Learning Experience Through RoboCupJunior: Promoting Engineering and Computational Thinking Skills through Robotics Competition

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Learning Experience Through RoboCupJunior: Promoting Engineering and Computational Thinking Skills through Robotics Competition
(Research to Practice)

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Introduction

This paper presents a case study which examines the effect of the RoboCupJunior competition on the US team members who participated in RoboCupJunior World Championship in 2013, Eindhoven, the Netherlands. RoboCupJunior (RCJ), an educational robotics initiative, aims to enhance learning through educational robotics competitions around the world. RCJ is a division of RoboCup, a robotics initiative aiming to promote Robotics and AI research, by offering publicly appealing, but formidable challenges. RoboCupJunior World Championship has been held in conjunction with RoboCup World Championship since 2000. RCJ has three distinguished leagues – Soccer, Rescue and Dance, which are familiar and attractive to students from all over the world. Each league offers diverse robotics challenges that require using technologies that are typical in the field of robotics. RCJ has been one of the most popular educational robotics competitions in various countries including Australia, Germany, Portugal, the UK, Japan, China, and Singapore.

In the US, RCJ was introduced in 2001 when RoboCup World Championship was held in Seattle, WA. Since 2002, the RCJ US competitions have been held in New York/New Jersey area annually. There were other RCJ competitions held at MIT, Duke University and CUNY Graduate Center in the past. This study examines how the participation in RCJ competitions have effectively influenced the the learning experience of US team members who participated in RoboCupJunior World Championship in 2013, Eindhoven, the Netherlands. This case study uncovers how participating in RCJ has enhanced the learning of various skills and knowledge among participating students from the US.

Following sections introduce robotics in education, educational robotics competition, and RCJ before presenting the studies on participating students’ learning experience through RCJ.

Robotics in Education

Benitti [1] points out the astounding increase of popular interest in robotics in the last several years. The availability of robotics for both graduate and undergraduate levels of education as well as for school-aged children is growing rapidly [2, 3]. Mataric urged us about a decade ago that robotics has “the potential to significantly impact the nature of engineering and science education at all levels, from K-12 to graduate school” [3, para 1]. In higher education, most of the courses that utilize robotics are for computer science/engineering related areas especially with introductory level courses [2, 4]. Drew, Esposito, and Perakslis point out that LEGO Mindstorms, an educational robotics kit widely available around the world, has been
integrated into curriculums at many higher education institutions across the world including MIT, Brown University, University of Maryland, Tufts University, University of Aarhus at Denmark, University of Utrecht in the Netherlands, Trinity College Dublin in Ireland, and University of Manchester in the U.K. [4]. For grades of K-12, most robotics activities are extra-curricula (i.e. after school programs and summer campus) [1, 5, 6]. This is the case in various countries, but especially in the U.S. Elkind [7] emphasizes that educational robotics opens a door for children to learn mathematics and scientific concepts through the method of inquiry, as well as to develop technological fluency. Through the systematic study of scientific literature on the use of educational robotics in schools, Benitti identifies that studies on educational robotics focused on the fields of mathematics and physics [1]. It also indicates that the skills developed through educational robotics are identified as thinking skills (observation, estimation and manipulation), science process skills/problem-solving approaches, and social interaction/teamwork skills. Several studies show that educational robotics provides effective learning opportunities for students in both content areas not only in mathematics and physics, but also include biology, geography, general science, electronics, and mechanical engineering, and critical academic skills, such as writing, reading, research, creativity, collaboration, critical thinking, decision making, problem solving, and communication skills [5, 8-16].

One of the prominent robotics educators describes the power of robotics in education, “Robots, like dinosaurs and space, arouse the curiosity and enthusiasm of most youngsters and robotics provides a hands-on introduction to technology” [17, p.7]. Educational robotics is an effective learning tool because it helps create a fun and engaging learning environment that keeps students interested and engaged in learning. Educational robotics is fun because it provides hands-on learning experience. Also, it is a great tool for project-based learning. Project-based learning provides a learning opportunity for students to work in groups to “explore real-world problems and challenges. With this type of active and engaged learning, students are inspired to obtain a deeper knowledge of the subjects they're studying” [18]. Educational robotics creates a great learning environment for students to encounter and develop solutions for real-world problems and to demonstrate their learning through the robots they developed.

