of their age and gender, (b) CT skills in most cases need time to fully develop (students' scores improve significantly towards the end of the activity), (c) age and gender relevant differences appear when analysing students' score in the various specific dimensions of the CT skills model, (d) the modality of the skill assessment instrument may have an impact on students' performance, (e) girls appear in many situations to need more training time to reach the same skill level compared to boys.

Barreto, F., & Benitti, V. (2012). Exploring the educational potential of robotics in schools: A systematic review. Computers & Education, 58, 10. https://doi.org/10.1016/j.compedu.2011.10.006

Abstract. This study reviews recently published scientific literature on the use of robotics in schools, in order to: (a) identify the potential contribution of the incorporation of robotics as educational tool in schools, (b)

present a synthesis of the available empirical evidence on the educational effectiveness of robotics as an educational tool in schools, and (c) define future research perspectives concerning educational robotics. After systematically searching online bibliographic databases, ten relevant articles were located and included in the study. For each article, we analyze the purpose of the study, the content to be taught with the aid of robotics, the type of robot used, the research method used, and the sample characteristics (sample size, age range of students and/or level of education) and the results observed. The articles reviewed suggest that educational robotics usually acts as an element that enhances learning, however, this is not always the case, as there are studies that have reported situations in which there was no improvement in learning. The outcomes of the literature review are discussed in terms of their implications for future research, and can provide useful guidance for educators, practitioners and researchers in the area.

Belpaeme, T., Vogt, P., Van den Berghe, R., Bergmann, K., Göksun, T., De Haas, M., Kanero, J., Kennedy, J., Küntay, A. C., & Oudgenoeg-Paz, O. (2018). Guidelines for designing social robots as second language tutors. International Journal of Social Robotics, 10(3), 325-341. https://doi.org/10.1007/s12369-018-0467-6

Abstract: In recent years, it has been suggested that social robots have potential as tutors and educators for both children and adults. While robots have been shown to be effective in teaching knowledge and skill-based topics, we wish to explore how social robots can be used to tutor a second language to young children. As language learning relies on situated, grounded and social learning, in which interaction and repeated practice are central, social robots hold promise as educational tools for supporting second language learning. This paper surveys the developmental psychology of second language learning and suggests an agenda to study how core concepts of second language learning can be taught by a social robot. It suggests guidelines for designing robot tutors based on observations of second language learning in human–human scenarios, various technical aspects and early studies regarding the effectiveness of social robots as second language tutors.

Bredenfeld, A., Hofmann, A., & Steinbauer, G. (2010). Robotics in education initiatives in europe-status, shortcomings and open questions. In Proceedings of international conference on simulation, modeling and programming for autonomous robots (SIMPAR 2010) workshops (pp. 568-574). https://graz.elsevierpure.com/en/publications/robotics-in-education-initiatives-in-europe-status-shortcomings-a

Abstract: For more than a decade now robotics in education has gained a lot of attention from teachers, researchers, politicians, authorities and other stake holders. During the years a great number of methodologies, courses, projects, initiatives and competitions had been developed. With the present position paper the authors who have been active in different educational robotics initiatives for several years like to summarize the status of educational robotics in Europe and to relate it to the state of the art as it is documented at international symposia and workshops. Starting from these observations the authors point out shortcomings and open questions and propose pragmatic strategies for future activities in Europe. The long-term goal is to make robotics in education stronger, more serious and evaluated and thus sustainable in order to achieve increasing technology competence of young people and to attract them for technical professional careers.

Brender, J., El-Hamamsy, L., Bruno, B., Chessel-Lazzarotto, F., Zufferey, J. D., & Mondada, F. (2021). Investigating the role of educational robotics in formal mathematics education: the case of geometry for 15-year-old students. https://doi.org/10.1007/978-3-030-86436-1_6.

Abstract: Research has shown that Educational Robotics (ER) enhances student performance, interest, engagement and collaboration. However, until now, the adoption of robotics in formal education has remained relatively scarce. Among other causes, this is due to the difficulty of determining the alignment of educational robotic learning activities with the learning outcomes envisioned by the curriculum, as well as their integration with traditional, non-robotics learning activities that are well established in teachers' practices. This work investigates the integration of ER into formal mathematics education, through a quasi-experimental study employing the Thymio robot and Scratch programming to teach geometry to two classes of 15-year-old students, for a total of 26 participants. Three research questions were addressed: (1) Should an ER-based theoretical lecture precede, succeed or replace a traditional theoretical lecture? (2) What is the students' perception of and engagement in the ER-based lecture and exercises? (3) Do the findings differ according to students' prior appreciation of mathematics? The results suggest that ER activities are as valid as traditional ones in helping students grasp the relevant theoretical concepts. Robotics activities seem particularly beneficial during exercise sessions: students freely chose to do exercises that included the robot, rated them as significantly more interesting and useful than their traditional counterparts, and expressed their interest in introducing ER in other mathematics lectures. Finally, results were generally consistent between the students that like and did not like mathematics, suggesting the use of robotics as a means to broaden the number of students engaged in the discipline.

Catlin, D., & Woollard, J. (2014). Educational robots and computational thinking. Paper presented at the Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education, Padova, Italy. https://eprints.soton.ac.uk/365505/

Abstract: In 1969 Seymour Papert developed the idea of Logo programming and Turtle robots. His thesis was that people learn according to the mental models available to them. He envisioned the potential of the computer to make students active learners, constructors of their own knowledge through the process of programming. The floor Turtles are devices the students can program and use to explore ideas and the world around them. The Logo approach was not simply writing code, it was about developing a student's thinking skills, problem solving and other sustainable learning traits. A 2006 seminal paper by Jeannette Wing prompted renewed interest in what is now called computational thinking. This paper examines this new perspective and how they relate to the theory and practical use of Turtle type educational robots.

Castledine, A.-R., & Chalmers, C. (2011). LEGO Robotics: An authentic problem solving tool? Design and Technology Education: An International Journal, 16(3). https://eric.ed.gov/?id=EJ960118

Abstract: With the current curriculum focus on correlating classroom problem solving lessons to real-world contexts, are LEGO robotics an effective problem solving tool? This present study was designed to investigate this question and to ascertain what problem solving strategies primary students engaged with when working with LEGO robotics and whether the students were able to effectively relate their problem solving strategies to real-world contexts. The qualitative study involved 23 Grade 6 students participating in robotics activities at a Brisbane primary school. The study included data collected from researcher observations of student problem solving discussions, collected software programs, and data from a student completed questionnaire. Results from the study indicated that the robotic activities assisted students to reflect on the problem solving decisions they made. The study also highlighted that the students were able to relate their problem solving strategies to real-world contexts. The study demonstrated that while LEGO robotics can be considered useful problem solving tools in the classroom, careful teacher scaffolding needs to be implemented in regards to correlating LEGO with authentic problem solving. Further research in regards to how teachers can best embed realworld contexts into effective robotics lessons is recommended.

Chalmers, C. (2018). Robotics and computational thinking in primary school. International Journal of Child-Computer Interaction, 17, 93-100. https://doi.org/10.1016/j.ijcci.2018.06.005

Abstract: This paper reports on a research study that examined how Australian primary school teachers integrated robotics and coding in their classrooms and the perceived impact this had on students' computational thinking skills. The study involved four primary school teachers, (Years 1–6) from four schools, introducing LEGO© WeDo© 2.0 robotics kits in their classrooms. The data collected from questionnaires, journal entries, and semi-structured interviews were analyzed using computational thinking and teaching frameworks. The results demonstrate that exploring with and using the robot kits, and

activities, helped the teachers build their confidence and knowledge to introduce young students to computational thinking. The study identified that teacher professional development (PD) needs to focus explicitly on how to teach developmentally appropriate robotics-based STEM activities that further promote computational concepts, practices, and perspectives.

Chen, G., Shen, J., Barth-Cohen, L., Jiang, S., Huang, X., & Eltoukhy, M. (2017). Assessing elementary students' computational thinking in everyday reasoning and robotics programming. Computers & Education, 109, 162-175. https://doi.org/10.1016/j.compedu.2017.03.001

Abstract: Based on a framework of computational thinking (CT) adapted from Computer Science Teacher Association's standards, an instrument was developed to assess fifth grade students' CT. The items were contextualized in two types of CT application (coding in robotics and reasoning of everyday events). The instrument was administered as a pre and post measure in an elementary school where a new humanoid robotics curriculum was adopted by their fifth grade. Results show that the instrument has good psychometric properties and has the potential to reveal student learning challenges and growth in terms of CT.

Chevalier, M., El-Hamamsy, L., Giang, C., Bruno, B., & Mondada, F. (2021). Teachers' perspective on fostering computational thinking through educational robotics. https://doi.org/10.1007/978-3-030-82544-7_17.

Abstract: With the introduction of educational robotics (ER) and computational thinking (CT) in classrooms, there is a rising need for operational models that help ensure that CT skills are adequately developed. One such model is the Creative Computational Problem Solving Model (CCPS) which can be employed to improve the design of ER learning activities. Following the first validation with students, the objective of the present study is to validate the model with teachers, specifically considering how they may employ the model in their own practices. The Utility, Usability and Acceptability framework was leveraged for the evaluation through a survey analysis with 334 teachers. Teachers found the CCPS model useful to foster transversal skills but could not recognise the impact of specific intervention methods on CT-related cognitive processes. Similarly, teachers perceived the model to be usable for activity design and intervention, although felt unsure about how to use it to assess student learning and adapt their teaching accordingly. Finally, the teachers accepted the model, as shown by their intent to replicate the activity in their classrooms, but were less willing to modify it or create their own activities, suggesting that they need time to appropriate the model and underlying tenets.

Dragone, M., O'Donoghue, R., Leonard, J. J., O'Hare, G., Duffy, B., Patrikalakis, A., & Leederkerken, J. (2005). Robot soccer anywhere: achieving persistent autonomous navigation, mapping, and object vision tracking in dynamic environments. Paper presented at the Opto-Ireland 2005: Photonic Engineering, Dublin, Ireland. https://doi.org/10.1117/12.608404

Abstract: The paper describes an ongoing effort to enable autonomous mobile robots to play soccer in unstructured, everyday environments. Unlike conventional robot soccer competitions that are usually held on purpose-built robot soccer "fields", in our work we seek to develop the capability for robots to demonstrate aspects of soccer-playing in more diverse environments, such as schools, hospitals, or shopping malls, with static obstacles (furniture) and dynamic natural obstacles (people). This problem of "Soccer Anywhere" presents numerous research challenges including: (1) Simultaneous Localization and Mapping (SLAM) in dynamic, unstructured environments, (2) software control architectures for decentralized, distributed control of mobile agents, (3) integration of vision-based object tracking with dynamic control, and (4) social interaction with human participants. In addition to the intrinsic research merit of these topics, we believe that this capability would prove useful for outreach activities, in demonstrating robotics technology to primary and secondary school students, to motivate them to pursue careers in science and engineering.

Eguchi, A. (2014, July). Robotics as a learning tool for educational transformation. In Proceeding of 4th international workshop teaching robotics, teaching with robotics & 5th international conference robotics in education Padova (Italy) (pp. 27-34).

Abstract: Educational robotics is a transformational tool for learning, computational thinking, coding, and engineering, all increasingly being viewed as critical ingredients of STEM learning in K-12 education. Although robotics in education for school age children has been in existence since the late 1900s and is becoming more popular among young students, it is not well integrated as a technological learning tool in regular school settings. The paper aims to convey the importance of integrating educational robotics as a technological learning tool into regular curriculum for K-12 students and explain how it helps students prepare for the future.

