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Abstract

STEAM education stands for Science, Technology, Engineering, Art and Mathematics, and aims at familiarizing students with hands-on science and cutting-edge technology through interactive activities, by promoting the practice of educational robotics combined with arts and crafts. The merits of STEAM education have already been acknowledged in the global environment of Knowledge Economy (KE), offering lifelong competitive advantages to the participants. At this paper, we propose a novel challenge-based educational methodology for STEAM education following the cooperative and learner-centered educational approaches, aiming to promote creative thinking and effective collaboration. In addition, we present the RoboPathFinder project implemented by secondary education students through the guidance of their coaches, following the proposed methodology. The RoboPathFinder concept has been inspired by the Mars Pathfinder robotic spacecraft, being created with open source software, an Arduino board, ultrasonic sensors, gear motors and a solar battery.

Keywords: STEM, STEAM, educational robotics, learner-centered methodology, Knowledge Economy.

Introduction

STEAM education aims at familiarizing students and young people with hands-on science and technology, by offering interactive activities that cultivate creativity and an innovative way of thinking, in ways that conventional education cannot offer, impelling the need for a new pedagogical viewpoint, driven by our society's contemporary educational needs. The value of knowledge related with programming and robotics in primary and secondary education has already been acknowledged in the global KE era. Besides, familiarization with cutting edge technology offers competitive advantage, especially in economies under crisis (Atkinson&Mayo, 2010).

More precisely, knowledge has become a critical success factor for the global society and economy, known as KE, as a key to sustainable innovation and growth. "We are entering a new age; an age of knowledge, in which the key strategic resource necessary for prosperity has become knowledge itself—educated people and their ideas" (Duderstadtetal., 2005). In this context, students are expected to develop "soft skills", essential for their future such as effective communication and creativity, as well as, the capability for multi-disciplinary research approaches (Stamou, 2017).

The practice of educational robotics combined with arts and crafts, adding the "A" in STEM education, aims at approaching a wider range of students, such as female students that are traditionally underrepresented in engineering universities. The merits of STEAM education are considered to offer lifelong competitive advantages to the participants, helping

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also the "underachievers" to advance their competencies at school in general (Connoretal., 2015). More precisely, STEAM education promotes challenge-based learning, and cultivates the "engineering way of thinking", presenting a number of lifelong benefits to the participants, such as using imagination to develop multiple solutions to real life problems - known as creativity, optimism, systems thinking, collaboration skills, communication and ethics (Basham&Marino, 2013).

Considering Greece, during the last years, courses related with Informatics and Communication Technologies (ICT) have been included in primary and secondary education schools curricula. Furthermore, national educational robotics competitions have been established, while, students Olympic medalists in educational robotics gain direct access to universities.

At this paper, we propose a novel challenge-based educational methodology for STEAM education following the cooperative and learner-centered educational approaches, aiming to promote creative thinking and effective collaboration. The followed cooperative and learner-centered educational model aims to help the learners to acquire in depth scientific knowledge, while, it assists in cultivating their soft skills including creative thinking and effective collaboration. In addition, we present the RoboPathFinder project implemented by secondary education students through the guidance of their coaches, following the proposed methodology. The goal for the participants was to learn how to efficiently collaborate as a team, in order to design, create and program a functional robot, as well as, to present the outcomes of their work to the public. More precisely, in the following sections, the educational process and pedagogical perspectives are presented, followed by the implementation of the project and a discussion of the results. Lastly, the paper is concluded in the last section.

Educational process and pedagogical perspectives

Millennials' key characteristics

The Industrial-Age school system was not designed to meet individual learners, as it compartmentalizes learning into subject areas and students are expected to learn the same content in the same amount of time (Reigeluth, 1993). As a result, a number of students are forced to move on with the rest of the class, even if they have not acquired the sufficient knowledge, resulting to become "underachievers" and eventually to drop-out. This reflects on the general phenomenon of dissatisfaction and loss of trust in schools, which has been observed during the last decades, impelling the need for a new pedagogical viewpoint, driven by our society's contemporary educational needs.