Learning through robotics has become more and more accessible to younger students because of the variety of robotics components and tools are now available for the students and teachers to experiment. There are various robotic kits that students can use out of the box with simple building by assembling pieces together without wiring and soldering. The LEGO Mindstorms kit has been in the market for more than a decade. LEGO recently released a new and more advanced set, EV3, with more sophisticated controller and sensors. For the LEGO Mindstorms kit, many third party sensors are available to add on, which makes the kit more robust and attractive. The fischertechnik, a German-based company, provides a robotics set, ROBO, which bears similar features to the LEGO Mindstorms kit (figure 1). Robotis, a Korean-based company that produces a humanoid robot called DARwIn-OP, also provides educational robotics kits for school age children. OLLO (figure 2) is for younger students (elementary school), and BIOLOID (figure 3) is for older students (upper elementary, middle school to high school). Daisen, a Japanese company, has several robotic kits that can be expanded with more robust sensors and motors. These are just a few examples out of a very long list of makers of robotics kits, components, and tools that are available today for educators and students, and are ready to be used out of the box without any specific training or technical requirements.
What makes educational robotics more attractive to teachers and students is that students can continue to learn by using more sophisticated and challenging robotics tools when they are ready. Advanced and older students can construct a robot from scratch using a controller, motors, sensors, and other parts individually purchased. Since the introduction of Arduino, an open-source single board microcontroller that is less expensive than robotics kits and accessible for use because of many online resources and publications, it has become easier for school age students to build do-it-yourself types of robotics creations. RaspberryPi and BeagleBone Black are credit-card size microprocessors that can also be used to control robots. Although a controller itself cannot be directly connected with other necessary parts to create a robot, using Arduino with breadboard and different shields to build a robotic creation is much easier than before. To make a transition from kit robots to controller based robots easier, Arduino sells an Arduino Robot, an Arduino with the necessary platform for a robot creation developed in collaboration with Complubot, a Spanish educational organization that offers a base for robotics with Arduino. Dexter Industries’ BrickPi makes robotics with RaspberryPi easier. BrickPi allows RaspberryPi to communicate with LEGO Mindstorms NXT motors and sensors, which opens up a door for NXT users to advance their robotics learning to the next level.
Figure 4 Arduino Robot

Educational Robotics Competitions

Another factor that has contributed to the popularity of robotics in education for school age children world-wide is the development of educational robotics competitions. Some of the most popular robotics competitions include the FIRST Robotics Competition, the FIRST Tech Challenge, the FIRST LEGO League, and the Junior FIRST LEGO League, organized by The FIRST organization (http://www.usfirst.org/); BotBall organized by KISS Institute for Practical Robotics (http://www.botball.org/); WRO - World Robot Olympiad organized by the World Robot Olympiad Association (http://www.wroboto.org/); RobotChallenge (http://www.robotchallenge.org/), and RoboCupJunior (RCJ) by the RoboCup Federation (http://www.robojunior.org). This growth has been more visible in the last decade, however; the idea of educational robotics competitions for school age children has been in existence for almost two decades. For example, the FIRST Robotics Competition, BotBall, and RCJ all planted their seeds back in the late 90s and Micromouse competitions were developed even a decade earlier.

Educational robotics competitions provide a unique and effective learning opportunity for school age children because they employ goal-oriented and project-based approaches to learning. Those are popular approaches in the fields of engineering, computer science, and artificial intelligence; however, not widely employed in K-12 education.

The strategies followed by various competitions with regard to technical goals proposed to the students are also diverse as well as types of robotic kits that teams use. Some, including FIRST competitions and BotBall, provide a set of new challenges or problems for teams to solve every year. Other competitions, including RCJ, focus on continuity of student learning and maintain the main goals or challenges year to year, with some specific updates. Several of those competitions including FIRST and BotBall require teams to use specific robotic kits. For example, FIRST LEGO League and WRO require teams to use LEGO kits. BotBall requires the kit developed by KISS Institute for Practical Robotics. However, RCJ leaves it open for teams to decide. RCJ teams can use robot kit, controller, or components they wish to create their robotics creation. As a matter of fact, many teams participating in RoboCupJunior World Championships develop their robots from various controllers and/or components that are not part of kit robots. Moreover, RCJ caters for a broad range of technical challenges, offering both entry-level competitions that impose low costs and involve low complexity, and competitions for advanced students that require more sophisticated technological research and development, which can be continued in the RoboCup major leagues.

