

Are 21st Century Skills Evaluated in Robotics Competitions? The Case of First LEGO League Competition

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Abstract: Citizens of the 21st century need to acquire skills related to collaboration and project design in order to be able to meet the current demands for the workplace. Challenge-based learning contexts such as FIRST LEGO League (FLL) Competition connect students with professionals and enable them to solve real-world problems and develop 21st century skills. Main aim of this study is to examine whether 21st century skills are evaluated in the context of FIRST LEGO League (FLL) Competition within Core Values, Project and Robot Design competition categories. Our study is based on an expert analysis of the 21st century skills as presented in the FIRST LEGO League (FLL) evaluation rubrics. Results show that the main 21st century skills are displayed at the FLL evaluation rubric, in particular communication and problem solving. This study could be helpful to FLL experts and coaches and could enable them to better target 21st century skills in the teams' training and evaluation.

1 INTRODUCTION

The World Economic Forum (2016) projected that from 2020, there will be a shift in employee skill requirements. Most needed skills would be (Complex) problem solving, Critical thinking, Creativity, and Coordinating with others.

Most curricula in formal education in primary and secondary school cover science and math subjects, however, less effort is applied in developing creativity and problem solving (Pellegrino and Hilton, 2012) - skills that are usually identified as 21st century skills (Binkley et al., 2010; Voogt and Pareja Roblin, 2012). Formal learning alone is not sufficient to anticipate these evolutions in society since it takes too long to set it up (Baert, 2000). In order to reinforce the development of students' skills, new learning methods need to be implemented in both formal and informal educational contexts. As Trilling and Fadel (2009) points out "new learning methods should include inquiry, design and collaborative learning projects".

During the last decade, results from different studies in the field of educational robotics (ER) highlight that primary and secondary school students' engagement with ER has the potential to transmit key skills for future citizens and equip them with important for the 21st century skills (Eguchi, 2013; Afari and Khine, 2017). ER is popular among students of all ages however, it is mainly being applied in informal learning contexts (Alimisis, 2013). Robotics competitions is an informal educational context that offers a lot of opportunities for learning and proposes new learning methods.

In our research, the main aim is to explore whether 21st century skills are evaluated in the context of First Lego League (FLL) competition. We will study the 21st century skills (as defined in the most mentioned frameworks) in comparison with the categories and skill areas of the FLL evaluation rubric.

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2 21st CENTURY SKILLS

Puncreobutr (2016) states that the 21st century context requires a new set of competences and skills such as critical thinking, creativity and innovation, cross-cultural understanding, information and media literacy, career and learning skills. This new set of skills goes far beyond the 20th century skills addressed in formal education (Wisniewski, 2010), based on the 3 R's of Reading, wRiting, and aRithmetic and focusing on the "lower levels of Bloom's taxonomy—knowledge, comprehension and application". According to Trilling and Fadel (2009), 21st century skills are those skills required to succeed in learning, working, and living.

Given the highly informal nature of 21st century skills (Kickmeier-Rust and Dietrich 2012) and the fact that researchers and educational projects have developed different definitions of the 21st century skills (Voogt and Pareja Roblin, 2012), there is yet no commonly accepted definition nor list of skills (Romero et al., 2015). However, the existing frameworks are largely consistent and generally focused on skills related to communication, collaboration and problem solving.

Our aim is to better understand the evaluation of 21st century skills in the context of robotics competitions and in particular in the FLL Competition. To achieve that, we will study the 21st skills century skills as reported by Romero et al. (2015), in the context of Game-based Learning Their research was based on the Voogt and Pareja Roblin (2012) meta-analysis of the six following frameworks: , P21 (2007), EnGauge 21st century skills (Metiri Group and North Central Regional Educational Laboratory, 2003), Assessment and teaching of 21st century skills (ATCS), National Educational Technology Standards and International Society for Technology in Education (NETS/ISTE) framework, competences for new millennium learners by Organization for Economic Cooperation and Development (OECD, 2005), and Center for Social and Economic Research (Gordon et al., 2009). In this research, the focus is on the eight most mentioned skills of the 21st century skills frameworks, as stated by Romero et al. (2015), (Figure 1).

From the perspective of skills development and evaluation, some authors consider that 21st century skills should be instructed early from primary school levels and be addressed both in formal and in informal learning settings (DeJarnette, 2012). However, as mentioned above, formal learning alone could not be sufficient, since it takes too long to set it up (Baert,

2000). In this regard, according to Voogt et al. (2013), there is substantial potential to acquire 21st century skills in informal learning settings. Furthermore, the adoption of active learning methodologies seems to encourage self-regulated learning and help students develop these skills (Bell and Kozlowski, 2008).

