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The case of the Robotics Academy @ Frederick University: 21st Century Skills Developed through a Non-formal Educational Setting

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The case of the Robotics Academy @ Frederick University: 21st Century Skills Developed through a Non-formal Educational Setting

Ακαδημία Ρομποτικής του Πανεπιστημίου Frederick: Ανάπτυξη Δεξιοτήτων 21ου Αιώνα μέσα στα πλαίσια Μη-Τυπικών Εκπαιδευτικών Περιβαλλόντων Μάθησης

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Abstract

The Educational Robotics Curriculum developed by the Robotics Academy (Frederick University) provides a realistic, visually compelling, and motivating environment for integrating robotics as a cognitive-learning tool. The study evaluates the overall impact of the robotics educational curriculum delivered, in a non-formal educational setting, to develop the 21st century skills needed for today's globalized, hi-tech environment. Specifically, employing a mixed method approach; the study explores the development of students' critical thinking, creativity-innovation and collaboration skills, through hands-on, technology-based and unplugged activities. The analysis of the data collected through surveys, observations and focus groups, statistically and qualitatively revealed the positive impact and great potential of integrating robotics as a cognitive-learning tool to develop students' 21st century skills.

Key words: *educational robotics, non-formal teaching, 21st century skills, elementary school students.*

Περίληψη

Το Αναλυτικό Πρόγραμμα Εκπαιδευτικής Ρομποτικής που αναπτύχθηκε από την Ακαδημία Ρομποτικής του Πανεπιστήμιου Frederick παρέχει ένα ιδιαίτερα ενδιαφέρον και ελκυστικό μαθησιακό περιβάλλον μη-τυπικής διδασκαλίας και μάθησης με σκοπό την ενσωμάτωση της ρομποτικής ως γνωστικό-νοητικό εργαλείο. Η παρούσα ερευνητική εργασία διερεύνησε τη συνολική επίδραση του προγράμματος εκπαιδευτικής ρομποτικής σε περιβάλλον μη-τυπικής διδασκαλίας με σκοπό την ανάπτυξη δεξιοτήτων του 21ου αιώνα και συγκεκριμένα δεξιοτήτων κριτικής σκέψης, συνεργασίας, δημιουργικότητας και καινοτομίας. Η ανάλυση των δεδομένων που συγκεντρώθηκαν μέσω ερωτηματολογίων πριν και μετά την εκπαιδευτική παρέμβαση, παρατηρήσεων και ομάδων εστίασης αποκάλυψε στατιστικά και ποιοτικά τις θετικές επιπτώσεις και τις μεγάλες δυνατότητες ενσωμάτωσης της ρομποτικής ως γνωστικού-

νοητικού εργαλείου για την ανάπτυξη δεξιοτήτων του 21ου αιώνα για μαθητές δημοτικού.

Λέξεις κλειδιά: *εκπαιδευτική ρομποτική, μη-τυπική διδασκαλία, δεξιότητες 21ου αιώνα, μαθητές δημοτικού.*

Introduction and Theoretical Background

21st Century Skills

There is a great necessity for students, future citizens of the Information Society to develop various skills in order to survive in this globalized, interconnected, interrelated, competitive and rapid-changing society. These skills were named as 21st century skills. They have been outlined and described by various researchers and reports (e.g. Ananiadou & Claro, 2009; Bybee & Fuchs, 2006; Griffin & Care, 2105; Mojika, 2010; Rotherham & Willingham, 2010; Trilling & Fadel, 2009) and can be summarized as follows: communication, collaboration, critical thinking, problem solving, knowledge construction, creativity – innovation, self-directed learning, global citizenship and digital literacy. The development of the 21st century skills are important because of the changes in the global competition and collaboration, the focus on service economy, as well as the information growth. Given the aforementioned, the workforce needs have changed, the job tasks and type of work are changing and consequently the required skills are changing.

Having said the above, what is the context, the environment and the tools through which these skills can be developed? How technology can contribute to the development of students' 21st century skills that are considered important characteristics for today's globalized, interconnected world? The Educational Robotics Curriculum developed by the Robotics Academy at Frederick University aims to embrace all the above under its innovative umbrella.

Educational Robotics

Educational Robotics is a growing field with numerous researchers to have endorsed Robotics as educational tools (Frangou et al, 2008; Glăveanu, 2010). Robotics in the classroom has taken a global momentum especially because of its positive contributions in the teaching of science, technology, engineering and mathematics (STEM). Previous studies integrated robotics as an effective teaching method in the educational processes. These studies highlighted that in order to transform and improve the educational environment, robotics activities need to be appropriately designed and henceforth implemented in the educational practices (Bauerle, & Gallagher, 2003; Benitti, 2012; Papert, 1993). Robotics education mainly follows the constructionist educational approach developed by Papert (Papert 1980, Vygotsky 1980, Eguchi, 2010, Alimisis 2013). Constructionist learning, known as "learning through design" is based on the idea that individuals learn better when they are engaged in building and manipulating artefacts that are significant to them (Eguchi, 2010).