Several of those competitions have reported positive impacts on learning among participating students [5, 10, 11, 18-22]. Some of the highlighted impacts include:
- increased confidence in using technology [20],
- increased understanding of the role of science and technology in solving real-world problems [19],
- increased interests in pursuing degree/career in technical, math, or science related field [20],
- increased understanding of the team work value [20],
- increased self-confidence [20],
- enhanced learning on physics, programming, mechanical engineering, electronics, and science [11],
• enhanced skills of communication, teamwork, and personal development [11].

**RoboCupJunior**

The main focus of RoboCupJunior (RCJ) is education, using competition as a motivational factor. RCJ values the learning experience of participating students the most and aims to strive for providing a framework that enhances their learning. RCJ goals remain approximately the same each year, providing a scaffolded learning environment in which students continuously develop and advance their solutions as they grow and expand their skills and knowledge. Although the goals remain the same, the rules are improved every year through rigorous discussions among the technical committee members to improve, not only the competition itself, but also the learning experience for participating students. RCJ offers three leagues that emphasize both the cooperative and collaborative nature of design, programming and building in a team setting [22].

What makes RCJ unique compared with other educational robotics competition is its position as the entry-level to the international RoboCup initiative. RoboCup is strongly committed to research, education, and involvement of young people in technology in general and robotics in particular. The relationship between RCJ and RoboCup provides a venue for students who have participated in RCJ to continue advancing their skills and knowledge by following their path to join RoboCup’s more advanced research programs. It also provides opportunities for young robotists to explore what robotics, computer science, engineering and AI researchers are working on, which helps them envision their future, possibly, in STEM field.

**RoboCupJunior Leagues**

RCJ currently offers three leagues – Soccer, Rescue and Dance (Figure 5-7). The RCJ Soccer league was proposed in the scope of RoboCup 1998, Paris, France, as an entry level to the RoboCup major soccer leagues. For example, the dimensions of the RCJ Soccer robots are similar to those of the RoboCup Small Size League. In RoboCup 2000, Melbourne, Australia, RCJ Soccer had its official debut. RCJ Dance league was also introduced in 2000, which aims to attract female students into STEM fields by combining art with robotics (STEAM). There were 25 teams from three countries participated in 2000. The RCJ Rescue league appeared in the following year, in RoboCup 2001, Seattle, USA, inspired by the major Rescue league, which is also considered to be an entry level for the advanced RoboCup major league competition. There were 25 teams with 104 participants, including both students and mentors in 2001. They represented four countries: Australia, Germany, the UK and the US.

Since 2000, RCJ has grown to be a very popular educational activity for school age children in many countries from around the world, especially in China, Japan, Australia, Germany, Singapore, the UK, and Portugal. In recent years, there have been between 200 to 300 teams competing at the annual RoboCupJunior World Championship every year. In 2011, a decade after its initiation, the RoboCupJunior World Championship was held in Istanbul, Turkey, with a total of 251 teams comprised of 955 students from 30 countries. In 2012, the RoboCupJunior World Championship was held in Mexico City, Mexico. There were 209 teams participating with 796 students from 27 countries. The number of participating teams changes every year with RCJ due to the size of the venue where the competition is held. But the overall population of students participating in RCJ activity around the world is growing with more countries joining the RCJ initiatives each year. As of December 2013, there are
over 40 countries reporting their participation in RCJ initiatives with more countries expressing their interests in participating in RCJ competition in 2014.

In RCJ 2010, Singapore, Junior CoSpace was introduced to the RCJ community, combining virtual simulation robotics with real robotics. This initiative led to the addition of RCJ CoSpace Dance and Rescue as sub-leagues of RCJ Dance and Rescue, respectively, in RoboCup 2013, Eindhoven, the Netherlands.