El-Hamamsy, L., Papaspyros, V., Kangur, T., Mathex, L., Giang, C., Skweres, M., Bruno, B., and Mondada, F. (2021). Exploring a Handwriting Programming Language for Educational Robots. https://doi.org/10.1007/978-3-030-82544-7_25

Abstract: Recently, introducing computer science and educational robots in compulsory education has received increasing attention. However, the use of screens in classrooms is often met with resistance, especially in primary school. To address this issue, this study presents the development of a handwriting-based programming language for educational robots. Aiming to align better with existing classroom practices, it allows students to program a robot by drawing symbols with ordinary pens and paper. Regular smartphones are leveraged to process the hand-drawn instructions using computer vision and machine learning algorithms, and send the commands to the robot for execution. To align with the local computer science curriculum, an appropriate playground and scaffolded learning tasks were designed. The system was evaluated in a preliminary test with eight teachers, developers and educational researchers. While the participants pointed out that some technical aspects could be improved, they also acknowledged the potential of the approach to make computer science education in primary school more accessible.

El-Hamamsy, L., Bruno, B., Chessel-Lazzarotto, F., Chevalier, M., Roy, D., Zufferey, J. D., & Mondada, F. (2021). The symbiotic relationship between educational robotics and computer science in formal education. Education and Information Technologies, 1-31. https://doi.org/10.1007/s10639-021-10494-3

Abstract: Educational Robotics (ER) has the potential to provide significant benefits to education, provided an increase in outreach by transitioning from the extra-curricular initiatives in which ER has thrived to formal education. As Computer Science (CS) Education is undergoing curricular reforms worldwide, the present study addresses the case of a Digital Education reform that included ER as a means to teach core CS concepts. Approximately 350 teachers from the first four grades of primary school participated in a mandatory two-year continuing professional development (CPD) program. The first year of the program was dedicated to CS and introduced teachers to CS Unplugged (CSU) and Robotics Unplugged (RU) activities. As such, we analyse the interplay between these activities and focus on teachers' voluntary adoption of the proposed content in classrooms. This is complemented by an analysis of their perception and recommendation of ER. The findings highlight three main points. Firstly, ER benefits from the integration in the CS CPD, as this provides the necessary traction to introduce ER into teacher practices (the teachers freely devoted 2275 h to ER activities in their classrooms, over two years). Secondly, the presence of ER activities in the CS-CPD allows a higher proportion of teachers to adopt the CS content, as there are teachers that favour one type of activity over the other. Finally, the globally positive perception of ER registered in this study is relevant for two reasons: teachers were not voluntarily participating in the CPD, and results did not differ between pioneers and novices.

Fridin, M. (2014). Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education. Computers & Education, 70, 53-64. https://doi.org/10.1016/j.compedu.2013.07.043

Abstract: Kindergarten Social Assistive Robotics (KindSAR) is a novel technology that offers kindergarten staff an innovative tool for achieving educational aims through social interaction. Children in a preschool setting have previously been shown to benefit from playing educational games with the KindSAR robot. The experiment presented here was designed to examine how KindSAR can be used to engage preschool children in constructive learning. The basic principle of constructivist education is that learning occurs when the learner is actively involved in a process of knowledge construction. In this study, storytelling was used as a paradigm of a constructive educational activity. An interactive robot served as a teacher assistant by telling prerecorded stories to small groups of children while incorporating song and motor activities in the process. Our results show that the children enjoyed interacting with the robot and accepted its authority. This study demonstrates the feasibility and expected benefits of incorporating KindSAR in preschool education.

Jaipal-Jamani, K., & Angeli, C. (2017). Effect of robotics on elementary preservice teachers' self-efficacy, science learning, and computational thinking. Journal of Science Education and Technology, 26(2), 175-192. https://doi.org/10.1007/s10956-016-9663-z

Abstract: The current impetus for increasing STEM in K-12 education calls for an examination of how preservice teachers are being prepared to teach STEM. This paper reports on a study that examined elementary preservice teachers' (n =21) self-efficacy, understanding of science concepts, and computational thinking as they engaged with robotics in a science methods course. Data collection methods included pretests and posttests on science content, prequestionnaires and postquestionnaires for interest and self-efficacy, and four programming assignments. Statistical results showed that preservice teachers' interest and self-efficacy with robotics increased. There was a statistically significant difference between preknowledge and postknowledge scores, and preservice teachers did show gains in learning how to write algorithms and debug programs over repeated programming tasks. The findings suggest that the robotics activity was an effective instructional strategy to enhance interest in robotics, increase self-efficacy to teach with robotics, develop understandings of science concepts, and promote the development of computational thinking skills. Study findings contribute quantitative evidence to the STEM literature on how robotics develops preservice teachers' self-efficacy, science knowledge, and computational thinking skills in higher education science classroom contexts.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. Early Childhood Education Journal, 41(4), 245-255. https://doi.org/10.1007/s10643-012-0554-5

Abstract: This paper examines the impact of programming robots on sequencing ability during a 1-week intensive robotics workshop at an early childhood STEM magnet school in the Harlem area of New York City. Children participated in computer programming activities using a developmentally appropriate tangible programming language CHERP, specifically designed to program a robot's behaviors. The study assessed 27 participants' sequencing skills before and after the programming and robotics curricular intervention using a picture-story sequencing task and compared those skills to a control group. Pre-test and post-test scores were compared using a paired sample t test. The group of children who participated in the 1-week robotics and programming workshop experienced significant increases in post-test compared to pre-test sequencing scores.

Kyriazopoulos, I., Koutromanos, G., Voudouri, A., & Galani, A. (2022). Educational Robotics in Primary Education: A Systematic Literature Review. Research Anthology on Computational Thinking, Programming, and Robotics in the Classroom, 782-806. https://doi.org/10.4018/978-1-6684-2411-7.ch034

Abstract: The purpose of this chapter is to review the literature referring to the utilization of educational robotics (ER) in primary education. Keyword-based search in particular bibliographic databases returned 21 journal papers for the eight-year period of 2012-2019. The factors that were studied in each of them are as follows: learning environment, area of knowledge/course subjects, pedagogical framework, learning activities, robotic equipment, research methodology, and main findings. The outcomes, among other things, showed that the majority of ER activities took place in a formal learning environment and that ER is appropriate for teaching subjects of STEM education. Though many researches took into account various learning theories that support collaboration, problem-solving, discovery, and construction of knowledge, there were some researches that lacked any pedagogical framework. In spite of the positive cognitive and affective outcomes of ER in learning, there are aspects that require further investigation.

Kitano, H., Asada, M., Kuniyoshi, Y., Noda, I., & Osawa, E. (1995). Robocup: The robot world cup initiative. https://doi.org/10.1145/267658.267738

Abstract: The Robot World Cup Initiative (RoboCup) is an attempt to foster AI and intelligent robotics research by providing a standard problem where wide range of technologies can be integrated and examined. The first RoboCup competition will be held at IJCAI-97, Nagoya. In order for a robot team to actually perform a soccer game, various technologies must be incorporated including: design principles of autonomous agents, multi-agent collaboration, strategy acquisition, real-time reasoning, robotics, and sensor-fusion. Unlike AAAI robot competition, which is tuned for a single heavy-duty slow-moving robot, RoboCup is a task for a team of multiple fast-moving robots under a dynamic environment. Although RoboCup's final target is a world cup with real robots, RoboCup offers a software platform for research on the software aspects of RoboCup. This paper describes technical challenges involved in RoboCup, rules, and simulation environment.

Lemaignan, S., Edmunds, C., Senft, E., & Belpaeme, T. (2017). The free-play sandbox: a methodology for the evaluation of social robotics and a dataset of social interactions. https://doi.org/10.48550/arXiv.1712.02421

Abstract: Evaluating human-robot social interactions in a rigorous manner is notoriously difficult: studies are either conducted in labs with constrained protocols to allow for robust measurements and a degree of replicability, but at the cost of ecological validity; or in the wild, which leads to superior experimental realism, but often with limited replicability and at the expense of rigorous interaction metrics. We introduce a novel interaction paradigm, designed to elicit rich and varied social interactions while having desirable scientific properties (replicability, clear metrics, possibility of either autonomous or Wizard-of-Oz robot behaviours). This paradigm focuses on child-robot interactions, and builds on a sandboxed free-play environment. We present the rationale and design of the interaction paradigm, its methodological and technical aspects (including the open-source implementation of the software platform), as well as two large open datasets acquired with this paradigm, and meant to act as experimental baselines for future research.

Papert, S. (1980). Mindstorms, children, computers and powerful ideas. New York: Basic Books, inc., Publishers.

Abstract: This book is an exercise in an applied genetic epistemology expanded beyond Piaget's cognitive emphasis to include a concern with the affective. It develops a new perspective for education research focused on creating the conditions under which intellectual models will take root. For the last two decades this is what I have been trying to do. And in doing so I find myself frequently reminded of several aspects of my encounter with the differential gear. First, I remember that no one told me to learn about differential gears. Second, I remember that there was feeling, love, as well as understanding in my relationship with gears. Third, I remember that my first encounter with them was in my second year. If any "scientific" educational psychologist had tried to "measure" the effects of this encounter, he would probably have failed. It had profound consequences but, I conjecture, only very many years later. A "pre- and post-" test at age two would have missed them. Piaget's work gave me a new framework for looking at the gears of my childhood. The gear can be used to illustrate many powerful "advanced" mathematical ideas, such as groups or relative motion. But it does more than this. As well as connecting with the formal knowledge of mathematics, it also connects with the "body knowledge," the sensorimotor schemata of a child. You can be the gear, you can understand how it turns by projecting yourself into its place and turning with it. It is this double relationship---both abstract and sensory---that gives the gear the power to carry powerful mathematics into

the mind. In a terminology I shall develop in later chapters, the gear acts here as a transitional object. A modern-day Montessori might propose, if convinced by my story, to create a gear set for children. Thus every child might have the experience I had. But to hope for this would be to miss the essence of the story. I fell in love with the gears. This is something that cannot be reduced to purely "cognitive" terms. Something very personal happened, and one cannot assume that it would be repeated for other children in exactly the same form. My thesis could be summarized as: What the gears cannot do the computer might. The computer is the Proteus of machines. Its essence is its universality, its power to simulate. Because it can take on a thousand forms and can serve a thousand functions, it can appeal to a thousand tastes. This book is the result of my own attempts over the past decade to turn computers into instruments flexible enough so that many children can each create for themselves something like what the gears were for me.

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. International Journal of Technology and Design Education, 26(1), 3-20. https://doi.org/10.1007/s10798-015-9304-5

Abstract: In recent years there has been an increasing focus on the missing ''T'' of technology and ''E'' of engineering in early childhood STEM (science, technology, engineering, mathematics) curricula. Robotics offers a playful and tangible way for children to engage with both T and E concepts during their foundational early childhood years. This study looks at N = 60 children in pre-kindergarten through second grade who completed an 8-week robotics curriculum in their classrooms using the KIWI robotics kit combined with a tangible programming language. Children were assessed on their knowledge of foundational robotics and programming concepts upon completion of the curriculum. Results show that beginning in pre-kindergarten, children were able to master basic robotics and programming skills, while the older children were able to master increasingly complex concepts using the same robotics kit in the same amount of time. Implications for developmentally appropriate design of technology, as well as structure and pace of robotics curricula for young children are addressed.

Sullivan, A., Kazakoff, E. R., & Bers, M. U. (2013). The wheels on the bot go round and round: Robotics curriculum in pre-kindergarten. Journal of Information Technology Education, 12, 203-219. https://www.learntechlib.org/p/174802/

Abstract: This paper qualitatively examines the implementation of an intensive weeklong robotics curriculum in three Pre-Kindergarten classrooms (N=37) at an early childhood STEM (science, technology, engineering, and math) focused magnet school in the Harlem area of New York City. Children at the school spent one week participating in computer programming activities using a developmentally appropriate tangible programming language called CHERP, which is specifically designed to program a robot's behaviors. The children used CHERP to program "Robot Recyclers" that they constructed using parts from LEGO® Education WeDo™ Robotics Construction Sets. The Robot Recyclers were designed to help carry, push, and/or sort recyclable materials found in the classroom. Researchers were participant-observers in the robotics lessons over the course of curriculum implementation. Each lesson was taught by the researchers, with classroom teachers present in order to facilitate classroom management and assist with small group work. A combination of interviews, video, photographs, and classroom observations were used to document the students' experiences. Classroom teachers were also interviewed and asked to complete anonymous pre and post surveys. Results from this study provide preliminary evidence that Pre- Kindergarten children can design, build, and program a robot after just one week of concentrated robotics work. Additionally, results indicate that teachers were able to successfully integrate robotics work into their classrooms that included foundational math and literacy concepts while also engaging children in the arts. However, this study also highlights the difficulties and challenges that must be considered before implementing a robotics curriculum into a Pre- Kindergarten classroom, including opportunities for one-to-one adult assistance during building and programming activities.