Mentioned in all Frameworks	Mentioned in most Frameworks
<ul style="list-style-type: none"> • Communication • Collaboration • ICT literacy • Social and/or cultural skills 	<ul style="list-style-type: none"> • Creativity • Critical Thinking • Problem solving • Develop quality products/ productivity

Figure 1: 21st century skills mentioned in six related frameworks (adapted from Romero et al., 2015).

Active learning enhances engagement in learning tasks and offers significant added value to provide learners with the abilities to cope with new challenges, solve problems of real life, and adapt to changes in technology and knowledge (Edens, 2000).

When developing, assessing and evaluating 21st century skills, two main areas can be defined (Pellegrino and Hilto, 2012): Interpersonal and intrapersonal domains. These authors state that research in formal education, e.g. English language arts, illustrated the potential for developing both intrapersonal and interpersonal domains of 21st century skills, and its relation to motivational factors. Nevertheless, the authors admit that these domains are difficult to measure in formal instruction, as they focus on domain-specific learning goals.

Furthermore, Ma and Williams (2013), studied the development of 21st century skills in a robotics competition (FLL) from learners' standpoint. The authors found that teamwork was one of the more commented aspects when students were asked what they have learned from the FLL process.

From this review on the development and evaluation of 21st century skills in informal and active educational contexts, we can see that a team-based activity with robot design could assess most of these skills.

2.1 21st Century Skills in Educational Robotics

In the context of active and informal learning settings, research on the 21st century skills is just beginning. Our search for relevant literature was carried out with a selective literature review, through the research databases: Science Direct and EbscoHost. The two

search engines were chosen because most of the journals in the field of education can be found via these engines. We used two keywords: “21st century skills” and “robotics education” and publication years 2013-2019. From this process, 118 papers emerge. After getting the results from the two databases, each abstract and reference section were classified. All the references on 21st century skills and robotics education cited were also included and cross-referenced with the results found in the first search. From the database only 10 papers stand. Furthermore, up to authors’ knowledge, no research has been published in the particular topic of skills’ evaluation in robotics education.

Most of the studies in the field use self-reported questionnaires to measure students’ and teachers’ perceptions on the improvement of knowledge and skills in programming, problem solving, teamwork, project management, and communication (Petre and Price, 2004; Nourbakhsh et al., 2005; Robinson, 2005). However, the following studies aimed to measure skills’ improvement in the area of ER. Barker and Ansorge (2007) measured how robotics activities improved students’ achievement in science, engineering and technology in a quasi-experimental setting. Also, Williams et al. (2007) found that students’ physics content knowledge improved after a summer camp on robotics, however, it failed to show improvement on skills such as scientific inquiry. In our study, we are going to go a step further and attempt to study which skills that are being evaluated in the context of a robotics competition. To further look into the skills developed in a competition, first the educational benefits that ER brings regarding the acquisition of 21st century skills will be examined and then the specific context of robotics competitions will be presented.

The skills that students can acquire in the area of 21st century framework through ER activities are really important. First of all, according to Eguchi (2013), collaboration skills, communication skills, creative thinking, and critical thinking/problem-solving (4Cs), all skills that are needed to be successful as a 21st century citizen, can be targeted in an ER course. According to Eguchi (2017), “educational robotics is rich with opportunities to integrate not only STEM but also many other disciplines, including literacy, social studies, dance, music, and art”. Eguchi’s view on ER’s potential to be integrated across disciplines is in line with the Partnership For 21st Century Skills P21 (2015), that supports that it is important to “build understanding across and among key subjects as well as 21st century interdisciplinary themes”. Furthermore, Eguchi

(2017), underlines that in ER settings “students have the opportunity to find ways to work together to foster collaboration skills, express themselves using the technological tool, problem-solve, and think critically and innovatively”. The need to develop skills such as critical thinking, problem solving, communication and collaboration is also highlighted by P21 (2007).

2.2 21st Century Skills in Robotic Competitions

Regarding the context of robotics competitions, goal-oriented and project-based learning (PBL) approaches to learning are employed (Eguchi, 2016). Given the fact that PBL supports 21st century learning goals, (Buck Institute for Education, 2019), we could infer that robotics competitions can promote 21st century skills development. To be more precise, in the context of First Lego League (FLL) Competition, students perceive that they have improved their learning about real-world applications, problem solving, engagement, communication, and the application of the technology/engineering cycle (Chalmers, 2013) skills that are related to the 21st century skills framework. In particular, problem solving skills development is highly addressed in the context of FLL Competition (Chen, 2018; Varnado, 2015). In addition, it has also been reported that through FLL Competition, the participants develop their collaboration skills (Ma and Williams, 2013). The learning outcomes are significant in the context of the FLL competition: participants are equipped with necessary skills important for success in the 21st century.