Figure 5 - RCJ Soccer

Figure 6 – RCJ Rescue

Figure 7 - RCJ Dance

RCJ leagues accept teams of students up to 19 years of age, possibly accompanied by a teacher/mentor. There is no lower age limit as long as the participants can design, construct and program a robot essentially on their own. There are two age categories in RCJ, Primary and Secondary. The former category is for students up to 14 years old, while the latter
category is for students ranging in age from 15 to 19 years. Open sub-league category in Rescue and Soccer is open to any age up to 19 year old, typically involving more advanced challenges that, nevertheless, do not exclude advanced younger students who wish to try their skills against older ones.

**RoboCupJunior Soccer**

In the RCJ Soccer league two teams, each with two soccer robots, play on a special field. During a game, the robots are programmed to detect and maneuver a soccer ball emitting infrared light.

There are two RCJ Soccer sub-leagues, the Open League and the Light Weight league. As of November 2013, the maximum weight of a robot is 2,400g with the Open league, whereas with the Light Weight league, the maximum weight of a robot is 1,100g. The latter sub-league is further divided into primary and secondary age groups (table 1).

The size of the soccer field is 122cm x 183cm plus an additional 30cm outer area surrounded by walls (figure 8). The floor of the field is covered by a green carpet similarly to the major soccer leagues. Since the ball can easily go outside the field limits, the robots need to use fine controls more than just speed. Moreover, the goals are painted in different colors to facilitate the transition to vision-based sensing for more advanced teams.

<table>
<thead>
<tr>
<th>Table 1 – RCJ Soccer sub-leagues</th>
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<tbody>
<tr>
<td><strong>Sub-Leagues</strong></td>
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<tr>
<td>Light Weight Soccer</td>
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<tr>
<td>Primary</td>
</tr>
<tr>
<td>Light Weight Soccer</td>
</tr>
<tr>
<td>Secondary</td>
</tr>
<tr>
<td>Open Soccer</td>
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</tbody>
</table>

**Figure 8 – RCJ Soccer field diagram**

**RoboCupJunior Rescue**

The RCJ Rescue league requires teams to develop a rescue robot that can navigate through the rescue arena (figure 9), which represents a scaled-down simulated disaster scenario, to find and rescue victims. The main structure of the arena is pre-defined but its internal structure, position of victims and other aspects are unknown before each rescue run. This league has three sub-leagues, RCJ Rescue A and RCJ Rescue B briefly introduced next, and RCJ CoSpace Rescue introduced later on.
RCJ Rescue A is organized in primary and secondary age categories (table 2) and the technical challenge is based on line-following strategies to navigate through the respective arena where debris and obstacles are scattered, possibly blocking the line. In 2013, a new challenge has been added with which the robot needs to climb up to an upper floor and come back down using a ramp, before finishing its mission rescuing a victim in the final room. The victim is considered rescued when it is moved into the evacuation zone. For primary teams, the robot can push the victim into the evacuation zone, while with secondary teams the robot has to pick up and move the victim into the evacuation zone.

The RCJ Rescue B sub-league was officially added in RoboCup 2011, Istanbul, Turkey, to offer a technical challenge better suited for more advanced teams. RCJ Rescue B is open to any age up to 19 years old (table 2) and in this league a robot needs to navigate through a maze using wall following algorithms. Similarly to RCJ Rescue A, there are debris and obstacles which the robot needs to either go over or move around to avoid a collision. Victims for Rescue B emit heat and are scattered across the arena. The robot mission is to rescue the heat generating victims by indicating their locations.

<table>
<thead>
<tr>
<th>Table 2 – RCJ Rescue sub-leagues</th>
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<tbody>
<tr>
<td><strong>Sub-Leagues</strong></td>
</tr>
<tr>
<td>Rescue A Primary</td>
</tr>
<tr>
<td>Rescue A Secondary</td>
</tr>
<tr>
<td>Rescue B</td>
</tr>
</tbody>
</table>

Figure 9 – RCJ Rescue arenas (A: left, B: right)

RoboCupJunior Dance

The RCJ Dance league is more open-ended than other RCJ leagues in terms of the size and kind of robots that teams can create to foster creativity among teams. It has no size or number limit as long as they stay within the 6m x 4m stage performance area. This leads to surprising creations, from complex house-made humanoids and other animal-like machines, to swarms of simple but synchronized robots, and a hoovering robotic carpet.