Van Lith, P. (2007). Teaching robotics in primary and secondary schools. Proceedings, ComLab.

Abstract: Teaching robotics to young children is a very good introduction into Science and Technology. Not only do they learn to design and construct a robot, they also get a more complete idea what is required for an organism to act in the real world. Educational material has been developed to show children how to build and program small robots and a competition is organized where they can test their skills in games like Dance, Rescue and Soccer. Experiences with this approach with five Dutch and some international schools are described and suggestions are done for further work along these lines.

Virnes, M. (2014). Four seasons of educational robotics: substansive theory on the encounters between educational robotics and children in the dimensions of access and ownership: Itä-Suomen yliopisto. https://erepo.uef.fi/handle/123456789/14620

Abstract: Various kinds of educational robotics are available for use in education, but their mere availability in the classroom is not reason enough to use them as a learning tool. The suitability of educational robotics as a learning tool depends on how they Þt into the children's worlds, teachers' conceptions regarding learning and teaching and the educational setting as a whole. This study focused on the children's actions with educational robotics and investigated the types of encounters between educational robotics and children. The study further investigated the type of properties of educational robotics which contributed to children's action with it. The study interpreted educational robotics through the technological properties of robotics using a metaphor drawn from the concepts of theoretical linguistics. Educational robotics included the properties of 1) phonology that represented the appearance and "look" of the robot, 2) morphology that represented the structure and hardware as the body of the robot, 3) syntax that represented the functionality and software as the behavior of the robot and 4) semantics as the meaning and mind of the robot. The properties were linked to four temporal stages of work namely orientation, structure manipulation, function manipulation and playful action with the robot. The conducting of this research was a long-term process which took place in real life environments. The data collection, which took place in different research environments, took place from 2006 to 2008, and the phased analysis process by the GT method occurred between 2007 and 2011. This included 34 hours of video data and the categorizing of 1 769 video clips. However, constructing the substantive theory regarding the encounters between educational robotics and children was not an intensive process all the time as it included gaps (of sometimes months) during which ideas were developed beyond my other research and project activities. Analysis of the encounters was based on video data and a Grounded Theory (GT) methodology that examined the topic through the use of three different kinds of educational robotics, with three different groups of children in three different educational environments. The robotics kit, LEGO Mindstorms NXT, was used by a group of Þfth and sixth grade children in elementary special education. The construction kit, Topobo, was used by a group of children aged between four and Þve in kindergarten. The social robot, RUBI, was used by one- and two year-old children in early childhood education. Children's action with educational robotics and the responses of educational robotics to the children's actions showed that the encounters between educational robotics and children were two dimensional. Encounters comprised of elements that related to the promoting and preventing properties of educational robotics, children's action as recipients and producers, and time. Regarding the temporal dimension, encounters occurred during orientation, structure manipulation, function manipulation and playful action which all included elements of educational robotics that either promoted or prevented children's action, and the role of children as a recipient or a producer of educational robotics. Based on these dimensions encounters emerged as: wild, tame, slave and unapproachable which I metaphorically refer to as seasons. None of the seasons presented as a stable position but they changed during the childrenÕs working. They thus speciÞcally relate to the processes and the properties of educational robotics. An explanatory factor for the movement between seasons was the constant interaction between access and ownership. Access represented the technological and ownership the experimental features that emerged through children's action with educational robotics. Access and ownership appeared on the dimensions of achieved -

lost and limited - prospective. The constant interaction between access and ownership determined the course of children's action with educational robotics. Typically substantive theories can be used for either deÞning or constructing something. The unique feature of this substantive theory on the encounters between educational robotics and children is that it can be used for both deÞning and constructing educational robotics and children's action with it. The substantive theory can be used for proÞling educational robotics and in the development and evaluation of educational robotics as tools for education. If children are, for instance, expected to get through exercises, then only a limited number of technical properties that direct their action are available to them. If educational technology is expected to guide childrenÕs action, then technologies with unexpected functions, which emerge during the work with technology, should be selected. The study conceptualized childrenÕs action with educational robotics and deÞned the core of it via technological access that related to accessibility, and experienced ownership which, in turn, emerged via childrenÕs actions and related back to their commitment to work with educational robotics. Applicability of the substantive theory in the terms of access and ownership could be tested and further developed with other learning artifacts in future studies.

Augmented reality and educational robotics

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review, 20, 1-11. https://doi.org/10.1016/j.edurev.2016.11.002

Abstract: This study presents a systematic review of the literature on augmented reality (AR) used in educational settings. We consider factors such as publication year, learner type (e.g., K-12, higher education, and adult), technologies in AR, and the advantages and challenges of using AR in educational settings. The full range of SSCI journals was surveyed and a total of 68 research articles were selected for analysis. The findings reveal an increase in the number of AR studies during the last four years. The most reported advantage of AR is that it promotes enhanced learning achievement. Some noted challenges imposed by AR are usability issues and frequent technical problems. We found several other challenges and numerous advantages of AR usage, which are discussed in detail. In addition, current gaps in AR research and needs in the field are identified, and suggestions are offered for future research.

Cheli, M., Sinapov, J., Danahy, E. E., & Rogers, C. (2018). Towards an augmented reality framework for k-12 robotics education. Paper presented at the Proceedings of the 1st International Workshop on Virtual, Augmented, and Mixed Reality for HRI (VAM-HRI). https://doi.org/10.3390/info13070336

Abstract: In this paper, we investigate how augmented reality (AR) can help students "see the unseen" when learning to operate and program robots. We describe our prototype AR system for robotics education, along with a qualitative pilot study and its preliminary results. The objectives of the pilot study were 1) demonstrate that AR can be successfully deployed in a middle school robotics education setting; and, 2) identify and document how AR might (or might not) catalyze students' ability to understand their robot's behavior and adapt their code accordingly. Overall, the pilot study indicated that AR can help students debug their robot more easily, catalyzing discussions around sensor readings that led to code fixes and a reduction in the "barrier to entry" for some students. At the same time, we also gained some insight into usability issues and current challenges of using AR in the classroom.

Chen, C. H., Yang, C. K., Huang, K., & Yao, K. C. (2020). Augmented reality and competition in robotics education: Effects on 21st century competencies, group collaboration and learning motivation. Journal of Computer Assisted Learning, 36(6), 1052-1062. https://publons.com/publon/10.1111/jcal.12469

Abstract: Robotics education has received an increasing attention in recent years as a means to build students' motivation, team collaboration skills, and other valuable 21st century competencies. Yet there is a

lack of experimental studies to investigate and identify strategies to facilitate robotics education. This study adopted a 2 × 2 quasiexperimental design to investigate two strategies: the incorporation of augmented reality (AR) and the introduction of competition in robotics activities. Students' robotics task performance, team collaboration processes, 21st century learning competencies and learning motivation were measured as dependent variables. The results indicated that AR significantly improved students' motivation, team processes, and 21st century competencies. Moreover, the effects of AR were more pronounced with the competition groups. Implications are drawn to provide guidelines on the use of AR and competition in robotics education.

Magnenat, S., Ben-Ari, M., Klinger, S., & Sumner, R. W. (2015). Enhancing robot programming with visual feedback and augmented reality. Paper presented at the Proceedings of the 2015 ACM conference on innovation and technology in computer science education. https://doi.org/10.1145/2729094.2742585

Abstract: In our previous research, we showed that students using the educational robot Thymio and its visual programming environment were able to learn the important computer-science concept of event-handling. This paper extends that work by integrating augmented reality (ar) into the activities. Students used a tablet that displays in real time the event executed on the robot. The event is overlaid on the tablet over the image from a camera, which shows the location of the robot when the event was executed. In addition, visual feedback (fb) was implemented in the software. We developed a novel video questionnaire to investigate the performance of the students on robotics tasks. Data were collected comparing four groups: ar+fb, ar+non-fb, non-ar+fb, non-ar+non-fb. The results showed that students receiving feedback made significantly fewer errors on the tasks. Those using ar made fewer errors, but this improvement was not significant, although their performance improved. Technical problems with the ar hardware and software showed where improvements are needed.

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education, 123, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Abstract: This study presents a systematic review of the literature on the use of augmented reality technology to support science, technology, engineering and mathematics (STEM) learning. It synthesizes a set of 28 publications from 2010 to 2017. A qualitative content analysis is used to investigate the general characteristics of augmented reality applications in STEM education, the instructional strategies and techniques deployed in the studies reviewed, and the evaluation approaches followed in the interventions. This review found that most augmented reality applications for STEM learning offered exploration or simulation activities. The applications reviewed offered a number of similar design features based on digital knowledge discovery mechanisms to consume information through the interaction with digital elements. However, few studies provided students with assistance in carrying out learning activities. Most of the studies reviewed evaluated the effects of augmented reality technology in fostering students' conceptual understanding, followed by those that investigated affective learning outcomes. A number of suggestions for future research arose from this review. Researchers need to design features that allow students to acquire basic competences related with STEM disciplines, and future applications need to include metacognitive scaffolding and experimental support for inquiry-based learning activities. Finally, it would be useful to explore how augmented reality learning activities can be part of blended instructional strategies such as the flipped classroom.

Sırakaya, M., & Sırakaya, D. A. (2020). Augmented reality in STEM education: A systematic review. Interactive Learning Environments, 0(0), 1–14. https://doi.org/10.1080/10494820.2020.1722713

Abstract: This study aimed to systematically investigate the studies in which augmented reality (AR) was used to support Science, Technology, Engineering and Mathematic (STEM) education. In this framework, the general status of AR in STEM education was presented and its advantages and challenges were identified. The study investigated 42 articles published in journals indexed in SSCI database and deemed suitable for

the purposes of this research. The obtained data were analyzed by two researchers using content analysis method. It was found that the studies in this field have become more significant and intensive in recent years and that these studies were generally carried out at schools (class, laboratory etc.) using marker-based AR applications. It was concluded that mostly K-12 students were used as samples and quantitative methods were selected. The advantages of AR-STEM studies were summarized and examined in detail in 4 sub-categories such as "contribution to learner, educational outcomes, interaction and other advantages". On the other hand, some challenges were identified such as teacher resistance and technical problems.

WEKIT

Limbu B., Vovk A., Jarodzka H., Klemke R., Wild F., Specht M. (2019) WEKIT.One: A Sensor-Based Augmented Reality System for Experience Capture and Re-enactment. In: Scheffel M., Broisin J., Pammer-Schindler V., Ioannou A., Schneider J. (eds) Transforming Learning with Meaningful Technologies. EC-TEL 2019. Lecture Notes in Computer Science, vol 11722. Springer, Cham. https://doi.org/10.1007/978-3-030-29736-7_12

Abstract: Body-worn sensors can be used to capture, analyze, and replay human performance for training purposes. The key challenge to any such approach is to establish validity that the captured expert experience is actually suitable for training. In this paper, to evaluate this, we apply a questionnaire-based expert assessment and a complementary trainee knowledge assessment to study the approach adopted and the models generated with the WEKIT solution, a hardware and software application that complements Augmented Reality glasses with wearable sensor-actuator experience. This solution was developed using the ID4AR framework which as also developed within the WEKIT project. ID4AR framework is a domain agnostic framework which can be used to design augmented reality and sensor based applications for training. The study presented triangulates validity across three independent test-beds in the professional domains of aircraft maintenance, medical imaging, and astronaut training, with 61 experts completing the expert survey and 337 students completing the trainee knowledge test. Results show that the captured expert models were positively received in all three domains and the identified level of acceptance suggests that the solution is capable of capturing models for training purposes at large.