2.2.1 Evaluation of the 21st Century Skills in Robotics Competitions (FLL)

Ma and Williams (2013) studied the potential of FLL for teaching 21st century skills. It was found that FLL provided opportunities for acquiring many 21st century skills, in particular systems thinking, decision making, problem solving, teamwork, conflict resolution, flexibility, perseverance, and self-management. However, all these skills outlined above, have been reported by FLL participants. Our research aims at going one step further and investigating whether 21st century skills are also evaluated in the context of FLL.

2.2.2 Context: First Lego League Competition

FIRST LEGO League Competition (FLL) is an inter-

national ER competition addressed to students from 9 to 16 years old (FIRST LEGO League, 2019). The competition takes place in a lot of countries around the world and the participants are assessed by the same evaluation criteria regardless of the country in which they compete. FLL Competition always has a theme, the theme from 2018 season was “Hydrodynamics” (FIRST LEGO League). Teams compete in 4 categories, Robot Design, Core Values, Project and Robot Game. The content of each category will be briefly presented below.

First of all, in the Robot Design category, the teams are asked about the design of their robot in an interview called the technical review (Kelly and Daudelin, 2008). The judges look for well-designed robots that can accomplish missions in consistent, clever or unique ways (Kelly and Daudelin, 2008). As far as Core Values category is concerned, the judges make an evaluation based on how the team members work together to accomplish a given task. Teams show “Gracious professionalism” - meaning to act gracefully and respectfully to teammates, other teams, and visitors to the competition (FIRST LEGO League, 2019). If a disagreement comes up, the judges will expect the team members to listen to each other and professionally resolve the disagreement. The Project category is one of the non-robotic categories of the FLL competition and resembles to a science fair (Kelly and Daudelin, 2008). Based on the theme of the competition, the teams carry out a research, regarding a real-world and present their research and solutions. Teams are urged to choose a topic that has a direct impact to the community. The teams are asked to present the original research, e.g. personal interviews with scientists or information discovered during experiments in the judging rooms and in their pits. In the above-mentioned categories of the competition, teams are evaluated based on the respective evaluation sheets that will be presented in the instruments section (3.2.).

3 OUR STUDY

The main aim of our study is to explore the evaluation of 21st century skills in the context of the FLL competition analyzing the FLL rubric. This research is a first step in the study of 21st century skills in comparison with the categories, skill areas and sub-skill areas (items) of the FLL evaluation rubric.

The Research Question that will guide our work is: Can 21st century skills be evaluated using the FLL rubric?

3.1 Design

As previously mentioned, our main objective is to study if 21st century skills are evaluated in the competition by analyzing the evaluation rubrics used by the judging committees. An interpretative paradigm, with a qualitative methodology and an expert evaluation technique has been chosen to retrieve data.

Regarding the expert evaluation process, the 21st century skills table (Figure 1) was compared and contrasted with the evaluation rubrics for each competition category by 4 experts. The 21st-century skills table includes the following 8 skills: communication, collaboration, social/cultural skills, ICT literacy, creativity, critical thinking, problem-solving and development of quality products. These 8 skills were juxtaposed and contrasted with FLL evaluation rubrics in order to examine whether 21st century skills are evaluated in the competition. The experts examined carefully the evaluation rubrics and their reference to 21st century skills. To solve the issue of coding reliability, researchers worked together and disagreements were solved after discussion.

3.2 Instruments

The instruments used for data retrieval were the official evaluation sheets as retrieved by the official FIRST website <https://firstinspires.org>. There are three evaluation rubrics corresponding to each of the three judging committees Robot Design, Core Values and Project. The evaluation of the Robot Game is not based on a rubric related to assessment of skills, but rather on a scoring system for accomplishing missions. For this reason, Robot Game evaluation will be excluded from this analysis. The three evaluation sheets Robot Design, Core Values and Project share the same structure and instructions. Regarding structure, in each evaluation sheet, the team is evaluated based on 9 sub-skills each corresponding to 3 main skill areas. The judge is instructed to evaluate the teams' sub-skills by choosing what best describes the team's accomplishments among: “Beginning”, “Developing” “Accomplished” and “Exemplary”. Additionally, judges are asked to provide written comments under each skill area as feedback for the teams. The evaluation rubric for each judging committee is further explained below:

In Robot Design, the teams are evaluated on the following skill areas: mechanical design, programming and strategy and innovation (Judging

Rubrics, 2018). In mechanical design the teams are evaluated based on the robot’s durability and mechanical efficiency meaning the “Economic use of parts and time; easy to repair and modify” (Judging Rubrics, 2018). The second skill area is Programming, and teams are evaluated in programming quality, programming efficiency and automation/navigation. The third skill area is strategy and innovation and its evaluation is based on the following sub-skills: design process, mission strategy and innovation (Judging Rubrics, 2018).