Research has shown that robotics integration in education promotes the development of student higher-order thinking skills such as application, synthesis, evaluation, problem solving, decision making, and scientific investigation (Resnick, Berg, & Eisenberg, 2000; Bers et al., 2002; Williams, Ma, & Prejean, 2010). Using robots for educational purposes allows the development of different personal abilities (Chen & Chang, 2008; Miller, Nourbakhsh & Siegwart, 2008) and the 21st century learning skills (Alimisis, 2013; Botelho, Braz & Rodrigues, 2012;Khanlari, 2013; Zawieska & Duffy, 2015).

The challenge emerges in response to how best to cultivate students' creativity in the 21st century. Technology plays a crucial role in assimilation of these skills. Emerging technologies such as robotics provide challenges and opportunities to the learners to develop innovative ideas, disruptive thinking and higher order learning skills.

The Two Philosophies

In order to achieve the above, robotics should be integrated as tools and not as subject matters in the educational practice. When robotics is integrated as a subject matter, as an autonomous entity, there is limited educational potential and value. On the other hand, robotics integration as a learning tool within a well-designed learning environment, exploits its full potential; therefore it upgrades and enhances the teaching and learning process and promotes school transformation (Eteokleous, et al., 2013). The intention of this approach is not to learn how to use the robotics package, and its programming software, but to use it as a tool within a specific educational context. In other words, robotics is employed as a tool to teach and deliver concepts within various subject matters such as Mathematics (Whitehead, 2010), Engineering (Craig, 2014), Science (Vollstedt, 2005), Physics, and even in non-technology related fields such as Biology, Psychology (Bers, Ponte, Juelich, Viera & Schenker, 2002; Craig, 2014; Eguchi, 2007, Eteokleous, et al., 2013;). Robotics integration in the teaching and learning practice is defined as the use of robotics by students as a tool that enhances their learning experience and supports the achievement of specific learning goals (Eteokleous, et al., 2013; Jonassen, 1999; Ward, et al., 2012;). The philosophy that underpins the current study focuses on the integration of robotics as a cognitive-learning tool, where students will have the opportunity to build and program "thinking objects". This approach embraces two main elements: to learn how to use the robotics package, and its programming software, and to use it as a tool within a specific educational context to achieve learning objectives (Bers, et al., 2002; Craig, 2014, Eguchi, 2007; Eteokleous, et al., 2013; Vollstedt, 2005; Whitehead, 2010).

The Educational Robotics Curriculum

The Robotics Academy at Frederick University Cyprus (http://akrob.frederick.ac.cy,) (https://www.facebook.com/AkadimiaRompotikis) was launched aiming to establish and stimulate educational robotics. It is a research and educational unit which promotes and conducts research in the area of robotics education. The activities of the academy are multidimensional, including the following: Educational robotics courses, School Visits, Professional Development Training sessions to educators, Research Activity, Collaborations with various educational and social organizations. Based on the aforementioned experience and the scientific results of the experiments along the classroom interventions the educational material was developed.

Specifically, the Robotics Academy developed an innovative curriculum for students and educators in elementary and secondary school levels. The philosophy and the pedagogical framework developed by the Robotics Academy serve as the backbone of the design of the educational robotics curriculum. It focuses on two elements: 1) Learning by Playing: building and Programming robots, and 2) Robotics as partners in Learning (Examine, Explore and Discover through Construction and Programming). It employs innovative approaches which trace on the learning theory of constructionism where students are expose to their own learning construction when engaging in the making of concrete artifacts.

The first parameter of the robotics curriculum is based on the relationship of Robotics and Constructivism (Bauerle & Gallagher, 2003; Williams, Ma & Prejean, 2010). Constructivism highlights the educational value of such exercises as the ones the integration of robotics in the educational practice can provide. Such exercises are based on the philosophy of "learning by constructing", giving students the opportunity to develop interactive "thinking objects" (Bers et al., 2014; Eteokleous, 2016; Kazakoff, & Bers, 2012, Kazakoff, & Bers, 2014; Puntambekar & Kolodner, 2005; Sullivan & Moriarty, 2009; Sullivan & Bers, 2015).

