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## Exploration of learning analytics in educational modular robotics

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**Abstract:** Due to the interaction of hardware, software, and electronics, modular robotics is a multidimensional field aiming to create autonomous systems that can sense their environment to achieve certain goals or tasks. We can support creative problem solving (CPS) with the use of educational robots in ill-defined problem-solving tasks. The analysis of CPS in educational robotics can be supported by different assessment methodologies including direct observation, self-reported data but also learning analytics from the robots being used during the CPS tasks. Our intention in this research paper is to study learning analytics current state-of-the-art with a particular focus on modular robotics. This study can help in advancing the analysis of the current limits but also opportunities of learning analytics in modular educational robotics to be able to support automated ways to collect data and interpret them in the context of human CPS.

**Keywords:** educational robotics, learning robotics, creative problem-solving, learning analytics, modular robotics

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## 1. Introduction

Learning Analytics (LA) is the analysis and visualization of student data to improve the learning process. Siemens (2013) states that learning analytics (LA) is the “measurement, collection, analysis, and reporting of data about learners and their contexts, for the purposes of understanding and optimizing learning and the environments in which it occurs” (p. 1382). Joksimovic et al. (2019) advocated that “the concept of LA has been found in Pressey’s work (1927) through the development of the first automatic machine in the 1920s” (p. 40).

Siemens, (2013) noted that “learning analytics has multiple disciplinary roots as a field where Artificial Intelligence (AI), Statistical Analysis, Machine Learning, and Business Intelligence provide an additional description” (p. 1383) Oliva-Córdova et al (2020) mentioned that “LA’s aim is to improve decision-making and benefit the parties by optimizing the learning process through data analysis”. He further mentioned that “LA can be used in the classroom to improve the learning process of the teachers and to monitor and analyze the performance of the students during the teaching progress” (p. 1). The world is changing with the advent of technology, and LA can contribute a lot of data through technology.

LA could be valuable to better study learning processes such as creative problem-solving in Educational Robotics (ER). Nowadays ER activities have become more accessible in schools of every level. ER is an academic field of

study at the interface between computer science and engineering. Modular robotics is educational robotics designed with components that can be reconfigured to estimate different shapes and functions (Spacey, 2016). Different types of educational robots have been integrated into classrooms worldwide.

## 2. Educational robotics

Educational robotics (ER) can be considered a new trend in learning and its activities can be applied to any level of education from early childhood to graduation. According to Sullivan and Bers (2016), “robotics has provided educational opportunities for children to engage in Science, Technology, Engineering, and Math (STEM) subjects and coding activities and engineering concepts since kindergarten” (para-3). STEM activities are widely used to teach basic science-based concepts in primary and secondary education through the use of robotics (Harri et al., 2020; Smith & Watson 2019; Amo et al. 2020). STEM education can help manage potential future adaptation problems through the introduction of artificial intelligence and robotics (Narahara & Kobayashi, 2018). The basis of ER learning practices is found in Piaget and Papert's constructivist learning approach (Ackermann, 2001; Alimisis & Kynigos, 2009). Constructivism is considered to be one of the reasons for the integration of ER in primary and secondary education as an educational method based on constructivist education theory (Ben-Ari, 1998; Boudourides, 2003). For this reason, constructivist learning theory is considered the foundation of ER teaching and the learning process. According to the definition of constructivism, robotics can create new knowledge and understanding for students as a learning tool (Elby, 2000). For example, in a constructive way, teachers act as advisors and do not impart their knowledge directly through lectures unless students build some knowledge on their own through various experiences (Kamal et al., 2018).

To support constructivist learning, there are many robotics commercial-based kits available for teaching STEM, which use a specific software coding tool in a specific language (Amo, 2021). The combination of different components of the robotics kit, such as different types of sensors and interactions, customization, neutral gender color, and child-friendly programming environment design can make the robot accessible to all children regardless of gender, race, etc. To support the growing presence of educational robotics, there are many educational structures that are used to teach robotics to children from primary school to secondary education or high school (Veja, & Canas, 2018). ER activities can fulfill the purpose of learning from a wide range of disciplines and also change the role of teachers and students (Frangou, S. et al. 2008). For example, ER provides a hands-on learning experience that can help create a fun and engaging learning environment to keep students interested and engaged in learning (Eguchi, 2013). Teachers usually follow the traditional method of teaching for the learners but it can be more active to learn by adopting educational robotics (Lathifah et al. 2019). ER physical tools can support students to easily learn computational thinking skills (Isnaini et al. 2019). For example, The ER may allow a project-based approach that encourages students to engage in learning and increase their interest in STEM subjects in a variety of skills (Agatolio, 2018).