The Core Values evaluation rubric contains the main skill areas, inspiration, teamwork and gracious professionalism (Judging Rubrics, 2018). Inspiration is evaluated based on discovery, team spirit and integration, while teamwork is evaluated based on effectiveness, efficiency and “kids do the work” referring to “Appropriate balance between team responsibility and coach guidance” (Judging Rubrics, 2018). Gracious professionalism is evaluated based on inclusion, respect and “coopertition” - spirit of friendly competition and cooperation with others (Judging Rubrics, 2018).

As far as Project category is concerned, the three main skill areas are research, innovative solution and solution development (Judging Rubrics, 2018). First, research skill area is divided into the following sub-skills: problem identification, sources of information and problem analysis. The second skill area is evaluated based on team solution, innovation and solution development. Solution development refers to the “Systematic process used to select, develop, evaluate, test, and improve the solution” (Judging Rubrics, 2018). Finally, presentation is assessed based on sharing, creativity and presentation effectiveness (Judging Rubrics, 2018). Based on the sub-skills area analysis, it could be inferred that Project category is related to Project Based Learning.

3.3 Data Analysis

To study the link between the rubric and the 21st century skills, we had to take into account all three levels of analysis of the Rubric, corresponding to categories (Robot Design, Core Values and Project), the skill areas (9) and sub-skills (27). The procedure of the data analysis was based on an expert evaluation of the table, where 4 experts at Education and Robotics (two teachers and two researchers, one of them with experience in FLL) classified all 27 sub-skills of the evaluation rubric in 8 categories corresponding to the 8 skills of 21st century framework.

4 RESULTS

In this study there are two levels of analysis corresponding to the Categories (3) and skill-areas (9) of the FLL Rubric (Judging Rubrics, 2018). The 21st century skills (Romero et al., 2015) were compared to the two levels of analysis of the FLL rubric categories and skill areas (Figure 2).

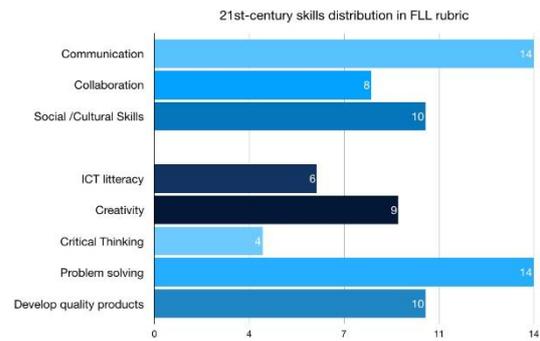


Figure 2: 21st-century skills distribution in the FLL Rubric.

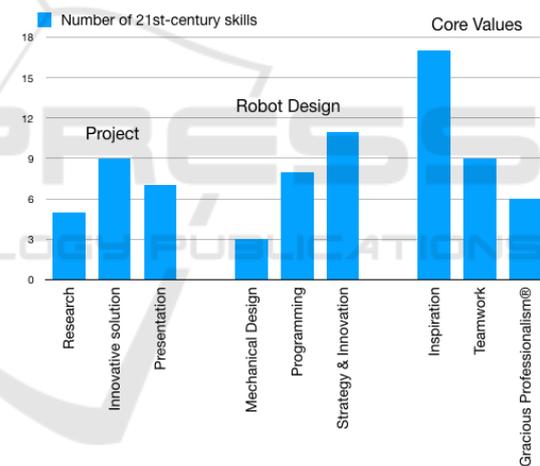


Figure 3: FLL Evaluation matrix VS 21st-century skills.

Analyzing the results displayed in Figure 2, in the Robot Design category, 21st century skills are reported in the rubric 22 times. Strategy/Innovation skill area refers 11 times to 21st century skills, programming skill area 8 times, while Mechanical Design 3 times. Project is the category measuring less skills, they are in total 21. Finally, Core Values is the category measuring more times the 21st century skills with 29 entries. In particular, the skill area Inspiration measures 21st century skills for 17 times, while Gracious Professionalism, and Teamwork 6 times each.

According to the results, the most evaluated 21st century skills are communication and problem

solving (Figure 3). Problem solving and communication are both displayed 14 times in the FLL rubric. Interestingly, the less evaluated skills are critical-thinking and ICT literacy- they are measured 4 and 6 times respectively.

5 DISCUSSION

The main aim of this study was to explore the evaluation of 21st century skills in the FLL Competition, using the FLL evaluation rubric. Up to our knowledge, there is no previous research regarding the evaluation of the 21st century skills in this context. Ma and Williams (2013) studied the case of FLL Competition from the point of view of exploring its potential for teaching 21st century skills. Continuing in this line of research, our research results on the FLL Competition encourage the development of the 21st century skills as the evaluation sheets used by the judging committees assess teams according to the 21st century skills.

The four skills most often assessed in the FLL evaluation rubric are presented and discussed in the table 1.

Further discussing the results, on one hand, the importance of the Communication and Social / Cultural skills is highlighted. These skills are evaluated in a number of FLL sub-skill areas, and allow researchers and coaches of the Competition to reflect on the importance of teamwork, respect and sharing in the process of the competition. The importance of teamwork in the FLL competition was also pointed out by previous research in the field (Petre and Price, 2004; Chalmers, 2013). According to Chalmers, the FLL participants perceive the importance of teamwork: they gain new ideas and/or different perspectives when communicating with other students. Our contribution to current literature lies on the fact that teamwork and communication skills are not only self-perceived skills by FLL participants but, they are now traced in the official FLL evaluation procedure.

On the other hand, Critical Thinking and ICT literacy are the least evaluated skills in the rubric. The first could be due to the fact that students between 9 and 16 years old still demand a high guidance from coaches and teammates (Suthers and Hundhausen, 2003). Additionally, it could be inferred that in the FLL evaluation rubrics, a greater emphasis is placed on Problem Solving competence, rather than on Critical Thinking. As also pointed out in previous research (Chen, 2018; Varnado, 2015), problem solving skills development is highly addressed in the

Table 1: The most addressed 21st century skills in the FLL Evaluation Rubric.

21st century skills	FLL Categories and skill areas evaluate (and can develop)
Communication	Project category, and Presentation skill area in particular evaluate this skill. Also, Core Values category (scoring higher in our study), with Inspiration and Teamwork to be the skill areas most closely related to this 21st century skill.
Problem Solving	Programming and Strategy and Innovation skill areas (from Robot Design category) are the areas that are most closely related to problem solving.
Develop Quality Products	Both Robot Design and Project (Innovative Solution and Inspiration skill areas) focus on planning and managing useful robots for real needs that are tested during the competition.
Social/Cultural skills	As in the above-mentioned Communication skill, Social/Cultural skills are mainly measured in Project and Core Values categories.

context of FLL Competition. As far as ICT skills are concerned, they are considered to be less frequently present in the FLL evaluation rubric and this could be due to the fact that FLL focuses on the development of engineering and programming skills (Oppliger, 2002) rather than the development of ICT skills. In accordance with this finding, Romero, Usart and Ott (2015) stated that the 21st context requires a new set of skills that go beyond the obvious information and communication technology (ICT) literacy.

Our findings are of particular interest to the coaches who will now be better aware of the skills that need to be reinforced during FFL training. Additionally, coaches could integrate suitable activities to address their team members' needs by making amendments to the existent training plan.

6 CONCLUSIONS

This study addressed the topic of 21st century skills evaluation in the context of FIRST LEGO League. The results from our exploratory study enable us to

draw the following conclusions:

- 21st century skills are indeed evaluated in the FLL competition through the evaluation rubric for each category (Robot Design, Core Values and Project). The 21st century skills evaluated in the competition are communication, collaboration, social/ cultural skills, ICT literacy, creativity, critical thinking, problem solving, developing quality products.
- The FLL evaluation rubric gives particular emphasis on the evaluation of Communication and Problem Solving skills.
- The FLL rubric is a 21st century skills evaluation instrument that FLL coaches and experts should take into account when delivering ER training sessions. In addition, the skills outlined could be integrated in the teaching of robotics in the formal curriculum. Last but not least, the teaching of these skills should be included into future teachers' training programs.

It must be underlined that this exploratory study is a first step in the research of how 21st century skills are reinforced and can be evaluated in the context of ER. Further research -as part of a PhD study- will include the integration and the evaluation of 21st century skills in the teacher training for educational robotics.

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