Limbu, B., Jarodzka, H., Klemke, R., Kreijns, K., and Specht, M. (2018). Using sensors and augmented reality to train apprentices using recorded expert performance: A systematic literature review. Educational Research Review. https://doi.org/10.1016/j.edurev.2018.07.001

Abstract: Experts are imperative for training apprentices, but learning from experts is difficult. Experts often struggle to explicate and/or verbalize their knowledge or simply overlook important details due to internalization of their skills, which may make it more difficult for apprentices to learn from experts. In addition, the shortage of experts to support apprentices in one-to-one settings during trainings limits the development of apprentices. In this review, we investigate how augmented reality and sensor technology can be used to capture expert performance in such a way that the captured performance can be used to train apprentices without increasing the workload on experts. To this end, we have analysed 78 studies that have implemented augmented reality and sensor technology for training purposes. We explored how sensors have been used to capture expert performance with the intention of supporting apprentice training. Furthermore, we classified the instructional methods used by the studies according to the 4C/ID framework to understand how augmented reality and sensor technology have been used to support training. The results of this review show that augmented reality and sensor technology have the potential to capture expert performance for training purposes. The results also outline a methodological approach to how sensors and augmented reality learning environments can be designed for training using recorded expert performance.

Limbu, B. H., Jarodzka, H., Klemke, R., Wild, F., & Specht, M. (2018). From AR to Expertise: A User Study of an Augmented Reality Training to Support Expertise Development. Journal of Universal Computer Science, 24(2), 108–128. https://doi.org/10.3217/jucs-024-02-0108

Abstract: Augmented reality and sensor technologies have been analysed extensively in several domains including education and training. Although, varieties of use cases and applications exist, these studies were conducted in controlled laboratory environments. This paper reports on the first user study of augmented reality prototype developed to support students to learn from trainers in professional domains using augmented reality and sensors. The prototype records the performance of trainers in the first phase to support students by making it available during practice in the second phase. The performance data is made available to both the students and trainers in the third phase for reflection. A total of 142 participants which included trainers and students from three professional domains, namely 1) aircraft maintenance 2) medical imaging and 3) astronaut training, evaluated the prototype. The trainers used the prototype to record their performance while the students used the prototype to learn from the recorded performance. Participants from the three professional domains evaluated the usability of the prototype by means of a questionnaire. Randomly selected participants were also interviewed to collect their opinions and suggestion for further usability improvement. Furthermore, they also evaluated the implementation of the instructional design methods, which were identified prior in a literature review, with a brief questionnaire. The questionnaire was designed to measure the acceptance of the implementation of instructional design methods and to evaluate its adherence to the authors definition. The results of this study show that the usability of the prototype is below expected standard acceptable level. The results of the questionnaire on the implementation of the instructional design methods varied show above average acceptance levels by both the trainers and the students in the three professional domains. To conclude, potential to be used in different domains to support expertise development.

yOUplay/ARLearn

Ternier, S., Storm, J., & Rusman, E. (2019). Spelenderwijs mobiel leren in de bieb. OnderwijsInnovatie, 21(4). https://onderwijsinnovatie.ou.nl/oi-december19/spelenderwijs-mobiel-leren-in-de-bieb/

Abstract: Leren in context, hoe doe je dat? De Open Universiteit heeft hiervoorhet mobiele gameplatform yOUplay ontwikkeld. Hiermee kunnen docenten educatieve games, zoals excursies en speurtochten, maken.

Rusman, E., Ternier, S., & Specht, M. (2018). Early second language learning and adult involvement in a real-world context: Design and evaluation of the “ELENA Goes Shopping” mobile game. Journal of Educational Technology & Society, 21(3), 90-103. https://www.jstor.org/stable/26458510

Abstract: This article describes the theory-informed design of the “ELENA goes shopping” mobile game and reports on the evaluation of its effectiveness through a design research approach. The game aimed to foster young children’s (aged 4-8) interest in a neighboring (geographically proximate) language and to familiarize them with its sounds, pronunciation and vocabulary. Additionally, it strived to involve adults in young children’s language learning activities. To achieve these objectives, the game connects playful learning activities to an accessible, familiar real-world setting (supermarket). The game was developed and evaluated through three iterative design research cycles. First, interdisciplinary experts (n = 8) evaluated the game by means of a questionnaire and focus group discussion. In the second and third cycles, the game’s feasibility and usability was evaluated via questionnaires, semi-structured interviews and a language learning outcome test. Results revealed that children (34) and adults (14) alike found the game useful for familiarization with and motivation to learn another language, and feasible to involve adults. Nevertheless, children could play the game autonomously with minimum adult assistance. A dependent t-test on a repeated vocabulary test revealed adults’ and children’s perception that the game helped them familiarize with another language to be consistent with test results. A limitation to this study is that the test was administered immediately after game playing. Future studies could explore effects of “real-world” contextualization on early second language learning and vocabulary recall by measuring after longer time spans and compare results versus a non-contextualized game.

Ternier, S., Klemke, R., Kalz, M., Van Ulzen, P., & Specht, M. (2012). ARLearn: augmented reality meets augmented virtuality [Special issue]. Journal of Universal Computer Science - Technology for learning across physical and virtual spaces, 18(15), 2143-2164. https://doi.org/10.3217/jucs-018-15-2143

Abstract: This article deals with educational opportunities for mixed reality games and related scenarios for learning. It discusses several issues and educational challenges to be tackled when linking augmented reality and augmented virtuality. Second, the paper describes the architecture of the ARLearn system which offers highly flexible support for different educational settings. Three prototypical use cases implemented based on the underlying ARLearn framework are discussed, which are a field trip system, an augmented Google StreetView client called StreetLearn, and a real time crisis intervention game. ARLearn combines real time notification and mixed reality games across Mobile Augmented Reality and Virtual Reality and the authors aim to use the underlying (open source) framework for further case studies and mixed reality applications for learning support.

Conceptual

Emmerich, F., Klemke, R., & Hummes, T. (2017). Design patterns for Augmented Reality learning games. In J. Dias, P. Santos, & R. Veltkamp (Eds.), Games and Learning Alliance. GALA 2017. Lecture Notes in Computer Science, vol 10653 (pp. 161-172). Springer, Cham. https://doi.org/10.1007/978-3-319-71940-5_15

Abstract: Augmented Reality (AR) is expected to receive a major uptake with the recent availability of high quality wearable AR devices such as Microsoft's Hololens. However, the design of interaction with AR applications and games is still a field of experimentation and upcoming innovations in sensor technology provide new ways. With this paper, we aim to provide a step towards the structured use of design patterns for sensor-based AR games, which can also inform general application development in the field of AR.

Wild, F., Klemke, R., Lefrere, P., Fominykh, M., & Kuula, T. (2017). Technology acceptance of Augmented Reality and Wearable Technologies. In International Conference on Immersive Learning (pp. 129-141). Springer, Cham. https://doi.org/10.1007/978-3-319-60633-0_11

Abstract: Augmented Reality and Wearables are the recent media and computing technologies, similar, but different from established technologies, even mobile computing and virtual reality. Numerous proposals for measuring technology acceptance exist, but have not been applied, nor fine-tuned to such new technology so far. Within this contribution, we enhance these existing instruments with the special needs required for measuring technology acceptance of Augmented Reality and Wearable Technologies and we validate the new instrument with participants from three pilot areas in industry, namely aviation, medicine, and space. Findings of such baseline indicate that respondents in these pilot areas generally enjoy and look forward to using these technologies, for being intuitive and easy to learn to use. The respondents currently do not receive much support, but like working with them without feeling addicted. The technologies are still seen as forerunner tools, with some fear of problems of integration with existing systems or vendor-lock. Privacy and security aspects surprisingly seem not to matter, possibly overshadowed by expected productivity increase, increase in precision, and better feedback on task completion. More participants have experience with AR than not, but only few on a regular basis.

Antonaci, A., Klemke, R., & Specht, M. (2015). Towards design patterns for augmented reality serious games. In International Conference on Mobile and Contextual Learning (pp. 273-282). Springer, Cham. https://doi.org/10.1007/978-3-319-25684-9_20

Abstract: For professional workers today, keeping up with knowledge and the continuous technology progress is challenging. Increased innovation speed and dynamic work situations shorten preparation times for new tasks significantly. Traditional professional training approaches preparing employees for new tasks are becoming inappropriate. Thus new educational means are needed. These would help employees get acquainted with new situations faster and more efficiently. According to learning theories such as action learning and situated learning, which embed the learning process in the application context and challenge the learner to be actively involved help to improve the learning process. These theories are the basis for mobile learning and serious games. From research in Serious Games we know that games have the potential to actively involve learners and to immerse them in a learning situation and increase their engagement. With Augmented Reality (AR) and wearable devices a new generation of tools and applications becomes available, which inherently are mobile, contextualized and personalized. First successful application scenarios show the potential of these new technologies for education and training. While the application of game-design patterns to learning processes help to systematically design learning games supporting specific learning outcomes, an empirically tested, systematic approach towards the design of AR-based learning solutions is still missing. Based on the state of the art in AR research and in applying design patterns for serious games, we consequently propose a research methodology to apply game design patterns to augmented reality-based learning games for the training of professionals in dynamic situations

Specht, M., Ternier, S., & Greller, W. (2011). Dimensions of Mobile Augmented Reality for Learning: A First Inventory. Journal of the Research for Educational Technology (RCET), 7(1), 117-127. https://rcetj.org/index.php/rcetj/article/view/151

Abstract: This article discusses technological developments and applications of mobile augmented reality (AR) and their application in learning. Augmented reality interaction design patterns are introduced and educational patterns for supporting certain learning objectives with AR approaches are discussed. The article then identifies several dimensions of a user context identified with sensors contained in mobile devices and used for the contextualization of learning experiences. Finally, an AR game concept, "Locatory", is presented that combines a game logic with collaborative game play and personalized mobile augmented reality visualization.

Programming robots in Education

Ahmed, I., Lubold, N., & Walker, E. (2018). ROBIN: using a programmable robot to provide feedback and encouragement on programming tasks. Paper presented at the International Conference on Artificial Intelligence in Education. https://doi.org/10.1007/978-3-319-93846-2_2

Abstract: LEGO Mindstorms robots are a popular educational tool for teaching programming concepts to young learners. However, learners working with these robots often lack sufficient feedback on their programs, which makes it difficult for them to reflect on domain concepts and may decrease their motivation. We see an opportunity to introduce feedback into LEGO Mindstorms programming environments by having the robot itself deliver feedback, leveraging research on learning companions to transform the programmable robot into a social actor. Our robot, ROBIN, provides learners with automated reflection prompts based on a domain model and the student's current program, along with social encouragement based on a theory of instructional immediacy. We hypothesize that by having the robot itself provide cognitive and social feedback, students will both reflect more on their misconceptions and persist more with the activity. This paper describes the design and implementation of ROBIN and discusses how this approach can benefit students.

Caci, B., Chiazzese, G., & D'Amico, A. (2013). Robotic and virtual world programming labs to stimulate reasoning and visual-spatial abilities. Procedia-Social and Behavioral Sciences, 93, 1493-1497. https://doi.org/10.1016/j.sbspro.2013.10.070

Abstract: The individuals' cognitive skills, academic performance and their relationship with programming of robots or virtual learning environment is a topic of particular interest in the area of human-robot interaction. This paper presents a pilot study performed on a group of 36 lower secondary school students involved in a 32-hours laboratory based on the combination of LEGO Mindstorm NXT and Microsoft Kodu Game Lab (KGL)

and aimed at programming first a robot and further a more complete virtual world based on a narrative-designed scenario. The findings of the research will be discussed in the light of the effectiveness of using robotics and virtual world programming as a meaningful and playful learning environment for improving cognition in children.

Caci, B., D'Amico, A., & Chiazzese, G. (2013). Robotics and Virtual Worlds: An experiential learning lab. In Biologically Inspired Cognitive Architectures 2012 (pp. 83-87): Springer. https://doi.org/10.1007/978-3-642-34274-5_19

Abstract: Aim of the study was to investigate the cognitive processes involved and stimulated by educational robotics (LEGO® robots and Kodu Game Lab) in lower secondary school students. Results showed that LEGO® and KGL artifacts involve specific cognitive and academic skills. In particular the use of LEGO® is related to deductive reasoning, speed of processing visual targets, reading comprehension and geometrical problem solving; the use of KGL is related to visual-spatial working memory, updating skills and reading comprehension. Both technologies, moreover, are effective in the improvement of visualspatial working memory. Implications for Human-Robot Interaction and BICA challenge are discussed.

Demo, G. B. (2009). Robot programming integrated in a junior high school curriculum. Paper presented at the Proc. Informatics Education Europe IV Conf., Freiburg, Nov.

Abstract: Schoolchildren and students have opportunities of actively and concretely manipulate concepts from traditional disciplines when designing, writing and verifying programs for controlling the motion of mini-robots. Thus, educational robotics may naturally allow integrating robot programming activities into traditional subjects of standard curricula instead of adding some form of ICT as a (software) tool for practicing topics from one subject or as one more separate subject. Such an integration, though considered a most fruitful educational usage of computers already in Papert's researches of the 70's, is nowadays rarely present in the proposals for introducing computing technologies in schools. Here we present in-progress activities with pupils in the age range 11-14 using RCX and NXT Lego bricks, with a Logo-like programming language supplemented by a development environment specifically implemented for young students. We describe how robot programming has given pupils the chance of manipulating direct and inverse proportions and the concepts of speed and friction in activities coordinated with presentations of these topics in pupils school curriculum. We also comment on the opportunities, while programming mini-robots, of discussing with pupils for comparing solutions to given problems and identifying specific and more general ones. A future direction of our work, toward motivating elementary algebra, arises from these discussions.

Fanchamps, N., Slangen, L., Hennissen, P., & Specht, M. (2019). The Influence of SRA Programming on Algorithmic Thinking and Self-Efficacy Using Lego Robotics in Two Types of Instruction. International Journal of Technology and Design Education, 1-20. https://doi.org/10.1007/s10798-019-09559-9

Abstract: This study investigates the development of algorithmic thinking as a part of computational thinking skills and self-efficacy of primary school pupils using programmable robots in different instruction variants. Computational thinking is defined in the context of twenty-first century skills and describes processes involved in (re)formulating a problem in a way that a computer can process it. Programming robots offers specific affordances as it can be used to develop programs following a Sense-Reason-Act (SRA) cycle. The literature provides evidence that programming robots has the potential to enhance algorithmic thinking as a component of computational thinking. Specifically there are indications that pupils who use SRA-programming learn algorithmic skills better and achieve a higher level of selfefficacy in an open, scaffold learning environment than through direct instruction. In order to determine the influence of the instruction variant used, an experimental research design was made in which pupils solved algorithm-based mathematical problems (grid diagrams) in a preliminary measurement and their self-efficacy determined via a questionnaire. As an intervention, pupils learn to solve programming issues in pairs using "Lego NXT" robots and "Mindstorms" software in two instruction variants. The post-measurement consists of a Lego

challenge, solving mathematical problems (grid diagrams), and a repeated selfefficacy questionnaire. This research shows an increase of our measures on algorithmic thinking dependent on the amount of SRA usage (though not significant). Programming using the SRA-cycle can be considered as the cause of the measured effect. The instruction variant used during the robotic intervention seems to play only a marginal role.

Fanchamps, N., Specht, M., Hennissen, P., & Slangen, L. (2020). The Effect of Teacher Interventions and SRA Robot Programming on the Development of Computational Thinking. Paper presented at the International Conference on Computational Thinking Education 2020, Hongkong.

Abstract: The implementation of programming in primary education is currently receiving a considerable amount of attention in the context of developing 21st century skills and digital literacy. The application of programmable robots is a playful integration of developing programming skills and computational thinking. Once pupils understand the basics of robot programming, they can solve challenging new programming tasks themselves without the teacher taking over too much of the learning process. It is therefore worthwhile to investigate the extent to which teachers' instructional approach and guiding interventions influence the development of pupils' computational thinking. Furthermore, programming robots have some special affordances for educational purposes as robots typically have to be programmed to interact with their environment. Little evidence is known to which extent programmable robots using the SRA-approach contribute to the development of computational thinking skills among primary school pupils. The use of Sense, Reason and Act (SRA) programming includes the application of loops, routines and conditionals when controlling actuators on the basis of sensory information with which the robot can anticipate changes in the environment. Our findings indicate that teachers versus students experience the way of teaching (perceived monitoring and scaffolding) significantly different when programming robots. We make recommendations as to which competences the guiding teacher needs. It is also shown that programming robots using an SRA-approach contribute to the development of specific characteristics (reformulating problems, problem decomposition, abstraction, algorithms and procedures & parallelisation) of computational thinking.

Fanchamps, N.L.J.A., Slangen, L., Specht, M. et al. The Impact of SRA-Programming on Computational Thinking in a Visual Oriented Programming Environment. Educ Inf Technol (2021). https://doi.org/10.1007/s10639-021-10578-0

Abstract: Visual programming environments are popular instruments in teaching Computational Thinking (CT) in schools today. Applying Sense-Reason-Act (SRA) programming can influence the development of computational thinking when forcing pupils to anticipate the unforeseen in their computer programs. SRA-programming originates from the programming of tangible robots, but can also be of equal value in visual programming with on-screen output. The underlying rationale is that programming in a visual programming environment using SRA leads to more understanding of the computational concepts addressed, resulting in a higher level of computational skill compared to visual programming without the application of SRA. Furthermore, it has been hypothesised that if pupils in a visual programming environment can anticipate unforeseen events and solve programming tasks by applying SRA, they will be better able to solve complex computational thinking tasks. To establish if characteristic differences in the development of computational thinking can be measured when SRA-programming is applied in a visual programming environment with an on-screen output, we assessed the applicability of SRA-programming with visual output as the main component of the execution of developed code. This research uses a pre-test post-test design that reveals significant differences in the development of computational thinking in two treatment conditions. To assess CT, the Computational Thinking Test (CTt) was used. Results show that when using SRA-programming in a visual programming environment it leads to an increased understanding of complex computational concepts, which results in a significant increase in the development of computational thinking.

Ilieva, V. (2010). Robotics in the Primary School. How to do it? Paper presented at the Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots, Darmstad.

Abstract: The paper describes how to introduce primary school children to robotics. Robotics is a part of ICT education and is implemented using LEGO constructional material. The principles on which the teaching method is based are outlined. The prerequisite conditions for a successful teaching environment are made clear. The teaching approach described has developed over many years of everyday teaching practice in primary schools in Bulgaria. Robotics is considered, not as a school experiment or short term attraction but in terms of curriculum. In Bulgaria robotics can officially be part of a school#s curriculum, important for children#s knowledge, children#s thinking, and children#s experience. It demands a lengthy, organized and systematic process of teaching.

Jeschke, S., Kato, A., & Knipping, L. (2008). The engineers of tomorrow: Teaching robotics to primary school children. Paper presented at the Proceedings of SEFI Annual Conference 2008.

Abstract: In Germany we have seen a rising concern on lacking in numbers of students in science and engineering in recent years. Technological subjects are often regarded as not attractive by potential students. To address these problems early in the development of the children we offer courses in robotics. These benefit from the attractiveness of robots in popular culture, imposing a very low inhibition threshold. Positive technology experience for the participants of both genders can be created by paying attention to gender-sensitive aspects. By using tool sets like LEGO Mindstorms one can provide hands-on experiences and immediate results, giving the children both opportunities for creativity and a sense of achievement. A wide range of scientific and technological skills can be covered easily by employing this highly interdisciplinary field.

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. Early Childhood Education Journal, 41(4), 245-255. https://doi.org/10.1007/s10643-012-0554-5

Abstract: This paper examines the impact of programming robots on sequencing ability during a 1-week intensive robotics workshop at an early childhood STEM magnet school in the Harlem area of New York City. Children participated in computer programming activities using a developmentally appropriate tangible programming language CHERP, specifically designed to program a robot’s behaviors. The study assessed 27 participants’ sequencing skills before and after the programming and robotics curricular intervention using a picture-story sequencing task and compared those skills to a control group. Pre-test and post-test scores were compared using a paired sample t test. The group of children who participated in the 1-week robotics and programming workshop experienced significant increases in post-test compared to pre-test sequencing scores.

López, J. M. S., Otero, R. B., & García-Cervigón, S. D. L. (2021). Introducing robotics and block programming in elementary education. Revista Iberoamericana de Educación a Distancia, 24(1), 95-113. https://doi.org/10.5944/ried.24.1.27649

Abstract: This study shows the relevance of introducing visual block programming and robotics in primary education. The study describes how robotics are effectively implemented in schools, based on computational concepts and the classroom activities. We describe, apply and present specific resources teachers, who may think of introducing programming and robotics in education must consider. These resources can be adapted to their students’ levels and education stages. It is essential to be aware of the resources available and adapt them to students’ needs. The analysis involves 107 fifth-grade students in primary education at three schools. The sample of the study was non-probabilistic and intentional. The study is bidimensional. The first dimension is a quasiexperimental design obtaining data from a test. Construct validity was tested by an exploratory factor analysis. The second dimension details the results for four scales previously described: active learning, computational concepts, perceived usefulness and enjoyment. This dimension examines the

results of the aforementioned scale, which analyses the pedagogical interactions. Statistically significant improvements were achieved in the understanding of basic computational concepts such as sequences, loops, conditional statements, parallel execution, event handling and use of robotics. Improvements were also noted in didactic interaction, and in greater enjoyment, enthusiasm, efficiency and active participation of students. They also showed stronger motivation, commitment and interest in the process.

McGill, M. M. (2012). Learning to program with personal robots: Influences on student motivation. ACM Transactions on Computing Education, 12(1), 4. https://doi.org/10.1145/2133797.2133801

Abstract: One of the goals of using robots in introductory programming courses is to increase motivation among learners. There have been several types of robots that have been used extensively in the classroom to teach a variety of computer science concepts. A more recently introduced robot designed to teach programming to novice students is the Institute for Personal Robots in Education (IPRE) robot. The author chose to use this robot and study its motivational effects on non-computer science students in a CS0 course. The purpose of this study was to determine whether using the IPRE robots motivates students to learn programming in a CS0 course. After considering various motivational theories and instruments designed to measure motivation, the author used Keller's Instructional Materials Motivation Survey to measure four components of motivation: attention, relevance, confidence, and satisfaction. Additional items were added to the survey, including a set of open-ended questions. The results of this study indicate that the use of these robots had a positive influence on participants' attitudes towards learning to program in a CS0 course, but little or no effect on relevance, confidence, or satisfaction. Results also indicate that although gender and students interests may affect individual components of motivation, gender, technical self-perception, and interest in software development have no bearing on the overall motivational levels of students.

Miglino, O., Lund, H. H., & Cardaci, M. (1999). Robotics as an educational tool. Journal of Interactive Learning Research, 10(1), 25-47. https://www.learntechlib.org/primary/p/9274/

Abstract: This paper explores a new educational application of Piaget's theories of cognitive development i.e. the use, as a teaching tool, of physical robots conceived as artificial organisms. By using simple assembly kits, students at all levels are able to project and construct real robots that simulate the behaviors of animals. The process of constructing real robots helps students to understand concepts about complex dynamic systems – in particular how global behavior can emerge from local dynamics. This is done through a construction process. In order to obtain a given behavior students modify both the "mind" and the body of artificial organisms. The construction of populations of artificial organisms helps the students to realize the difference between observing behavior at the individual (microscopic) level and at the population (macroscopic) level. The development of a population of robots with a given behavior is an evolutionary process. The selective reproduction of a population of robots is a powerful tool for teaching the Darwinian theory of evolution: experiments using artificial – as opposed to biological - organisms make it possible to rapidly observe the results of selection, reproduction and mutation. The paper reviews a number of educational projects using real robots. It is shown that the use of intelligent systems to enlarge our view of biological reality could become an integral part of curricula in science, technology, psychology and biology.