A dance team can build a robot or multiple robots that move to music, which is up to 2 minutes in duration. The creative and innovative presentation and performance of robot(s) are emphasized in the Dance league (figure 10). For the assessment of robotic performances, score sheets are used as rubrics. This helps teams to understand what is required to make their robotic performance successful. The score sheets emphasize the demonstration of creativity,
innovation, taking risks with complicated or advanced programming and construction, and creative use of different sensors. As part of the assessment process, all teams are interviewed by a set of technical judges including RCJ Dance technical and organizational committee members. The RCJ Dance league also divides teams into primary and secondary age categories.

Figure 10 – RCJ Dance Team with Creative Robots

RoboCupJunior CoSpace

CoSpace robotics uses the technology of Co-existing Space (http://cospacerobot.org) where both physical and virtual worlds communicate and interact. CoSpace robotics combines and connects robots in a real physical space and robots in a 3D virtual-reality world, giving students a richer technical experience. The virtual-reality robots, however, are also based on real world physics models.

RCJ CoSpace was integrated in Rescue and Dance leagues as their sub-leagues since RoboCup 2013. RCJ CoSpace Rescue has a specific theme each year. During first mission, each team has to develop appropriate AI strategies for a virtual robot to navigate through the treacherous terrain, avoid obstacles, and collect treasures in the 3D virtual environment while competing against an opponent robot performing the same mission. Second mission requires teams to apply the same AI strategies to the identical but real robots to search the treasures in the real world with the same set-up as the virtual arena. RCJ CoSpace Dance requires teams to develop both real and virtual robots, and create a performance in a co-existing space. The communication between real and virtual environments is mandatory.

In this initial year as official sub-leagues, 16 CoSpace Rescue teams and 3 CoSpace Dance teams participated. Being new sub-leagues, they are generating a growing interest with new local user communities starting in the UK, the USA, Korea, and Germany.

Educational Impact of RoboCupJunior – Past Studies with Teams Participating in the World Championships

Since the inception of RCJ in 2000, we have conducted surveys and interviews with the students and mentors who participated in the RoboCupJunior World Championships. The analysis of the collected data was presented in 2004 [5]. The focus of the study was to identify overall effects of RCJ on students’ learning in various areas, including subject knowledge, and personal skills such as communication, collaboration, and problem-solving skills.

Learning from RCJ 2012 Study
In 2012, another survey was conducted with students participating in RCJ 2012, Mexico City. For the evaluation of the educational value, we used a 4-point Likert scale (‘yes, very much’, ‘some what’, ‘not much’, and ‘no’) to identify educational impacts on the participating students.

PARTICIPANTS: There were 209 teams with 796 students participating from 26 countries in 2012. The breakdown by league is Soccer – 79, Rescue – 87, and Dance – 43 teams. The survey was distributed to the teams randomly during the competition. The participation in the survey was voluntary. The survey was collected in a box at the RCJ organizing committee office. There were 168 students participating in the survey, which is 21% of RCJ participants. The participants of the survey were from 19 countries, which represent 73% of the participating countries. The age of the students ranged from 10 to 19 year old. The majority (92%) of the students are 13 to 18 year olds. Eighty percent (80%) of the participating students were male. Among those, 64% responded that it was their first participation in the annual International RCJ competition. Among the 58 students who have participated in the International RCJ competition in the past, 22 students (13%) participated more than once in previous years. Among those who participated in the survey, 73% participated in Soccer competitions, while 27% participated in Rescue competition. None of the students participated in Dance or CoSpace competitions. Twenty-four students (14%) indicated that they have tried other leagues as well. This shows that the majority of the participating students continues with the same league that they started with.

RESULTS: The analysis of the data indicated the following results.