Considering current generation of students is comprised by the so called "millenials", which present a number of distinguishing characteristics (Monaco&Martin, 2007). Millennials are those individuals being born from 1982 and afterwards and they influence and will continue to influence education as they return to it as educators. Millennials are confident, believing that their generation is capable of correcting societal ills. They are also keen on technology, with the younger ones being technology-natives and they (over)use internet, while they spent a considerable amount of time on social networking sites. Rickes (2009) points out that today's educator must understand the millennial generation audience and the way they learn, in order to be able to create a learning-centered environment and not only being the content expert. A transformation in teaching strategies should be implemented by intergrading creative content delivery in order to keep the students engaged and challenged both in and out of the classroom.

The learner-centered and the cooperative educational paradigms

Considering all the above, a new educational paradigm has to be adopted fitting all learners' educational needs, which can be referred as the learner-centered paradigm (Leeetal., 2016). The learner-centered paradigm aims "to evolve teaching into a learning centered classroom that focuses on student learning rather than on teacher delivery" (Monaco&Martin, 2007). More precisely, the basic principles of the learner-centered approach promote strategic thinking in order for the student to identify and accomplish complex learning goals, through motivational-based learning, where the learner progresses by her/his interests and personal goals by her/his own habits of thinking (Leeetal., 2016). In this way the learner's creativity is untangled and combined with the natural curiosity of the person to learn, the learning outcomes quality improves. Furthermore, the learner-centered approach takes into account the impact of the social influence in the learning process, such as social interactions, interpersonal relations and communication with others (Leeetal., 2016).

A related innovative educational paradigm to the learner-centered approach is the cooperative learning approach, inspired by the sport education principles, which highlights the value of self-action and research-based learning (Dysonetal., 2004). These principles are more efficiently implemented in the context of small teams, where the educator acts as a coach, and through interaction, cooperation and confrontation, the team seeks for solutions to the problems pursued (Slavin, 1996). In this context, a coach's role is to encourage her/his team to develop and work on skills that promote effective collaboration among team members. Effective collaboration is achieved when the results of the team's efforts are greater than what individual members could achieve on their own, by harnessing the different strengths of each individual personality.

One of the most crucial factors in collaboration is communication. Team members need to be able to express themselves clearly to each other and successfully manage channels of communication with regards to their project, aware of current challenges encountered and milestones reached. The ability to compromise is extremely important not only for results but also for team dynamics and work happiness, in order to reach the best possible solutions from an amalgamation of ideas. Each member has to act as a team player focused on reaching a common goal, conducting in a way that adds value to the shared work task, having trust among one another when sharing ideas and giving feedback (Slavin, 1996).

Proposed educational model

The merits of the learner-centered and cooperative educational paradigms can be perfectly combined into the STEAM educational process, in order to implement challenge-based learning, and cultivate the "engineering way of thinking". Additionally, a key objective of an effective educational process, considering STEAM education is to emphasize the importance for a correct pedagogical integration of the information and communication technologies (ICT). The role of technology in education has experienced increasing attention in the last decade. Both the rapid advances in education domain with a great scale of evolving requirements and the plethora of emerging technologies that are penetrated into the educational process contribute towards that end. The progressive development of the use of ICT will permit increasingly richer and more efficient contexts from a pedagogical viewpoint, making learning by discovery possible (GomezGalan, 2011).