Nowadays, “STEM is widely used in primary and secondary education curricula, primarily through the use of robotics to teach basic science-based concepts (Harris, et al., 2020; Smith, et al., 2019). The importance of robotics in pre-university education is increasing. Furthermore, it has the potential to inspire young students, almost as a field of knowledge for learning complex concepts in a play environment or as a tool to introduce technology and other subjects to those students in an interesting and inspiring way (Vega, et al., 2018; Nugent, et al., 2013). ER could facilitate the teaching of STEM through activities applied in education as well as using complex robots (Eguchi, 2010; Alimisis, 2013; Mikropoulos, 2013). The constructivist learning theory proposed by Piaget and Papert (González et al., 2020; Alimisis & Kynigos, 2009; Ackermann, 2001) is the basis of ER. In an ER activity or lesson, students design, build, program, debug and share their robotic construction. When students create these personal and expressive robots, they create their own unique meanings for ideas. The robotics competition is another scenario that has become widely available around the world in recent years (Alvarez Caro, 2011; Eguchi, 2016; Chung, et al., 2014; Bazylev et al., 2014). This scenario may include a variety of robotics frameworks and may arouse interest in robotics among primary and secondary students. This is why some schools learn using ER

curriculum, subjects, materials, and classrooms to practice for these events. To support constructivist education, many robotics commercial-based kits are available for teaching STEM. These are usually made with specific robotic hardware that is programmed into a specific language using a specific software coding tool that only works in a specific commercial-based kit suite. Also, for many schools in developing countries, the acquisition of these toolkits can be an economic barrier (Serrano Pérez & Juárez López, 2019). Therefore, some authors have commented that it is important to integrate the open robotics framework (Serrano Pérez, 2019). Learning robotics is integrated with other disciplines and fields, such as learning analysis (Rodríguez, 2018). In the case of learning analysis, the goal is to understand how students behave using robotics to improve the learning process. Siemens, which supports connectivism, first entered the academic debate to define the analysis of learning from an educational perspective." (Amo et al., 2018, p. 1-2)

## 2.2 Diversity of educational robots

There is an important diversity in Human-Robot Interactions (HRI) but also in ER technologies.

*"In the diversity of Human-Robot Interactions (HRI), Yanco and Drury (2002) develop a taxonomy for considering the different types of interactions humans can develop individually or in a team when engaged with a robot. In the updated taxonomy later by Yanco and Drury (2004) they expand the categories for classifying HRI to integrate the social nature of the task by considering the different types of human and the human-robot proximity. The taxonomy could fit the HRI for the use of robots in the professional field but should be expanded to consider the design, the programming, and the building phase of educational robots. In education, robots are not only pre-existing technologies to be interacted with, but could also be a set to engage the learner in a designing, programming and building process through the robot creation such in the case of Cubelets modular robotic kit" (Romero, 2019, p.3).*

## 2.3 Modular educational robotics

Modular robotics are a type of robot designed with parts that can be reconfigured to estimate different sizes and functions (Spacey, 2016). According to Modular Robotics, National Science Foundation, modular robotics began as a spin-off from Carnegie Mellon University, where founder Eric Showcard created the Cubelets modular robots while doing his Ph.D. in 2008 and it was released to the public in 2010. There are some different types of educational modular robotics, such as Cubelet (CreaCube), Robo Wunderkind, Moss Robot, ClicBot, etc. Each of these modular robots can take advantage of popular computing platforms and expand its capabilities in robotics. In education, modular robotics are used to teach critical problem-solving skills such as collaboration, engineering, design, and computational thinking. Using evolutionary algorithms (EA) to find the best solution, modular robots can perform better in terms of power consumption and loading capacity (Yang, & Chen, 2000).



Figure 1. Robo Wunderkind modular robot

### 3. Learning analytics

In ED there's a variety of purposes to integrate learning analytics (LA) such as the understanding of how students behave using robotics to improve the learning process (Siemens, 2012). LA can also help evaluate a learning design based on educational intent using a set of real-time, behavioral-based data about student interactions in a learning environment (Wong et al., 2016). "Siemens, describes Learning Analytics as "the use of intelligent data, learner-produced data, and analysis models to discover information and social connections and to predict and advise on learning" . He also added that "it is less clean, but it does not try to modify the educational system", but rather uses the analytical results to improve it" (Siemens, 2013). LA in ER is science-based and can help to improve the teaching and learning of art concepts and skills (Filvà et al., 2019; Siemens, 2013). LA can be also used to identify low-grade students in educational institutions and work with them to enhance their digital skills (Oliva-Córdoba et al., 2021).