**STEM Learning:**
Table 3 shows the STEM learning experience of the participated students. The survey asked if the participating students like Science, Mathematics, Engineering, Electronics, or Programming. Overall, around 90% of the students agreed that they like the STEM subjects. The majority of the participating students did like STEM subjects before their participation in RCJ. Moreover, the majority of students agree that RCJ did help them enjoy learning the STEM subjects.

<table>
<thead>
<tr>
<th></th>
<th>Science</th>
<th>Math</th>
<th>Engineering</th>
<th>Programming</th>
<th>Electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you like STEM subject?</td>
<td>98%</td>
<td>93%</td>
<td>93%</td>
<td>89%</td>
<td>92%</td>
</tr>
<tr>
<td>Did you like STEM subject before RCJ?</td>
<td>96%</td>
<td>86%</td>
<td>83%</td>
<td>69%</td>
<td>75%</td>
</tr>
<tr>
<td>Did RCJ help you to enjoy learning of STEM more?</td>
<td>89%</td>
<td>70%</td>
<td>91%</td>
<td>86%</td>
<td>90%</td>
</tr>
</tbody>
</table>

**College Preference:**
The majority of the students agree that they are interested in post-secondary education; however, considering participating in a graduate school is less than in college (College, 84%; Graduate School, 69%). The majority of participating students consider STEM fields as their future majors (table 4).
Future Major | 76% | 68% | 71% | 68% | 68% | 74%

RCJ Experience:
The results (table 5) show that the participating students learned the skills in 1) programming, 2) teamwork/collaboration, 3) electronics, and 4) communication, the most through their RCJ experience. When asked if they would participate in the future again, 82% of the participating students answered positively to this question.

Table 5 – Best Learning from RCJ

<table>
<thead>
<tr>
<th></th>
<th>Programming</th>
<th>Team work/ Collaboration</th>
<th>Electronics</th>
<th>Commun. Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>What did you learn the most from RCJ?</td>
<td>61%</td>
<td>54%</td>
<td>52%</td>
<td>52%</td>
</tr>
</tbody>
</table>

Educational Impact of RoboCupJunior – Case Study with US teams

The main focus of this case study is to investigate the learning experience of the US teams participating in the RoboCupJunior World Championship including their learning of STEM, and engineering thinking and computational thinking skills. Teams from the US have been participating in the annual RoboCupJunior World Championship since 2000. In 2013, there were ten teams from the U.S. participating in RoboCupJunior World Championship 2013, Eindhoven, the Netherlands. The ten teams were selected through the RoboCupJunior NY/NJ 2013 competition (http://rcjnynj.org/), which is the selection event for the US. There were total of 43 teams with 163 students participated in the RoboCupJunior NY/NJ 2013.

The data for the case study have been collected through an online questionnaire, which include 5-point Likert scale and open-ended questions, and a panel discussion of two US teams at the Workshop on Educational Robotics 2013 at the RoboCup Symposium 2013, which focused on the learning experience of team members through the participation in RCJ.

PARTICIPANTS: Out of ten teams participating in RoboCupJunior World Championship 2013, Eindhoven, the Netherlands, two teams were from Pennsylvania, one team was from New York City, and others were from New Jersey. There were four teams participating in Rescue, four in Soccer and two in Dance leagues. Among the ten teams, four teams were secondary level teams (students older than 14 year old) and six teams were primary level teams (students up to 14 year old). There were 36 students participating, among which four were female students (11%).

ONLINE QUESTIONNAIRE: The online questionnaire consists of demographic information (age and gender), past RCJ experience, learning experience in STEM, and engineering thinking and computational skills, and other soft skills (including collaboration, persistence, communication, creativity), STEM interests, and interests in pursuing their learning in college. Open-ended questions are also included to gather their personal account of the learning experience.

An email invitation to the participation of the case study was sent out to the team mentors. The team mentors were asked to distribute the link to the online questionnaire to their team.
members in December 2013. There are 14 students responded to the questionnaire. The age range of the students who responded to the questionnaire is from 10 to 18 years old. Among 14 students, there were ten male students and four female students. For eight students, this was their first time participating in RCJ competition. Out of 14 students, six students participating in Soccer, six students in Rescue, and two students in Dance.