In light of all these new technological challenges in the educational procedure, we propose a novel and adaptive learning methodology for STEAM education in practice that allows and contributes towards the consolidation of the knowledge in an effective and liberal way, by combining the merits of cooperative and learner-centered approaches. One of the most

important stages in such challenge-based methodology is to identify the challenges through the world exploration and conceive the basic idea through an amalgamation of different ideas from each team member (i.e. Idea Formation stage in Fig. 1). After this stimulating procedure, each team member should assign herself/himself a role according to her/his personal interests (i.e. Role Assignment stage in Fig. 1). Then, it is necessary to specify the artistic, technological and personal skills that are essential for completing the challenge, focusing on each member's individual role, but always through comprehension of the common goals (i.e. Planning stage in Fig. 1). Then, the involved participants (i.e., the team of the students) are ready to proceed towards the design and the creation of the artifact (that may interact dynamically with its environment), utilizing all the selected technological tools and taking advantage of the relative computer software and crafting resources (i.e. Design and Programming stage in Fig. 1). The final stage receives input from the other stages and the overall result will be disseminated to other participants, as well as, to other interested parties (i.e. Knowledge Sharing stage in Fig. 1). In that way this stage consists also an input for the first exploration stage, acting as a feedback process.

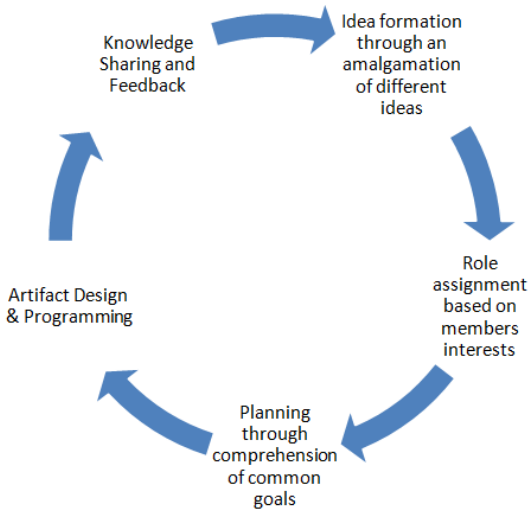

Figure 1 Proposed Educational Methodology.

Project implementation and outcomes

Team formation

The team was comprised by a small group of participants, and more precisely three teenager students in secondary education, who had not previously met each other, including both female and male members and their coaches. The goal for the participants was to learn how to efficiently collaborate as a team in order to design, create and program a functional robot, as well as, to present the outcomes of their work to the public. Hence, besides the technological aspects (i.e. programming, electronics, engineering, designing, physics, mathematics), soft-skills were also essential to be developed, such as cooperation, communication and presentation competencies. In addition, the project aimed to cultivate the participants' self-esteem and learning competencies, in order to assist in achieving enhanced

school and social performance, with the ultimate goal to become functional society members and future leaders.

For these reasons, we followed the proposed educational methodology, as presented in the previous section. The challenge-based educational methodology involved active role for all team members, while the coaches acted as mentors, offering guidance and support, as well as, the needed stimulation, in order to promote multi-disciplinary research and joy of discovery. Our priority was to create a learning environment based on cooperation and communication between team members and between mentors and team members, towards the direction of cultivating effective collaboration.

RoboPathFinder project implementation

The RoboPathFinder concept has been inspired by the Mars Pathfinder robotic spacecraft, being created with open source software, an Arduino Uno board, ultrasonic sensors, two servo motors and a solar battery, as depicted in Fig. 2 and Fig. 3. The team's goal was to build a functional robot, implementing a robotic artifact able to intercept the surrounding environment. More precisely, team members had to tackle with the issues of motor driving through Arduino / Raspberry Pi in order to create an autonomous robotic artifact, by investigating how to combine ultrasonic distance sensors and gear motors with the Arduino Uno, so as to enable the robotic artifact to avoid obstacles. In order for the setup to be functional, simple programs had to be implemented using the Snap4Arduino environment, while the Ardublock tool acted as a parser feeding the native Arduino IDE environment with the necessary code implementing the behavior of the artifact. Lastly, the robotic artifact was embellished using 3D printing tools (e.g., Tinkercad and Cura) to design and print the necessary 3D objects.