Sentance, S., & Csizmadia, A. (2017). Computing in the curriculum: Challenges and strategies from a teacher's perspective. Education and Information Technologies, 22(2), 469-495. https://doi.org/10.1007/s10639-016-9482-0

Abstract: Computing is being introduced into the curriculum in many countries. Teachers' perspectives enable us to discover what challenges this presents, and also the strategies teachers claim to be using successfully in teaching the subject across primary and secondary education. The study described in this paper was carried out in the UK in 2014 where teachers were preparing for the mandatory inclusion of Computing into the curriculum. A survey was conducted of over 300 teachers who were currently teaching Computing to elicit their perspectives on challenges and strategies. From the analysis of the data, extrinsic and intrinsic challenges were identified for both teachers and students. In addition, a variety of pedagogical strategies were recommended by teachers from their own practice. In categorising approaches taken by teaching to support students five key themes emerged: unplugged type activities, contextualisation of tasks, collaborative learning, developing computational thinking, and scaffolding programming tasks. Further investigation could support whether these strategies can alleviate the challenges of teaching and learning of Computing for students and teachers. In particular developing student resilience in Computing is seen as a challenge while not many strategies are suggested. The results of this study will be useful for teachers who are new to the teaching of Computing.

Silk, E., & Schunn, C. (2008). Using Robotics to Teach Mathematics. Paper presented at the American Society for Engineering Education Annual Conference 2007, Pittsburgh, PA. https://www.cmu.edu/roboticsacademy/PDFs/Research/SilkSchunn2008a-ASEE.pdf

Abstract: We report on a project that investigates the use of engineering as a context in which to learn mathematics through an evaluation of a LEGO-based robotics curriculum. We performed a content analysis of the curriculum in order to identify the types of mathematics topics that students would have an opportunity to learn, and investigated the extent to which those topics were aligned with national mathematics standards. The curriculum had a large percentage of tasks with clear relevance for mathematics and aligned well with the standards at the level of broad, topic areas (e.g., measurement, algebra, etc.). The curriculum was not well aligned at the more specific, topic level (e.g., use of measuring instruments, evaluating expressions, etc.), indicating that level of alignment is an important consideration when designing engineering curricula to teach mathematics. We simultaneously conducted a case study analysis of an implementation of the robotics curriculum in an eighth grade technology classroom to assess whether mathematics ideas were salient as students engaged with the tasks. When prompted by the teacher, especially during whole-class discussion, we observed students bringing in a wide range of formal mathematics ideas. Despite that, because of the multitude and diversity of those mathematics ideas, significant mathematics learning did not occur. These findings suggest that robotics is a promising engineering context in which to engage students in thinking about mathematics, but that further supports are required to effectively enable students' mastery of the more general mathematical ideas.

Alfieri, L., Higashi, R., Shoop, R. et al. Case studies of a robot-based game to shape interests and hone proportional reasoning skills. IJ STEM Ed 2, 4 (2015). https://doi.org/10.1186/s40594-015-0017-9

Abstract: Background. Robot-math is a term used to describe mathematics instruction centered on engineering, particularly robotics. This type of instruction seeks first to make the mathematics skills useful for robotics-centered challenges, and then to help students extend (transfer) those skills. A robot-math intervention was designed to target the proportional reasoning skills of sixth- through eighth-graders. Proportional reasoning lays the foundation for further progress within mathematics. It is also necessary for success in a number of other domains (engineering, science, etc.). Furthermore, proportional reasoning is a life skill that helps with daily decision making, planning, etc. However, it is a skill that is complex and often difficult for students. Previous attempts to design similar robot-math activities have struggled to focus students' attention on key mathematics concepts (in complex engineering domains), and to motivate students to use the math properly. The current intervention was designed with these challenges in mind. This intervention centers on a computer-based 3D game called Expedition Atlantis. It employs a game design that focuses student attention on a specific proportional reasoning task: students calculate correct quantities of wheel rotations to move the robot to desired locations. The software also offers individualized tutorials. Whole-class discussions around daily word problems promote further application of proportional reasoning outside the robot programming context. The 1-week intervention was implemented by three teachers at different schools with varying levels of ability among students.

Results. Overall, within-participant comparisons revealed that the intervention was successful in improving the number of correct responses, the number of problems attempted, the proportions of correct responses, students' interest in robotics, and students' valuing of mathematics within robotics from pre- to post-test. Further analysis of teachers revealed that the two class sections of special education benefited most. Consideration was given to the qualities of the implementation that might have led to these enhancements.

Conclusions. The success of this intervention suggests that robot-math activities might be successful when focused on a few target skills and when designed with individualized tutorials/prompts that motivate proper skills. Further investigations of student and implementation characteristics would help to refine these interventions further.

Zapata-Cáceres, M., & Fanchamps, N. (2021). Using the Beginners Computational Thinking Test to Measure Development on Computational Concepts Among Preschoolers. Paper presented at the 5th APSCE International Computational Thinking and STEM in Education Conference 2021, Singapore.

Abstract: The implementation of programming in primary education is in the forefront of attention in many countries. The application of programmable robots offers many opportunities to learn the basic concepts of programming. Learning and understanding these underlying concepts is not only reserved for students of five years and older but can also be learned at a younger age. Until now, making a development on Computational Thinking (CT) objectively measurable among preschoolers was not possible since no validated instrument was available for this purpose. Furthermore, it is unclear which capabilities of CT are achieved at each age and which are not reachable. To establish which CT skills are of interest to students and within the reach of each age group and therefore, teachable, this study has been carried out. To assess CT, the Beginners Computational Thinking test (BCTt) was used, along with direct observation and interviews. Results show the suitability of the BCTt among 5 years-old students and, partially among 4 years-old students. When applying two types of programmable robots a significant increase in the development of CT was observed. A development of specific complex programming concepts can also be demonstrated. In addition to the skills shown, it also appears that children are highly motivated to learn programming at a very young age.

Zapata-Cáceres, M., Martín-Barroso, E., & Román-González, M. (2020). Computational thinking test for beginners: Design and content validation. Paper presented at the 2020 IEEE Global Engineering Education Conference (EDUCON), Porto, Portugal. https://doi.org/10.1109/EDUCON45650.2020.9125368

Abstract: Computational Thinking (CT) is a fundamental skill that is not only confined to computer scientists' activities but can be widely applied in daily life and is required in order to adapt to the future and, therefore, should be taught at early ages. Within this framework, assessing CT is an indispensable part to consider in order to introduce CT in the school curricula. Nevertheless, efforts involving the formal assessment of computational thinking has primarily focused on middle school grades and above; and are mostly based on the analysis of projects in specific programming environments. A Beginners Computational Thinking Test (BCTt), aimed at early ages, and based on the Computational Thinking Test [1], has been designed including several improvements; submitted to a content validation process through expert´s judgement procedure; and administered to Primary School students. The BCTt design is considered adequate by experts and results show a high reliability for the assessment of CT in Primary School, particularly in first educational stages.

Educational Robotics Technologies

Jung, S. E., & Won, E. (2018). Systematic Review of Research Trends in Robotics Education for Young Children. Sustainability, 10(4). https://doi.org/10.3390/su10040905

Abstract: This study conducted a systematic and thematic review on existing literature in robotics education using robotics kits (not social robots) for young children (Pre-K and kindergarten through 5th grade). This study investigated: (1) the definition of robotics education; (2) thematic patterns of key findings; and (3) theoretical and methodological traits. The results of the review present a limitation of previous research in that it has focused on robotics education only as an instrumental means to support other subjects or STEM education. This study identifies that the findings of the existing research are weighted toward outcome-focused research. Lastly, this study addresses the fact that most of the existing studies used constructivist and constructionist frameworks not only to design and implement robotics curricula but also to analyze young children's engagement in robotics education. Relying on the findings of the review, this study suggests clarifying and specifying robotics-intensified knowledge, skills, and attitudes in defining robotics education in connection to computer science education. In addition, this study concludes that research agendas need to be diversified and the diversity of research participants needs to be broadened. To do this, this study suggests employing social and cultural theoretical frameworks and critical analytical lenses by considering children's historical, cultural, social, and institutional contexts in understanding young children's engagement in robotics education.

Sapounidis, T., & Alimisis, D. (2020). Educational robotics for STEM: A review of technologies and some educational considerations. In Science and mathematics education for 21st century citizens: Challenges and ways forward (pp. 167–190). Nova Science Publishers.

Abstract: Educational robotics (ER) nowadays is booming at the research and educational level while more and more teachers and schools are introducing robotics as a core activity in school classrooms to teach Science, Technology, Engineering and Mathematics (STEM). However, despite the growing research interest and efforts in educational robotics, it seems that enough attention has not been paid to important factors like guidance and collaboration scripts, which are significant elements of the ER curricula. At the same time, there are many ER systems in the literature that have not been used extensively, and therefore they are mostly unknown to the related community. Furthermore, factors such as age and gender, which should be taken into consideration for the selection for the most appropriate ER system, seem to be ignored. Therefore, on the one hand, the existing curricula do not fully support teachers and learners, preventing educational robotics to become a truly effective tool in teachers' hands. On the other hand, teachers do not seem to be fully aware of the available robotic design technologies and principles, in order to make the right choices for their students. This chapter provides evidence on the importance of collaboration scripts and guidance informing the development of more comprehensive curricula in the future. It also discusses the role of age and gender in relation to the ER technology selection. Finally, the chapter provides a systematic review of the available educational robotics technologies that have appeared in the international literature aimed to support both researchers and STEM educators.

Schad, M., & Jones, W. M. (2020). The Maker Movement and Education: A Systematic Review of the Literature. Journal of Research on Technology in Education, 52(1), 65–78. https://doi.org/10.1080/15391523.2019.1688739

Abstract: The maker movement has sparked interest from stakeholders in K12 educational institutions based on its emphasis on science, technology, engineering, and math (STEM) content areas. However, the interest has not yet culminated in clearly defined best practices for K12 student or teacher learning. This systematic review of literature aims to analyze the research to date associated with the maker movement in K12 education. Prominent research databases were searched for literature published about the maker movement in education between the years 2000 and 2018 so as to provide a current description of research on this topic.

Other sources

These articles were collected in Google Scholar.

Nuria Arís and Lara Orcos (2019) Educational Robotics in the Stage of Secondary Education: Empirical Study on Motivation and STEM Skills. Education Sciences. 2019; 9(2):73. https://doi.org/10.3390/educsci9020073

Abstract: Educational robotics (ER) is increasingly present in secondary education classrooms and has acquired greater projection, especially with the appearance of championships, such as FIRST® LEGO® League. These competitions are based on a globalizing focus of the different areas of the curriculum, therefore, we consider that it directly links with the achievement of STEAM (science, technology, engineering, arts, and mathematics) skills. We present a research study that provides objective data based on the opinions of teachers and students that participated in this championship during the course 2017/2018 about its impact in the learning process. To this end, Spanish students and teachers answered questionnaires to collect their perceptions and assessments just after their participation. The results obtained allow us to conclude that both teachers and students believe this project promotes interest and scientific curiosity, as well as social skills through teamwork.

Gwen C. Nugent, Bradley S. Barker and Neal Grandgenett The Impact of Educational Robotics on Student STEM Learning, Attitudes, and Workplace Skills Source Title: Robotics: Concepts, Methodologies, Tools, and Applications. 2014, https://doi.org/10.4018/978-1-4666-4607-0.ch070

Abstract: This chapter discusses findings from a National Science Foundation (NSF) project funded by the Innovative Technologies Experiences for Student and Teachers (ITEST) program. The project has an ongoing research agenda focusing on the impact of robotics summer camps and competitions targeted at middle school youth. The research focused on the impact of the interventions on youth a) learning of computer programming, mathematics, and engineering concepts, b) science, technology, engineering, and math (STEM) attitudes, c) workplace skills, and d) STEM career interest. Results show that robotics camps and competitions appear to be viable strategies to increase student STEM learning, robotics self-efficacy, and problem solving skills

Theodosios Sapounidis and Dimitris Alimisis (2020). Educational Robotics For Stem: A Review of Technologies and Some Educational Considerations. In book: Science and Mathematics Education for 21st Century Citizens: Challenges and Ways Forward. Chapter: 9. Nova science publishers: Hauppauge, NY, USA.