Chart 1 – Age of Students Responded to the Questionnaire

<table>
<thead>
<tr>
<th>Age of Students Responded</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
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<td>13</td>
<td>3</td>
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<td>14</td>
<td>4</td>
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<td>5</td>
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<td>6</td>
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<td>17</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>19</td>
<td>9</td>
</tr>
</tbody>
</table>

ONLINE QUESTIONNAIRE RESULTS: The analysis of the data indicated the following results.

*Did RCJ enhanced students’ interest in STEM?:*

The survey asked if the participation in RCJ enhanced their interest in subject areas including Science, Mathematics, Physics, Engineering, Mechanical Engineering, Electronics, Programming, and Art. Overall, the students agreed that the participation in RCJ enhanced their interest in STEM subjects (table 6).

<table>
<thead>
<tr>
<th>Enhanced STEM interests through RCJ</th>
<th>Math</th>
<th>Electronics</th>
<th>Engineering</th>
<th>Programming</th>
<th>Mechanical Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>71%</td>
<td>100%</td>
<td>86%</td>
<td>93%</td>
<td>79%</td>
</tr>
</tbody>
</table>

*The Effects of Participation in RCJ:*

The students agreed that overall they learned STEM related subject through their participation in RCJ (table 7). Moreover, they agreed that they learned engineering thinking and computational thinking skills through their participation in RCJ (table 8). Soft skills also received positive responses (table 9).

<table>
<thead>
<tr>
<th>Table 7 – Effects of RCJ Participation on STEM Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEM Learning through RCJ</td>
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<td>---------------------------</td>
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<table>
<thead>
<tr>
<th>Table 8 – Effects of RCJ Participation on Engineering and Computational Thinking Skills</th>
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</table>
RoboCup gives an inside look into how to work on a project with other team members. I also learned how to deal with deadlines, and how to break a problem down into manageable parts.

Problem solving was highlighted in the statements by five students. For example, one student described:

I think the best is figuring out how to trouble shoot the may problems we encountered. For example, not just with the program, how to make a dribbler on a (soccer) robot, where you have to make many designs to make it work. Also being patient with the program because it takes a lot of trail and error to even get simplest things to work.

Another student explained his learning in detail:

I gained many things from RoboCupJunior. Some of the most valued aspects are a better ability to problem solve and the ability to seriously check your work for errors - debugging. These skills can be applied in nearly all aspects of life you continue in the profession of your choice. Overall, as written above, I feel that some of the greatest thing you learn from this competition is that there is, nearly, always another way to do something, and that your first answer will need (to be) checked. Aside from those two points, students who participate also gain vast knowledge to the world of programming and mechanical design – Rescue B and Soccer, more than others, and great leadership and teamwork skills.

Six students pointed out their learning of teamwork skills:

I believe that the best part was on teamwork and communication because our team had several issues sometimes and had to be able to compromise with each other and deal with arguments.
About their future career paths, all 14 students responded that they intend to go to college to study further. Out of 14 students, five students indicated that they are interested in pursuing their study in engineering including mechanical engineering and electrical engineering. Four students indicated their interests in computer science including programming and Artificial Intelligences. Two students are interested in some type of science or physics.

PANEL DISCUSSION: Two secondary teams (high school students) were invited to participate in the student panel discussion at the Workshop of Educational Robotics 2013 at the RoboCup Symposium 2013. The panel discussion lasted about 30 minutes with eight students from the US Soccer and Rescue teams (three students participated in Soccer and five students participated in Rescue; two female students and six male students). The main question was what they learned from their experience participating in RCJ.

The learning of problem solving was also highlighted by the student panel. A male student explained, “[Robotics is] not only about writing a program or building a robot, it’s learning about a process and problem solving, how to solve a problem that you have in front of you.” Another male student who did not know what programming and building robots were about before taking an elective robotics class elaborated on his statement:

Through experimenting and trying things out yourself, you learned how to build on your own and how to really understand problem solving. At the end of a year at school and coming to the robotics competition, I did learn a lot more just from seeing different levels and how much time they have spent on it. ... we learned, spending two months how to work on soccer robots, and programming and building. Even in one month, spending a lot of time on things, I believe it was a whole different level of learning.