The following approach best describes the 2nd parameter of the educational robotics curriculum. Robotics integration in the teaching and learning practice is defined as the use of robotics by students as a tool that enhances their learning experience and supports the achievement of specific learning objectives (Bers, 2010; Bers, et al., 2014; Bernstein, et al., 2016, Eguchi, 2007, Eteokleous, et al., 2013, Thomaz et al, 2009). This approach is related to the learning with computers or computers as mindtools, initially introduced by Jonassen (1999), where computers and overall technology is introduced as students' partners within the teaching and learning process.

The educational robotics curriculum employs various educational robotics packages and visual programing platforms. The participants are engaged in hands-on, technology-based and unplugged activities related to robotics, based on the grounds of gamification, project, problem and inquiry based learning. Specifically, it includes presentations, educational games, documentary, rich audiovisual material, hands-on activities, interactive activities (building & developing robots), technology-based (educational software & simulations) and unplugged activities,

Main Aim

The current study evaluates the application of a pioneer educational robotics curriculum delivered, in a non-formal educational setting, aiming to develop students' 21st century skills. It investigates the role of robotics integration as a cognitive -learning tool to develop: Critical thinking, Creativity – Innovation, and Collaboration skills. The study addresses the following objectives:

To evaluate the overall impact of the robotics educational curriculum to the participating students, in regards to the development of Critical thinking, Creativity – Innovation, and Collaboration skills,

To examine the changes in the development of the aforementioned skills after the completion of the educational robotics curriculum (pre and post measurements),

To examine the role of the variables "Gender" and "Age" to the development of each of the aforementioned skills.

Research Methodology

A mixed method approach was employed, making use of quantitative and qualitative data (Creswell, 2003). The quantitative component was addressed through 3 different surveys, where each one measures different skill: 1) critical thinking, 2) creativity-innovation, and 3) collaboration. The questionnaires were taken from the Buck Institute of Education (www.bie.org) and were adjusted for the purposes of this study. They were translated in Greek and pilot tested. Specifically, 2 teachers and 5 students participated in the pilot study. The authors took into consideration participants' comments and accordingly adjusted the questionnaires. Qualitative data was collected through observations and focus groups.

Robotics Academy collaborated with a Private Summer School to provide robotics lessons to kids from 8 to 12 years old. Three Robotics Academy instructors delivered the lessons. The robotics courses duration was 5 weeks and the students experienced for one hour each day the educational robotics curriculum. Through the intervention four different educational robotics packages were used: 1) the Bee-Bots, 2) Lego WeDo, and 3) Lego Mindstorms NXT and 4) Lego Mindstorms EV3.

The robotics courses were delivered to four different age groups: Group 1: 8-9 years old, Group 2: 9-10 years old, Group 3: 10-11 years old, and Group 4: 11-12 years old. Pre- and post- questionnaires were given to 123 students. The response rate was 87% for the pre-measurement, and 78% for the post measurement (Table 1). The questionnaires were different for each grade due to the age of the students (as suggested by the Buck Institute of Education). For the younger groups (Group 1 and 2) a simple form of questionnaire was given, where a combination of smiley / sad faces and phrases (as responses) were used. However, for the Groups 3 and 4 a different form of questionnaire was used; the students were required to address various statements using a 5 Likert-type scale.

Table 1 – Students' Demographics

A/A	**Age**	**Students**			
		Pre		**Post**	
		Frequencies	**Percentages**	**Frequencies**	**Percentages**
Group 1	8-9 years old	24	23%	21	22%
Group 2	9-10 years old	28	26%	25	27%
Group 3	10-11 years old	30	28%	26	28%
Group 4	11-12 years old	25	23%	22	23%
Total		107	100%	93	100%

The SPSS package (version 19) was used to analyze the data gathered. Descriptive (frequencies, percentages, and medians) and non-parametric inferential statistics (Wilcoxon pared ranked test and Mann-Whitney U-test) were conducted, in an attempt to compare and contrast the pre- and post-measurement data. The qualitative data collected through observations and focus groups were analyzed by using the continuous comparison of data approach (Maykut & Morehouse, 1994).

Research Results

The study statistically and qualitatively examined the relationship between the robotics and the development of Critical thinking, Creativity-Innovation, and Collaboration skills, through the application of the educational robotics curriculum. The findings emerged from the analysis are encouraging since the positive impact of the educational robotics curriculum in developing 21st century skills has been revealed to a great extent. Overall, the analysis of pre and post measurements revealed changes in skills development. In all groups, Critical thinking skills revealed to have great increase. Specifically, for Groups 1, 3 and 4 statistical significant differences revealed in all parameters and for Group 2 statistical significant differences revealed for only one parameter (Asking questions regarding the assignments/ exercises). Regarding the Creativity-Innovation Skills increase was also achieved and statistical significant differences revealed in Groups 3 and 4 for specific parameters. Finally, Collaboration Skills were increased for only Group 2 students and statistical significant differences revealed for the parameter "Giving attention to the ideas of the other team members" (Table 2).