### 4. Method

We have used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to conduct the systematic review. We present the results of a qualitative systematic review of manuscripts on aspects obtained from research articles. We have quantified, categorized, and analyzed the ideas available to explain what has been researched and published until this moment. In this systematic review, we have considered 3 selected articles from scientific journals and Papers published during the conference activities from 2016 to March 2022. This work is intended to describe the state of the art of educational modular robotics in descriptive, school, and learning environments. To do this, the educational interventions published on the subject in recent years have been reviewed.

#### 4.1 Inclusion and Exclusion Criteria

The papers sought to review teaching and learning methodologies from the last 6 years used to learn concepts and skills related to modular robotics in K-12 education.

To achieve the reliability and security of the process recommended by PRISMA, the two authors are equally involved in all stages, including data search, selection, and extraction.

## 4.2 Trial Flow/Selection Process

The search found a total of 52 articles, of which 17 were dropped after being selected in 2016 and beyond. 13 out of 35 resulting articles have been removed due to duplication. After that, 1 additional article was canceled. The remaining 11 were abstractly analyzed to see if they covered the research questions. As a result, 8 more articles have been omitted, leaving 3 final articles that have been thoroughly studied. Thus, data were obtained for 3 articles, which were analyzed in the following sections. This data has been refined and clarified at a later stage.

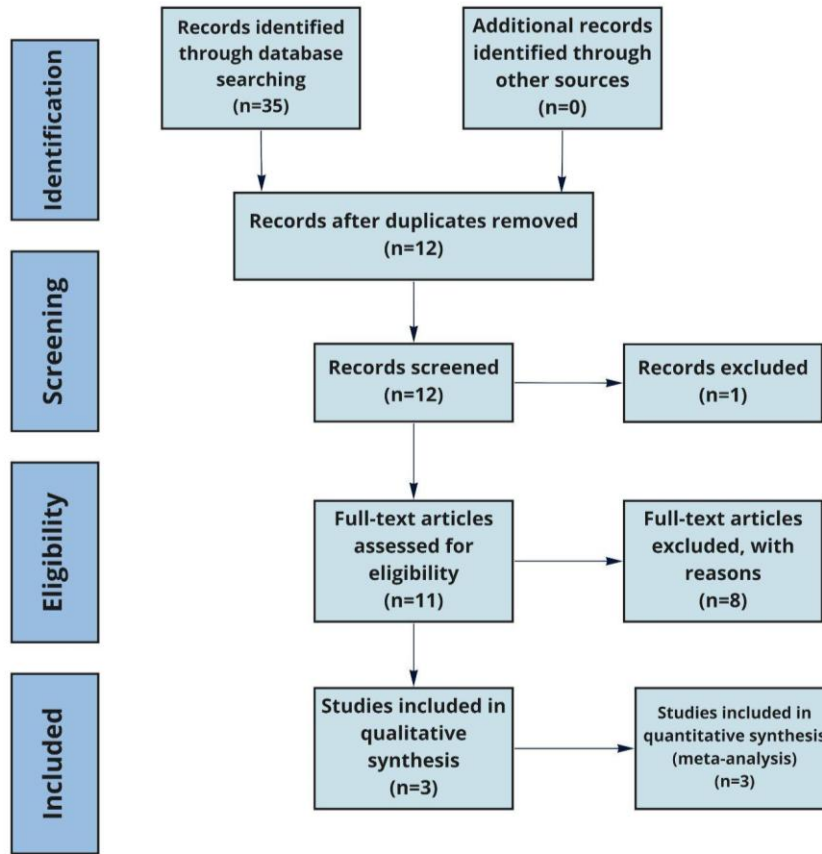


Figure 2. Flow diagram to show the study-selection process.

## 5. Learning analytics in modular educational robotics

The study of Amo et al (2018) analyzes ER. In relation to ER and LA, he identified two studies :

“One expressly applies learning analytics using machine learning techniques, specifically the Elbow Method, performing a k-means clustering (Scaradozzi et al. 2020). The other uses robotic sensors to collect environmental data (Hartigan & Hademenos, 2019), where students learn data literacy by analyzing the resulting data and making objective decisions. Both analytical actions are part of the foundation of learning analytics. With these two findings, we realize there is still a long way to go in developing the intersection of two scientific fields such as learning analytics and robotics sensors. Therefore, we observe the need to continue learning analytics and ER as applied to robotics sensors as a line of research”.