Abstract: Educational robotics (ER) nowadays is booming at the research and educational level while more and more teachers and schools are introducing robotics as a core activity in school classrooms to teach Science, Technology, Engineering and Mathematics (STEM). However, despite the growing research interest and efforts in educational robotics, it seems that enough attention has not been paid to important factors like guidance and collaboration scripts, which are significant elements of the ER curricula. At the same time, there are many ER systems in the literature that have not been used extensively, and therefore they are mostly unknown to the related community. Furthermore, factors such as age and gender, which should be taken into consideration for the selection for the most appropriate ER system, seem to be ignored. Therefore, on the one hand, the existing curricula do not fully support teachers and learners, preventing educational robotics to become a truly effective tool in teachers' hands. On the other hand, teachers do not seem to be fully aware of the available robotic design technologies and principles, in order to make the right choices for their students. This chapter provides evidence on the importance of collaboration scripts and guidance informing the development of more comprehensive curricula in the future. It also discusses the role of age and gender in relation to the ER technology selection. Finally, the chapter provides a systematic review of the available educational robotics technologies that have appeared in the international literature aimed to support both researchers and STEM educators.

Araceli Martinez Ortiz, Beth Bos and Shaunna Smith. The Power of Educational Robotics as an Integrated STEM Learning Experience in Teacher Preparation Programs Journal of College Science Teaching Vol. 44, No. 5 (2015), pp. 42-47. https://www.jstor.org/stable/43631847

Abstract: The use of integrated science, technology, engineering and mathematics (STEM) instruction has the affordances of combining harmonious content area connections into real-world experiences that are both engaging and challenging. This article introduces findings from a study that used an integrated robotics module to expose in-service and preservice teachers to the engineering design process, programming, mathematical connections and context, and problem-based learning. With participants ranging from novice to advanced user, this integrated module proved that given the appropriate scaffolding, anyone can successfully program a robot and have fun while engaging in STEM learning along the way. Implications lead to the conclusion that teacher preparation programs should integrate activities such as this to better equip teachers to engage students in the wonders of STEM in their own classrooms.

A. Mehrotra et al., Accessible Maker-Based Approaches to Educational Robotics in Online Learning, in IEEE Access, vol. 9, pp. 96877-96889, 2021, https://doi.org/10.1109/ACCESS.2021.3094158

Abstract: Educational Robotics holds the potential to promote the development of important 21st century skills, such as creativity and problem-solving skills in addition to digital literacy. However, the emergence of

the Covid-19 pandemic has posed particular obstacles that had to be overcome in order to allow Educational Robotics activities to be conducted in distance learning. In the first place, the obligation to work from home limited the access to required equipment for many students. Secondly, many teachers had to face the novel challenge of creating pedagogically meaningful activities in online learning formats. Aiming to address these challenges, this work explored maker-based approaches as a way to implement Educational Robotics activities in online learning. The devised tools and activities were evaluated in two case studies performed with (i) high school students participating in a mobile robotics summer school and (ii) in-service teachers attending a professional development course on Educational Robotics. The teachers' and students' perception of the proposed activities was analyzed using online surveys and video interviews. The findings showed that the combination of the devised tools and activities allowed teachers and students to explore the basics of mobile robotics while helping them develop a maker mindset. The use of ubiquitous construction materials and affordable electronic components promotes the accessibility of the approach. The proposed tools and activities may therefore provide an exemplary framework for more general applications of Educational Robotics in online learning that go beyond the context of emergency remote teaching.

Sokratis Tselegkaridis and Theodosios Sapounidis Simulators in Educational Robotics: A Review. Educational Science 2021, 11(1). https://doi.org/10.3390/educsci11010011

Abstract: Educational robotics (ER) seems to have a positive effect on students and, in many cases, might help them to successfully assimilate knowledge and skills. Thus, this paper focuses on ER and carries out a literature review on educational robotics simulators with Graphical User Interfaces (GUIs). The review searches for relevant papers which were published in the period 2013–2020 and extracted the characteristics of the simulators used. The simulators that we describe in this article cover various robotic technologies, offering students an easy way to engage with virtual robots and robotics mechanisms, such as wheeled robots or drones. Using these simulators, students might cover their educational needs or prepare themselves for educational robotic competitions by working in as realistic as possible conditions without hardware restrictions. In many cases, simulators might reduce the required cost to obtain a robotic system and increase availability. Focusing on educational robotics simulators, this paper presents seventeen simulators emphasizing key features such as: user's age, robot's type and programming language, development platform, capabilities, and scope of the simulator.

David Scaradozzi, Laura Screpanti, Lorenzo Cesaretti. Towards a Definition of Educational Robotics: A Classification of Tools, Experiences and Assessments Smart Learning with Educational Robotics pp 63-92

Abstract: Robotics in education (RiE) covers a variety of applications of robots to the world of teaching and learning. Despite all the benefits that robotics can bring to education, a clear definition of the purpose for introducing robotics in education is still missing. Authors aim at facing this issue proposing a classification of RiE experiences, stating the difference between RiE and educational robotics (ER). The need for this classification arises from the wide usage of ER to indicate a diverse range of activities using robots and from the lack of clarity when describing how ER impacts students' curricula. Moreover, a definition of ER can impact the definition of the policies on the integration of ER into formal and non-formal education; it can also provide a basis for further studies whose aim is to provide clear evidence on the benefits of ER activities; finally, it can enhance the replicability of ER activities. To better characterise ER, authors propose two more classifications: one for the robotic tools used in the ER activities and one for the evaluation of ER activities. Drawing upon the proposed classifications, authors point out some distinctive features of ER comparing them to literature. This general outline aims at creating a starting point to open a debate on the definition of ER.

Daniela, L (2019) Smart Learning with Educational Robotics Using Robots to Scaffold Learning Outcomes

Abstract: Temporary school closures caused by the Covid-19 pandemic have posed new challenges for many teachers and students worldwide. Especially the abrupt shift to online distance learning posed many obstacles to be overcome and it particularly complicated the implementation of Educational Robotics activities. Such activities usually comprise a variety of different learning artifacts, which were not accessible to many students during the period of school closure. Moreover, online distance learning considerably limits the possibilities for students to interact with their peers and teachers. In an attempt to address these issues, this work presents the development of an Educational Robotics activity particularly conceived for online distance learning in primary school. The devised activities are based on pen and paper approaches that are complemented by commonly used social media to facilitate communication and collaboration. They were proposed to 13 students, as a way to continue ER activities in online distance learning over the time period of four weeks.

Christian Giang, Lucio Negrini. Educational Robotics in Online Distance Learning: An Experience from Primary School Christian. https://doi.org/10.48550/arXiv.2105.09700

Abstract: The COVID-19 pandemic and the subsequent school closures created several challenges for teachers and students. From one day to the next, teachers had to rethink their educational activities and move to remote learning. Especially with regard to educational robotics activities, which makes large use of physical artefacts, this abrupt shift towards online learning represented a major change in how activities had to be designed and implemented. In this chapter, some experiences of online educational robotics activities carried out in compulsory schooling and teacher training are presented. The experiences are then discussed using a model for the development of educational robotics activities in order to reflect on how to design such activities that can be carried out online. The examples presented in this chapter showed there is great potential for educational robotics in online learning.

Zhong, B., Xia, L. A Systematic Review on Exploring the Potential of Educational Robotics in Mathematics Education. Int J of Sci and Math Educ 18, 79–101 (2020). https://doi.org/10.1007/s10763-018-09939-y

Abstract: By providing students with a highly interactive and hands-on learning experience, robotics promises to inspire a new generation of mathematical learning. This paper aims to review the empirical evidence on the application of robotics in mathematics education and to define future research perspectives of robot-assisted mathematics education. After a systematic search in online database via keyword search and snowballing approach, we analyzed 20 empirical studies on how to teach and learn mathematical knowledge through robotics. The results indicate that (1) most studies were conducted with a small sample size, the largest research groups were elementary school students and secondary school students, most studies used LEGO robots, robots were primarily applied to teach and/or learn graphics, geometry, and algebra, and almost half of the studies taught mathematics by engaging students in game-like interactions with robots; (2) half of the studies adopted a non-experimental research design, and most studies evaluated student performance through observation, test/examination, questionnaires, or verbal interviews; and (3) instructional implications proposed in the 20 papers can be clustered into four themes: human-robot interaction, connections between mathematics and real life, pedagogical suggestions, and facility conditions. The 20 papers suggest that robotics generally plays an active role in mathematics education; however, there are indeed situations in which no significant improvement was found in students' mathematical learning. In view of this, we prospect the future research perspectives of robot-assisted mathematics education and propose that more rigorous intervention studies could be conducted to further explore the integration of robotics and mathematics education. Robotics is now facing the challenge of deploying newly developed devices into human environments, and for this process to be successful, societal acceptance and uptake of robots are crucial. Education is already playing a key role in raising awareness and spreading knowledge about robotic systems, and there is a growing need to create highly accessible resources to teach and learn robotics. In this paper, we revise online available educational material, including videos, podcasts, and coding tools, aimed at facilitating the learning of robotics related topics at different levels. The offer of such resources was recently boosted by the higher demand of distance learning tools due to the COVID-19 pandemic. The potential of e-learning for robotics is still under-exploited, and here we provide an updated

list of resources that could help instructors and students to better navigate the large amount of information available online Accessible Educational Resources for Teaching and Learning Robotics.

Alamo, J.; Quevedo, E.; Coll, A.S.; Ortega, S.; Fabelo, H.; Callico, G.M.; Zapatera, A. Sustainable Educational Robotics. Contingency Plan during Lockdown in Primary School. Sustainability 2021, 13, 8388. https://doi.org/10.3390/su13158388

Abstract: New technologies have offered great alternatives for education. In this context, we place robotics and programming as innovative and versatile tools that adapt to active methodologies. With the arrival of COVID-19 and lockdowns, physical resources were kept out of use, and the virtual lectures did not propose to incorporate these elements in a meaningful way. This recent situation raises as an objective of study the need to evaluate if robotics and programming are content that can be taught virtually in these circumstances, without physical resources and without face-to-face lectures. To do this, a mixed methodology consisting of questionnaires and interviews has been incorporated, aimed at primary education teachers, families, and primary education grade students. The results suggest that the virtualization of robotics and programming is a feasible and beneficial alternative for students, which allows the development of digital skills, while it is enhanced with the use of audiovisual materials and online resources. Even though face-to-face classes have other benefits not offered by virtualization, and teacher training needs to be up to the task to face this situation, it is a matter of time to respond to these situations and to guarantee a high-quality distance education.

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A Systematic Review of Studies on Educational Robotics. Journal of Pre-College Engineering Education Research (J-PEER), 9(2), Article 2. https://doi.org/10.7771/2157-9288.1223

Abstract: There has been a steady increase in the number of studies investigating educational robotics and its impact on academic and social skills of young learners. Educational robots are used both in and out of school environments to enhance K–12 students' interest, engagement, and academic achievement in various fields of STEM education. Some prior studies show evidence for the general benefits of educational robotics as being effective in providing impactful learning experiences. However, there appears to be a need to determine the specific benefits which have been achieved through robotics implementation in K–12 formal and informal learning settings. In this study, we present a systematic review of the literature on K–12 educational robotics. Based on our review process with specific inclusion and exclusion criteria, and a repeatable method of systematic review, we found 147 studies published from the years 2000 to 2018. We classified these studies under five themes: (1) general effectiveness of educational robotics; (2) students' learning and transfer skills; (3) creativity and motivation; (4) diversity and broadening participation; and (5) teachers' professional development. The study outlines the research questions, presents the synthesis of literature, and discusses findings across themes. It also provides guidelines for educators, practitioners, and researchers in areas of educational robotics and STEM education, and presents dimensions of future research.

Dorotea, N.; Piedade, J.; Pedro, A. Mapping K-12 Computer Science Teacher's Interest, Self-Confidence, and Knowledge about the Use of Educational Robotics to Teach. Educ. Sci. 2021, 11, 443. https://doi.org/10.3390/educsci11080443

Abstract: This paper reports a case study, developed in K-12 Portuguese Education, that aimed to analyze the computer science teachers' knowledge, interest, and self-confidence to use educational robotics and other programable objects in classroom activities to teach computer science concepts and to promote students' computational thinking skills. The research design was organized into a descriptive and exploratory quantitative approach. The participants were 174 in-service computer science teachers of Portuguese public education. The data was gathered from the participants, through the online application of the Robotics Interest Questionnaire scale (RIQ). Very positive levels of teacher's knowledge, interest, and self-efficacy to

use educational robotics for teaching purposes were reported in the study outcomes. These constructs were underlined in several studies as relevant factors to promote the use of educational robotics and other similar technologies by the teachers. Despite the study limitations and the small context, a set of relevant results was highlighted on computer science in-service teachers' interest and preparation to use robotics and to support their students in learning activities with these artifacts.

Pozzi M, Prattichizzo D, Malvezzi M. Accessible Educational Resources for Teaching and Learning Robotics. Robotics. 2021; 10(1):38. https://doi.org/10.3390/robotics10010038

Abstract: Robotics is now facing the challenge of deploying newly developed devices into human environments, and for this process to be successful, societal acceptance and uptake of robots are crucial. Education is already playing a key role in raising awareness and spreading knowledge about robotic systems, and there is a growing need to create highly accessible resources to teach and learn robotics. In this paper, we revise online available educational material, including videos, podcasts, and coding tools, aimed at facilitating the learning of robotics related topics at different levels. The offer of such resources was recently boosted by the higher demand of distance learning tools due to the COVID-19 pandemic. The potential of e-learning for robotics is still under-exploited, and here we provide an updated list of resources that could help instructors and students to better navigate the large amount of information available online.

Annex II. Clustered AR-ER ideas

Ideas on the use of AR for ER generated in the Group Concept Mapping study with ideas that belong to the so called Go-Zone highlighted with bold font and marked with ** and bridging value statistics provided for individual ideas and clusters (average).

Cluster Generic educational design ideas (bv=0.10)	0.10
1. ER-AR educational scenarios can be designed as a sequence of steps to be done (e.g., on step 1, find components A and B, on step 2, connect them like this, where AR is used for providing these instructions and correctness check) (bv=0.12)**	0.12
8. In online teaching / COVID-19, we should replace the real ER components with AR simulations, because such components are inaccessible (bv=0.21)**	0.21
13. The ER platform and the teaching approach need to allow teaching of the main STEM subjects, i.e. IoT (such as sensors and actuators) and robotics (such as mobility transmission issues) (bv=0.20)**	0.20
15. The combination of ER and AR provides students with the opportunity to learn through the power of concrete imagination (bv=0.04)**	0.04
16. AR in combination with ER supports crossing boundaries between primary education and secondary education (bv=0.18)	0.18
21. We need to determine what the combination of ER and AR gives the user (students) in terms of learning outcomes that can later be made measurable. This could be in the area of knowledge about programming concepts, computational thinking skills and STEM skills, etc. (bv=0.15)**	0.15
27. Using AR applications in the classroom should be beneficial to all students (bv=0.05)**	0.05
35. The possibilities and impossibilities of the ER-AR app should be made explicit (e.g., if it be used for direct instruction, collaboration, assessment,...) to prevent misuse and encourage high quality implementation (bv=0.17)**	0.17
38. The implementation of ER and AR applications should create new learning opportunities (bv=0.10)**	0.10
53. We need to make a conscious choice within any educational design about the role of the robots, because they can play different roles in ER (e.g., to learners, the robot can be a peer, a tutor, a learning tool, the end product of an assignment ...) (bv=0.04)**	0.04
54. ER-AR educational scenarios can be designed as a sequence of steps to be done, which will reduce the time commitment of a teacher because instructions and feedback are provided through AR (bv=0.07)	0.07
57. The design of the ER-AR app should take into account different talents of students than the traditional educational approach (classroom) (bv=0.07)	0.07
59. AR should play a prominent role in providing customized, tailored education (bv=0.02)	0.02
62. In programming education, a programming code for an AR simulation can be used to enable different educational use cases (complete a template, find a mistake, solve a problem) (bv=0.10)	0.10
64. We need to explore more what pedagogical scenarios AR can bring to ER. For example, AR for: Explanation, instruction, deepening, working principles, problem-solving, guidance, semi-stand-alone, etc (bv=0.14)**	0.14
66. The implementation of ER and AR applications should solve existing problems in teaching STEM subjects (0.00)**	0.00

67. AR can be used by the teacher/lecturer in any subject area (bv=0.09)	0.09

Cluster Feedback design ideas (bv=0.32)	0.32
2. In the ER-AR app, it should be possible to visualize errors (e.g. wrong chemical compounds, or calculus errors in physics) (bv=0.53)**	0.53
20. Relevant learner actions of using ER-AR systems can be documented / logged for learning analytics (e.g., using standards like xAPI) (bv=0.18)	0.18
26. In an ER-AR app, instruction of a procedure step can be visualized in AR in the following way if the learner does not know which component to connect next and where to connect it, the app can show a 3D model of a real ER component in the right place (bv=0.49)**	0.49
29. Each AR-simulated ER component needs to act independently and interact with other components (not only in pre-defined scenarios) to allow for potentially many scenarios and give teachers a means to create their own (bv=0.24)	0.24
32. The ER-AR app should utilize the ER potential to enable learning by doing (bv=0.21)**	0.21
34. The ER-AR app should allow teachers to go through the actions performed by the students, showing and discussing with them the results (bv=0.25)	0.25
35. The possibilities and impossibilities of the ER-AR app should be made explicit (e.g., if it be used for direct instruction, collaboration, assessment,...) to prevent misuse and encourage high quality implementation (bv=0.17)	0.17
36. An ER-AR app should provide the learner with automatic feedback, specifically in case of different errors (e.g., when visually it is not clear what doesn't work and why) (bv=0.42)**	042
37. With AR, students can see consequences of their actions (i.e. if one makes coding mistakes or wrong assumptions) (bv=0.34)**	0.34
51. We need to add AR objects to a learning activity. E.g., visualize what a robotic arm will do prior to executing an instruction **(bv=0.29)**	0.29

Cluster Interaction design ideas (bv=0.24)	0.24
3. The ER-AR app should use modularity to allow working with more than one ER platform (bv=0.34)	0.34
5. In an ER-AR app, user interaction should include interacting with 3D models - tapping on the phone screen (bv=0.45)**	0.45
6. The proximity of component cards has to be detected by the ER-AR app, and the AR-simulated parts of the components need to change their state (if they can interact) or not change (if they cannot interact) (bv=0.29)	0.29
12. In an ER-AR app, user interaction should include interaction via the "screen-space" user interface elements on the phone (bv=0.19)	0.19
18. For each ER component@ an image marker can be created. An AR app can detect the image marker and simulate the real ER component on top of it: both how it looks (3D model for each state) and how it interacts with other components (3D animations) (bv=0.22)	0.22
19. We should create an AR components library for the ER parts (bv=0.17)**	0.17

23. An authoring tool can be used to create content versus creating/programming each scenario individually (bv=0.16)	0.16
30. AR visualizations need to work even if the ER-component cards overlap or physically touch each other (some ER scenarios might require such overlap) (bv=0.24)	0.24
39. The ER-AR app should allow changing parameters on runtime (when the app is running), while the AR visualization should react to the changes (bv=0.27)	0.27
40. In an ER-AR app, user interaction should include moving the physical ER cards (bv=0.20)	0.20
41. The ER solution should have tangible parts and a graphical UI (bv=0.19)	0.19
43. Instead of AR-simulated ER cardboard-based components, these components could be made "virtual", displayed on the screen. In such a case, AR is not needed (no physical object to augment) (bv=0.15)	0.15
44. Some of the pre-designed scenarios can include the need to assemble multiple ER components together, so that the ER-AR app should recognize the arrangement of the ER components** (bv=0.20)	0.20
45. The ER-AR app should allow standardization of suggestions and cues (bv=0.35)	0.35
46. AR solutions should display contextual information using icons, glyphs@ or images overlayed over ER components cards (bv=0.25)	0.25
49. The ER-AR app needs to remember which ER cardboard cards are "in play" and not to forget them as soon as they are out of the view of the phone camera (bv=0.15)	0.15
52. The AR environment should be able to modify physical conditions to do troubleshooting of the system. For example, if you want to check if your humidity sensor is working properly, you could change the humidity digitally and check if the AR components react (bv=0.16)	0.16
56. AR labels that point to different ER components may be switched on and off by the learner (potentially in any scenario) (bv=037)	0.37
61. The ER-AR app should interface with ER hardware components or robots (e.g., using Unity3D that support AR multi-platform development as well as C#) (bv=0.28)	0.28
65. We need to find appropriate 3D models of ER components for a successful ER-AR app (bv=0.24)**	0.24
68. The ER-AR app needs to support AR-simulated visualizations (3D models) that are much larger than the cards, be of the same size or smaller than the cards (bv=0.12)	0.12
70. In an ER-AR app, AR should similarly augment one or both of the following: 1) real hardware (e.g., LittleBits piece), 2) simulated (e.g., cardboard image) (bv=0.26)	0.26
72. AR solutions should include spatial tracking in addition to the standard image tracking **(**bv=0.23)	0.23

Cluster Hardware design ideas (bv=0.34)	0.34
4. We need to use real ER hardware components and augment them with AR (bv=0.53)	0.53
9. AR can augment hardware components to show how they work (bv=0.48)**	0.48
10. AR development should support tablets and laptops with touch screen (e.g., the microsoft surface) (bv=0.32)**	0.32
11. AR solutions should include object tracking in addition to the standard image tracking (bv=0.26)	0.26

14. For the development of a new AR platform, we need to have a possibility to develop AR modules by different organizations (bv=0.25)	0.25
28. Development of AR for mobile devices should support both Android and iOS (bv=0.26)**	0.26
31. In programming education, the same code can be applied to AR simulation and to a robot wirelessly (bv=0.25)	0.25
58. We need to replace the ER components with simulated components (like cubed made from cardboard) augmented through AR (bv=0.36)	0.36
63. Our AR content must be optimized for both tablets and mobile phone devices (bv=0.36)	0.36
69. If using real ER hardware components, they should be modular and have wireless communication (BT, LoRa, Wi-Fi) (bv=0.35)	0.35
71. Wireless communication between multiple AR devices should be used in a collaborative mode (bv=0.32)	0.32

Cluster ER Platform selection ideas (bv=0.69)	0.69
7. An experiment should be set up to design (or implement) the same ER scenario using two different ER platforms so that the common and different elements can be determined to make the AR simulation independent from the specific ER platform (i.e. applicable to multiple ER platforms) (bv=0.63)	0.63
17. When choosing an ER platform, we should consider if it has possibilities for sensors**	0.53
25. When choosing the ER platform for the ER-AR app@ we should consider if it has an existing active community on the web.	0.88
42. To succeed in developing the ER-AR app, we should create or join an active community on the web.	1.00
47. When choosing an ER platform, we should consider it is friendly to novice programmers**	
50. When choosing the ER platform for the ER-AR app, we must choose a low-cost ER solution (arduino@ esp32, pico).	0.67
55. We need a range of AR platforms to be able to select one to build upon.	0.45

Cluster Framing A-ER concept (bv=0.42)	0.41
22. We need an overall conceptual framework to combine ER and AR**	0.33
24. For the development of a new AR platform, we need to jointly develop a conceptual framework that links ER and AR.	0.27
33. We need integration with LMS (e.g., Moodle) to enable uptake and use in online learning.	0.50
48. We need to start with building educational scenarios on an ER platform, such as LittleBits, and then simulate the scenarios with cardboard cubes with printed simple images (and/or QR codes) that are augmented via AR.	0.51
60. We need to find examples of systems that implement different AR features and ER scenarios.	0.46