Table 2 – Pre and Post Measurements*

Skills	**Group 1**	**Group 2**	**Group 3**	**Group 4**
Critical Thinking	Statistical Significant Differences in all Parameters	*Parameter*: 1.Asking questions regarding the assignments/ exercises (p = 0,018)	Statistical Significant Differences in all Parameters (from p = 0,014 to p = 0,025).	Statistical Significant Differences in all Parameters
Creativity-Innovation	No statistical significant differences	No Statistical Significant Differences	*Parameters*: 1.Developing ideas (p = 0,011) 2.Selecting ideas (p = 0,014)	*Parameters*: 1.Integrate team members' comments to improve ideas (p = 0,053)
Collaboration	No Statistical Significant Differences	Parameter: 1.Giving attention to the ideas of the other team members (p = 0,038)	No Statistical Significant Differences	No Statistical Significant Differences

***** *The non-parametric statistic Wilcoxon paired ranked test was conducted*

The analysis showed that the variable "Gender" does not have any impact on the development of the skills under investigation. On the other hand, the variable "Age" revealed to influence the development of the 21st century skills. Specifically, for the younger ages (Group 1 and 2), two Critical Thinking skills parameters revealed to have statistical significant differences during pre-measurement; and during post-measurement all parameters in Critical Thinking skills revealed to have statistical significant differences between the age Groups 1 and 2. Along the same lines, "Age" revealed to influence different parameters during pre- and post-measurements for Creativity-Innovation skills for age Groups 3 and 4. Finally, age Groups 1 and 2 revealed to have statistical significant differences during post-measurement for Collaboration Skills (Table 3). Given the aforementioned, it seems to be important for students to experience educational robotics during their early childhood.

Table 3 – The role of the variable "Age"

	Pre		**Post**	
Skills	**Group 5 & 6**	**Group 7 & 8**	**Group 5 & 6**	**Group 7 & 8**
Critical Thinking	Parameters: 1.Information use from various sources (p= 0,925) 2.Explain the importance of an idea (p=0.937)	No Statistical Significant Differences	Statistical Significant Differences in all Parameters (p = 0,00)	No Statistical Significant Differences
Creativity-Innovation	No Statistical Significant Differences	Parameters: 1.Developing ideas (p = 0,002) 2. Improving ideas (p = 0,007).	No Statistical Significant Differences	*Parameters:* 1.Choosing ideas (p = 0,012) 2.Ideas' improvement (p = 0,038).

Collaboration	No Statistical Significant Differences	No Statistical Significant Differences	*Parameter:* 1.Respect team members (p=0,012)	No Statistical Significant Differences

** The non-parametric statistic Mann-Whitney Test was conducted*

The observations and focus groups confirmed, complemented, and further explained the results of the quantitative analysis. Students' excitement, the opportunities provided through the educational robotics curriculum, its value and importance was highly articulated by the students. The students strongly emphasized the necessity of experiencing something similar in a formal educational setting. Additionally, the qualitative data gave important insights in regards to the instructors' and students' roles, the guidelines, support and help needed by the students, as well as how to: structure and deliver the lessons, solve discipline, technical and other problems, form students-teams (e.g. mixed-gendered teams revealed to work more efficiently).

Overall, the results of the study suggest that educational robotics positively influence the development of 21st century skills and specifically Critical Thinking, Creativity-Innovation and Collaboration. Results reveal that is possible to employ robotics within the educational practice within a well-designed learning environment (in this case using the pioneer educational robotics curriculum developed by the Robotics Academy) where students experience various hands-on, technology-based as well as unplugged activities.

Conclusion

The paper has important educational and theoretical significance. It adds to the relatively new body of literature related to robotics integration within the teaching and learning practice and its impact on specific skills development. The results of the study revealed the great potential of integrating robotics as a cognitive-learning tool, promoting research in the field of educational robotics in order to further examine and define the appropriate learning pedagogies and teaching approaches to be employed. Additionally, it underlies the value of integrating robotics as an innovative form of teaching and learning to be applied in schools, in order to promote the development of the skills needed for future citizens. In order for students to become active citizens and promote local and national innovation and development; they should be provided with those opportunities and experiences that will adequately prepare them for the unknown.

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