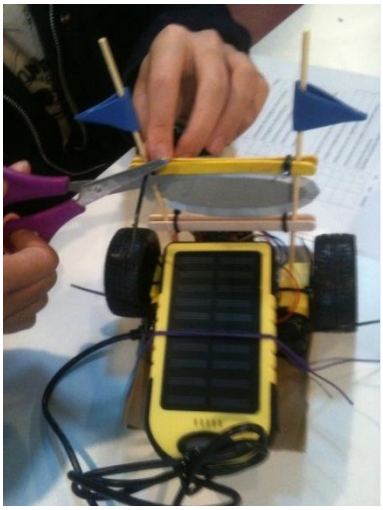

Figure 2 The RoboPathFinder (during process).

Furthermore, a number of technical issues had to be resolved, such as the following. Typical gear motors demand higher amperage to work than a led, so the students were not able to directly connect them to the Arduino's digital outputs. To cover the gap, a dedicated circuit had to be used. Also, considering the values from the ultrasonic sensors, they had to be

verified through the Arduino IDE's Serial Monitor tool. Therefore, from the Arduino IDE, Ardublock tool had to be invoked in order to show the readings of the distance between the sensor and the target in centimeters and exclude erroneous readings that appeared due to reflections of the emitted sounds to obstacles.

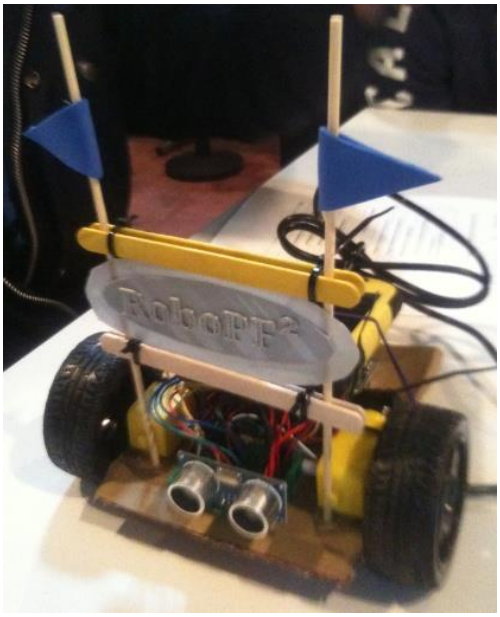

Figure 3 The RoboPathFinder (completed).

Pedagogical outcomes

Educational issues that appeared managed to be resolved in the relevant context, including not only technical, but also soft issues. Research-based way of thinking succeeded to be promoted: RoboPF was inspired by the Mars Pathfinder project as the students made their research on the internet about robots that avoid obstacles, stimulating their imagination. The team presented supplementarity: Each student focused on her/his individual interests, as for example one was interested more on the design of the craft, while the other was keener on programming. However, each team member has to acquire adequate knowledge on each activity, so they were encouraged to contribute also to the activities that there were not their favorites, at least to a degree. It has been observed that after familiarizing with activities that were not "favorite" in the beginning, after understanding that it is not so difficult as they imagined at first, they gained confidence and they asked voluntarily to contribute more. For example, one team member was involuntary to present the outcomes to the public and more eager on design and crafts, but after some presentation rounds he asked to present a part of the project by himself.

Conclusion

STEAM education promotes challenge-based learning, and cultivates the "engineering way of thinking", presenting a number of lifelong benefits to the participants. In the current paper,

we presented a novel educational methodology for STEAM education. The educational methodology of the followed learner-centered and the cooperative educational model paradigms involved active role for all team members, while the coaches acted as mentors, offering guidance and support, as well as, the needed stimulation, in order to promote multi-disciplinary research-based learning and joy of discovery. In addition, we presented the RoboPathFinder project following the proposed educational methodology, implemented by secondary education students through the guidance of their coaches, inspired by the Mars Pathfinder robotic spacecraft, being created with open source software, an Arduino board, ultrasonic sensors, gear motors and a solar battery. Our priority was to create a learning environment based on cooperation and communication between team members and between mentors and team members, towards the direction of cultivating creative thinking and effective collaboration. The participants not only acquired better understanding of the relevant scientific knowledge, but also cultivated their soft skills and succeeded to work as a team.

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