In Scaradozzi et al (2020) they engage participants with Lego Mindstorms EV3 and then analyze the Python programming sequence to analyze the following observables :

- *Motors: how many Motor blocks are contained in the sequence;*
- *Loops: how many Loop blocks are contained in the sequence;*
- *Conditionals: how many Conditional and Sensors blocks are contained in the sequence;*
- *Others: how many blocks are contained in the sequence belonging to different categories than Motors, Loops, and Conditionals;*
- *Added: how many blocks have been added, compared to the previous sequence;*
- *Deleted: how many blocks have been deleted, compared to the previous sequence;*
- *Changed: how many blocks have been changed, compared to the previous sequence;*
- *Equal: how many blocks have remained unchanged, compared to the previous sequence;*
- *Delta Motors: the amount of change in Motor blocks parameters, compared to the previous sequence (calculated only for blocks of the "Changed" category);*
- *Delta Loops: the amount of change in Loop blocks parameters, compared to the previous sequence;*
- *Delta Conditionals: the amount of change in Conditional blocks parameters, compared to the previous sequence;*
- *Delta Others: the amount of change in Other blocks parameters, compared to the previous sequence."*

After considering LA in modular robotics in Amo et al (2018), we revise Cubelets' supported CreaCube task analytics. Cubelets (CreaCube) are a set of cubic building blocks connected by magnets.

CreaCube task is "an ill-defined task where the player has to engage in a creative problem-solving activity (Romero et al, 2019). CreaCube task can be decomposed into several states that represent all possible configurations of the four cubes, the initial state shows the four disconnected cubes, and the final state allows each structure to run autonomously and allows the task to solve. Once students are aware of the functionality of these robotic pieces, they will be able to identify that they will be able to reuse the same design when creating future robots. CreaCube activity is considered a distinct process aimed at designing a solution that is innovative and suitable for the subject and work). Thus the activity is more likely to require creativity skills as there is no known method for solving problems. For example, CreaCube activity can fit into the technology-creative computational thinking section. As a creative problem-solving task, the "CreCube" activity is a unique process aimed at designing a solution that is innovative and suitable for the subject or task" (Palaude et al., 2022).

"The purpose of the CreaCube activity is to engage the player in a playful challenge to evaluate their creative problem-solving skills (Romero et al 2018). The CreaCube task presents the player-students with four robotic modular cubes that allow them to create an autonomous vehicle to reach the finish point without prior knowledge (Romero, M. et al., 2019). In the CreaCube task, participants need to monitor how the cubes behave and try to find the solution. The CreaCube task can be solved in various ways, but it is quite difficult to solve on the first try for players who are not familiar with it before (Romero, 2019). Task innovation and technology-driven problem solving for participants can affect their cognitive flexibility in the CreaCube task (Romero, 2019)." (Palaude, 2022, p. 6-9)

Cognitive flexibility is defined as the ability of a person to adapt to cognitive processing techniques in new and unexpected situations that may be internally associated with problem-solving tasks (Canas et al. 2003). For most participants, modular robotics is an unknown technology, especially for adults who are not familiar with such technology (Romero & Loos, 2018). "The purpose of the creative exploration is to understand the artifact to be able to solve problems that can help learners analyze creative problem-solving activities using parts of unknown modular robotics. CreaCube activities can help participants become more aware of their problem-solving strategies.



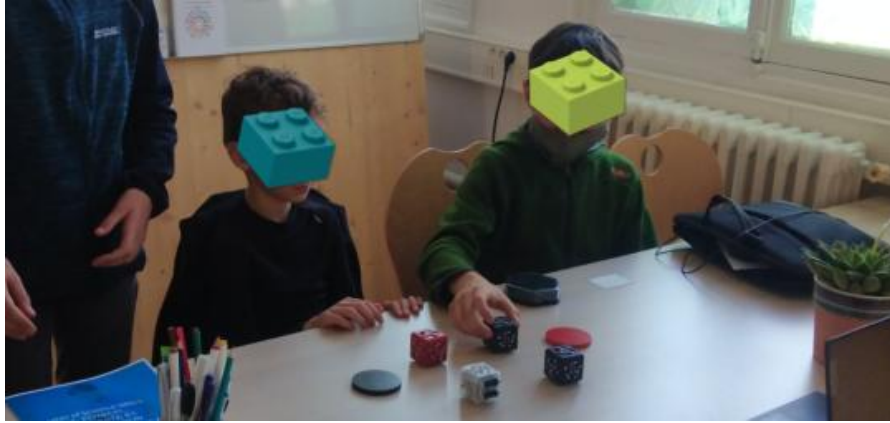


Figure 3. Children playing the CreaCube task with Cubelets.

## 6. Conclusion

In this report, our aim is to systematically review evidence of the effectiveness of modular educational robotics. The general purpose of these various studies is to improve the learning environment where modular robotics is taught. On one hand, it allows students to learn STEM and the development of transversal competencies in varying degrees of depth, and, on the other hand, it offers modular robotic solutions adapted to every learning need. CreaCube can be used to analyze the creative problem-solving process through a playful activity created from interconnected electronic cubes.

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