The student also highlighted how robotics helps them learn the concepts of engineering:

Robotics is our only class in school that actually promotes engineering comparing to other classes including physics, chemistry, and math. Robotics is the only class actually requires you to accumulate all the skills, all the thing that you learned, and put it into one thing, and start building, putting things together with your team mates, all by yourself. That really helped me to be interested in robotics, especially for building. (Laugh) I might have built around 50 robots during the course of this.

In addition, his statement indicated that, through the experience of participating in RCJ and building robots for his team, he specifically learned the process of iteration by rebuilding his robots 50 times.

Other students on the panel emphasized how their experience with robotics helped them with their future career decisions. One male student explained:

I think, in the culture of robotics... I went to RoboCup two years ago, and I did not know what I want to do in college, through participating in the competitions, you know, I want to do engineering in college. Doing this actually helped me to decide what I am going to do in the future.

Another female student on the panel followed up and stated:
It’s actually interesting that a lot of us are actually interested in engineering or looking at engineering and robotics, or computer science and robotics. Doing robotics at school and going to RoboCup I think really influenced how we are going to spend the rest of our life.

Discussion

The results from the case study of the US teams show that their experience participating in RCJ provided positive impact on their interests in STEM subjects, as similar to the RCJ 2012 study of the teams participating in RoboCup Junior World Championship 2012. Although robotics competitions in general attracts students who are already interested in some of STEM subjects, the participating students to state that the experience through RCJ made positive impacts on their interests in STEM subject is notable.

The results on the students’ future education choice show that all of the students are interested in moving on to post-secondary education, which is much higher than the results from the 2012 study. Though the sample size of the case study is very small and it is impossible to generalize the results, future study on how educational robotics competition, RCJ in particular, influences their future education choice by investigating if RCJ generally attracts students who already aim on moving on to college or RCJ itself does have an impact on their decision making will help us understand the effect from the participation in RCJ better. The results from the student panel indicate, however, that their participation in RCJ did have impact on their decision on future subject of study. Although the sample size is too small for generalization, the student’s commenting on how his experience with RCJ did help him decide the subject that they will pursue in college is noteworthy.

The results from the case study, both from the online questionnaire and the panel discussion, emphasize the students’ learning of problem solving skills, much more than the results from the 2012 study. Although the data itself from the 2012 study shows that problem solving was one of the learning that the participating students highlighted, it was not as highly marked as teamwork/collaboration skills and communication skills. Although the project-based activities like robotics, specifically robotics competitions, naturally provide opportunities for students to learn the skills necessary for problem solving, this leads us to a new set of questions on whether it is a specific trend for US teams, and whether it is because the type of education that US students receive in school does not provide enough experience for them to learn to be good problem solvers. The skills necessary for problem solving including iteration, logical thinking, breaking down a large problem into smaller and doable size, and debugging, are all important skills of computational thinking and engineering thinking. The statement from the student panel that criticized how few classes in the US schools provide a class that teaches engineering provides us with a serious warning. This leads us to a bigger question – are we providing enough opportunities in school for our students to learn the critical skills necessary for them to be successful in the future?

Conclusion

Educational robotics is proven to promote STEM interests among students. The hands-on project-based learning experience that educational robotics provides has long-lasting impacts on student learning and motivation for further exploring STEM related fields. The case study presented in this paper further highlights the impact that RCJ has on student learning specifically on their STEM learning, and the learning of computational thinking and
engineering thinking. Moreover, it promotes STEM interests in participating students and has positive impact on their future career decisions. RCJ has committed to promote educational robotics learning experience among students from around the world. The self-study conducted in 2012 has enhanced and the case study with the US teams presented further supports the results from previous studies and provided stronger evidence that RCJ has positive impacts on participating students’ learning of STEM subjects, and engineering and computational thinking skills.

To advance our mission, RCJ alongside with RoboCup, is dedicated to collaborate with organizations/schools interested in promoting RCJ in their country from around the world. We believe RCJ can provide valuable impacts on the education of next generations, by promoting learning of STEM subjects, engineering and computational thinking skills, and technological awareness and capabilities.

Bibliographies: