Educational Robotics for Promoting 21st Century Skills

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Abstract:

This paper introduces an educational robotics course offered as one of the Interdisciplinary Studies Courses under General Education category at a liberal art college that serves predominately underprivileged population of students from neighboring communities in New Jersey. It also presents the case study to examine participated students' learning from the course. The results show that, although the focus of the course is the educational robotics and programming to control robots created with LEGO Mindstorms, the students identified their learning of collaboration and cooperation skills as well as communication skills as one of the best learning outcomes from the course.

Keywords*: robotics in education, 21st century skills*

1. Introduction

This paper presents a case study of an undergraduate level educational robotics course offered as one of the Interdisciplinary Studies Courses under General Education category at a liberal art college. Bloomfield College serves predominately underprivileged population of students from neighboring communities in New Jersey, such as Newark and Oranges. Since Fall 2006, the educational robotics course has been offered every semester (twice a year) for last 6 years. After the first offering, students' learning during the educational robotics course was evaluated using the instructor's observation of student's in-class activities and reflective essays focusing on their learning experience. This paper aims to report on the students' learning especially with regard to their learning of 21st Century Skills.

2. 21st Century Skills

21st Century Skills have been the focus of educational reform in several countries including the U.S., Australia, Finland and Singapore. Especially in U.S., the focus on 21st Century Skills is the core of the educational reform. The Partnership for 21st Century Skills, a national organization (http://www.p21.org/) that advocates for 21st century readiness for every student, states:

In an economy driven by innovation and knowledge… in marketplaces engaged in intense competition and constant renewal … in a world of tremendous opportunities and risks… in a society facing complex business, political, scientific, technological, health and environmental challenges… and in diverse workplaces and communities that hinge on collaborative relationships and social networking… the ingenuity, agility and skills of the American people are crucial to U.S. competitiveness [2].

The Partnership for 21st Century Skills focuses on the 21 Century Skill Framework, which identifies 21st Century student outcomes and skills:

Core Subjects and 21st Century Themes:

- *Core Subjects – English, World languages, Arts, Mathematics, Economics, Science, Geography, History*
- *21st Century Themes – Global awareness; Financial, economic, business and entrepreneurial literacy; Civic literacy; Health literacy*

Learning and Innovation Skills:

- *Creativity and innovation skills*
- *Critical thinking and problem solving*
- *Communication and collaboration skills*

Information, Media and Technology Skills:

- *Information literacy*
- *Media literacy*
- *ICT*

Life and Career Skills:

- *Flexibility and adaptability*
- *Initiative and self-direction*
- *Social and cross-cultural skills*
- *Productivity and accountability*
- *Leadership and responsibility*

Among those skills, 4Cs (Critical thinking and problem solving, Communication, Collaboration, and Creativity and innovation) are core skills for our students to be successful in the future.

Assessment & Teaching of 21st Century Skills, another organization with international collaboration based in Australia (http://atc21s.org/), organizes 21st Century Skills into four broad categories as follows:

- **Ways of thinking.** Creativity, critical thinking, problem-solving, decision-making and learning
- **Ways of working.** Communication and collaboration
- **Tools for working**. Information and communications technology (ICT) and information literacy
- **Skills for living in the world.** Citizenship, life and career, and personal and social responsibility

Both organizations emphasize the importance of creativity, critical thinking, communication and col-

laboration (4Cs) as key of success in the 21st century. In next section, why educational robotics help promote 21st century skills among young students is explained.

3. Robotics in Education (RiE)

Educational use of robotics for school-aged children has been around for more than a decade. However it has been observed in the last several years that popular interest in robotics has increased astonishingly [2]. In addition, the availability of robotics for both post-secondary level education and school-aged children is growing rapidly [3 and 4]. Mataric argues 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, paragraph 1]. In higher education, robotics is use mostly with the courses for computer science/engineering related areas. Educational robotics tool, for example, LEGO Mindstorms set, is usually used with introductory level courses [4 and 5]. For example, Drew, Esposito et al. 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 UK [5]. For grades of K-12, most robotics activities are extra-curricula (i.e. after school programs and summer campus) [2, 6 and 7]. Elkind [8] points out that educational robotics open a door for helping children learn about mathematics and scientific concepts through the method of inquiry, as well as for developing technological fluency. The systematic study of scientific literature on the use of educational robotics in schools by Benitti, which focuses on quantitative results, identifies that most of the studies have focused on the fields of mathematics and physics [2]. It also indicates that the skills developed through educational robotics are thinking skills (observation, estimation and manipulation), science process skills/problem-solving approaches, and social interaction/teamwork skills. Several studies have also shown that educational robotics provides effective learning opportunities for students in both content areas such as physics, biology, geography, mathematics, science, electronics, and mechanical engineering, and also critical academic skills, such as writing, reading, research, creativity, collaboration, critical thinking, decision making, problem solving, and communication skills [6, 9–18].

One of the reasons why educational robotics is an effective learning tool is that educational robotics 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. With project-based learning, students 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" [19]. Educational robotics creates a great environment for students to encounter and developed solutions for *real-world* problems and to demonstrate their learning through the robots they developed. Following section introduces the "Educational Robotics as Learning Tool" course, which has been offered as a general education course.

4. Educational Robotics as Learning Tool

"Robotics as Learning Tool" course was first offered in Fall 2006. Initially, the goal for offering the educational robotics course was for our pre-service teachers to learn to use this hands-on teaching tool so that they could use it in their classrooms in the future. However, the first educational robotics course was decided to be offered as an Interdisciplinary Studies Course under General Education (GE) program. The GE program at Bloomfield College offers a variety of courses aiming to foster the development of skills and knowledge needed to be successful in college and in the world. The program identifies seven areas of competence that are integrated into both the GE and major areas: Aesthetic Appreciation, Communication Skills, Community Orientation & Citizenship, Information Literacy, Multicultural Awareness, Problem-Solving & Critical Thinking Skills, and Scientific & Technological Skills. This course is structured to integrate three of the GE competencies; Communication Skills, Problem Solving & Critical Thinking Skills, Scientific & Technological Skills. Successful GE courses provide a key to success to the students at the Institution, which serves predominately Black and Hispanic population of students. Many of the students are also first generation to attend college or even first generation to graduate from high school. The institution is committed to enabling students, particularly those who have traditionally been excluded from higher education, to realize their intellectual and personal goals.

A. Course Overview

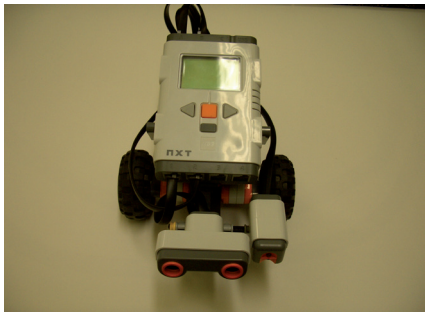

Fig. 1. LEGO NXT robot

"Educational Robotics as Learning Tool" is a semester long course that meets twice a week for one hour and forty minutes each session. LEGO Mindstorms Robotics Invention System NXT ("Mindstorms kit"; Fig. 1) is used for the course.

LEGO Mindstorms was used because it is easily accessible for anyone if students wish to continue with

robotics. The Mindstorms kit comes with a programmable brick, motors and several different sensors including a touch sensor, light sensor, rotation sensor, sound sensor, and ultra-sonic sensor (distance sensor). Programming can be done with PC or MAC to perform very simple tasks to very complicated and useful tasks. For programming, we use NXT-G programming Software (Education version), which is a standard programming software for the kit. NXT-G programming environment provides a simple graphic programming environment (Fig. 2), not like usual text-coding programming languages. The graphic environment provides a very useful tool for teachers teaching young children and those who are new to programming since it uses a drag-and-drop function with icons that are pre-programmed for some tasks. Entities used in programming, such as motors and sensors are represented as icons in a small menu section on a computer screen. Students need to simply drag an icon that they want to use for their program and drop it on a blank space on the screen to create a code. This graphic environment is highly visual and provides a good first programming experience with procedural programming concepts. This is also a good programming environment for first time programmers at undergraduate institutions especially for those who are not intending to be a Computer Science major or become a programmer.

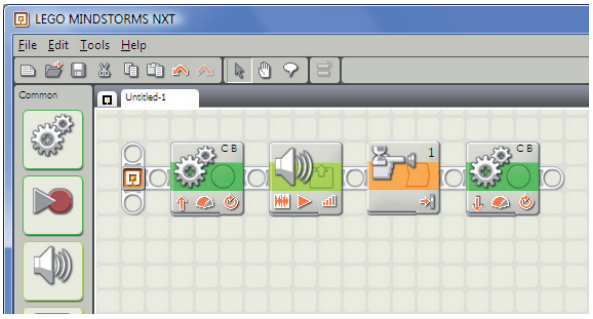

Fig 2. Simple NXT-G Program. This makes a robot go forward for 1 motor rotation, make a sound, wait till a touch sensor on port 1 is pressed, then go backward for 1 motor rotation

With this course, throughout a semester, students work in groups, usually either as a pair or a group of three. Students in each group share one robot and one computer. The intention is to promote collaborative learning more than if each student were to use his/her own robot and computer. We start each session by review programs created by each group in the previous session followed by a discussion on how to improve the programs. This promotes collaborative learning among the whole group. After the review, the instructor introduces one or two new programming concept(s) using SmartBoard to show examples on NXT-G. Following the brief lecture, the groups receive tasks (mini-projects) that require employing the new concepts. For the rest of the session, students work in groups to complete the tasks. This allows each group to progress at their own pace. However, this arrangement creates diverse differences of progress between the groups in class and makes it hard for one instructor to provide sufficient help needed. To solve this issue, advanced students are assigned by the instructor to help other groups. This encourages everyone to start offering help when asked – another way of promoting collaboration in the classroom setting.

After sessions, students are required to write a weekly reflective journal. They are required to reflect on their learning experience using the blog feature of the institution's Blackboard. Towards the end of a semester, students work on a final project. Each semester, the final project may be different. Students spend about a month for completing the final project, which is showcased on the final day of a semester. Each student also produces a lab report of the group's final project and a written reflection of their learning throughout the semester.

B. Revision of the Course Focus to Robotics Technologies

After its inaugural semester in 2006, several revisions have been made with the course curriculum. One of the biggest revisions is its focus on current robotics technologies. As Barker, Nugent, Grandgenett and Adamchuk [20] emphasize, in recent years, "we have seen an influx of new robotic systems in a variety of areas from space explorations to agriculture, from households to manufacturing production and medical institutions, and certainly through education" (p.xix). There are States in the US (currently two – California and Nevada) that have signed a new law that legalizes autonomous cars driving on city streets [21 and 22]. In Korea, Japan and China, there are robotic teacher's aids developed to assist teachers in classroom [23–27]. This trend of rapid technological development, both with robotics and any other technologies that we use in everyday life, including smartphones, tablet and computers, indicates the need of our next generation to have interests in as well as understanding of those technologies. *Technological literacy* (understanding of technology as a user and developer) should be part of 21st Century Skills along with information literacy in the near future. For this reason, current curriculum of the course has put more emphasise on the history of robotics development and current status of the technology. This part of the curriculum begins with the introduction of personal robots (AIBO produced by Sony in 1999) to the development of humanoid robots – QRIO by Sony, ASIMO by Honda, NAO by Aldebaran, and more. This is followed by the introduction of current robotics technologies. The instructor has created an online course list with online news on cutting-edge/latest robotics technology under the Robotics Resources section of Blackboard, which serves as a depository system for the curriculum and constantly updated by the instructor. Recent year's "current robotics technologies" list includes search and rescue mission robots from Japanese nuclear disaster, an autonomous car developed by Google, Robonaut by NASA, and a robot arm controllable by human brain signals.

5. Assessment of Student Learning

For the assessment of student learning for this study, the final reflective essays from two semesters (Fall 2011 & Fall 2012) were analyzed using text coding with quasi-grounded theory. The data from only fall semesters were used because the curriculum for spring semester is slightly different from that of fall semester, which include extra curricula activity. To keep the consistency of the students' learning experience for this study, the data from the fall semesters were used for the analysis. Total of 27 students enrolled in the course for those two fall semesters (17 students in Fall 2011 and 10 students in Fall 2012). Out of 27 students, 18 students completed the final assignment electronically (10 students in Fall 2011 and 8 students in Fall 2012), which were used for the analysis. The number of students who complete a semester is usually lower than the number of enrolled students each semester because of various reasons. The results indicate that the students in Fall 2011 & Fall 2012 highlighted the following learning in their essays:

1. they learned collaboration/team work skills (100%)
2. they learned about robotics and technology – increased interests in those areas (83%)
3. they enjoyed/had fun with the course (78%)
4. they learned to be creative/think creatively (67%), and
5. they learned problem-solving skills (67%).

In following sections, first two items (collaboration/team work skills and interests in robotics and technology) are explained in detail.

C. Learning to Collaborate

Although students' learning of collaboration/team work was high in the first study which was done after the first semester (Fall 2006), the result from Fall 2011 & Fall 2012 shows that all students highlighted their learning of collaboration skills in their essays. In Fall 2006 result, it was indicated that there was one student who felt that s/he could not build collaboration skills due to the lack of time the group worked together. Because of the structure of the course that forces students to work together, it is natural for students to notice the collaboration is the focus of the course. However, for all of the students studied to discuss their learning of collaboration and team work in their final essay in length is significant. Interestingly enough, several students stated that, in general, they are not in favor of working in groups mainly because they think group work ends up *unfair*. One student expressed:

> 'Working in groups was something I hated the entire time I was in high school, because when I used to work in group, only a portion of the group's members would be working. What made my anger even worst is that they would get the same grade as I, and they were just sitting there doing nothing while I was working.'

However, course gave her a new perspective on collaborating with others:

> 'Well, the only reason I work with a partner in robotics was because it was required; and I learned several lessons from it. First, working with a partner makes the assignment ten times easier than it is. It makes it easier because, as partners we divided our tasks by two, and each one of us would work on something different at the same time. Secondly, I got to share my ideas with that partner and his ideas too, and we just put everything together at the end. Sometimes when I felt too sick to work, he would work for me, and I would do the same. The third lesson that I have learned from working with a partner is not a good one, and I am glad it happened in this class, so it won't happen in other classes. The problem was that my first partner did not want to work with me, but he never had the guts to tell me that. One day he got up and went to work with another group without even telling me, I only heard that I did not have a partner anymore, I got myself another one and we did way better than the one before. But I learned never to divide our tasks, but switch them often. Because if we divide our tasks for example when one of us leaves the group, the one staying won't be able to do everything because he only used to work on a specific task.'

Although it was a difficult experience, it gave her a valuable lesson on collaboration. Another student also shared that this course gave him a new lesson. He states:

> 'The good thing about this was working in pairs (or in my case, a group of three). Working in a group was perhaps the best idea for this class. I usually prefer to work independently, and for reasons, I still stand by that notion. Yet, sometimes I caught myself in a bind with ideas on what to use and when. I would've never thought to use an ultra-sonic sensor to locate cups, and this is a fact. My partner's brains, on the other hand, seemed to know exactly what to do. It took us a long time to figure out how to get our robot around that circle without going straight, but after many trial and errors, and a little hint, it's like a light bulb went off in our heads. Working together has helped a lot to get the work done.'

In the class, the instructor strongly emphasizes and encourages students to help each other. She frequently asks advanced students to teach others. It is not only because she cannot provide help to eight to ten groups at once but also because this strategy gives students the valuable lesson of collaboration. One student explained his experience:

> 'There were many classes where we had to help out the rest of the groups and give out hints and advice whatever project we had to do. We even went so far as troubleshoot their work so we could tell them what was wrong or where their mistake was, so that they could go back and figure out the issue and fix it. For instance, the week of October 25–27, we acted as teachers to the class. We had to help the class with pushing cups out of a circle, without leaving the circle, until all the cups were

removed from the inside of the circle. Then we had to help them understand how to make the robot follow black circle without ever going straight.'

Those are one of the difficult programming tasks, which they successfully taught the other groups. This indicates their mastery of the programming skills required in class since teaching is the highest form of learning. The collaborative environment that this course provides the students not only helps them to learn collaboration skills but also enhance their learning.

D. Promoting Interests in Robotics and Technological Literacy

The result shows that the additional focus on the development of robotics and robotics related technology in the course after recent revision has proven to enhance the interests in robotics and robotics. Majority of the students (78%) highlighted their learning of robotics and robotics related technology in their essays. One student expressed her discovery:

'Using the NXT's [LEGO Mindstorms] helped out to understand a little bit about electronic devices. Majority of people take for granted the many machines around them. It's not on purpose though. It's a simple, pure lack of knowledge on people's part. The more technology that is created, the less people understand it.'

Prior to taking this course, robots, for many of the students, were things in science fiction movies. One student described:

'I learned a lot about technology and robotics as a whole. I've always thought of robots as technology of the future. Most people think of robots as *future human beings*. The fact is most robots today are here to do jobs human beings used to do.'

Another also commented:

'I really did not think much of robots till I started the class. I thought robots were like the robots in the movies but I was wrong. There is more to robots than just them taking over the world and being the bad guys. Robots are more than that. Robots are the future and will help us in life. Robots are good things and they are good for us.'

Because of the influences of science fiction movies, some students expressed that they believed that robots in the future would be like human beings or even take over the world. At the end of the semester for them to be able to state "I learned that some of these science fiction movies that I would watch that involved robot were somewhat impossible" is quite important learning. Another student added:

'The notable piece of the situation is that the human has complete control over the robot at all times, the robot is not permitted to freely think, it acts as an extension of the human. … As much as a fear of robots becoming aware may be irrational it is something that is implanted into all of us courtesy of Hollywood. It raises interesting questions and reminds us of how fragile we are compared to the machines we are capable of building. However, I am definitely excited to see where the discoveries being made with the assistance of robots and where the ever-changing world of robotics will take humanity.'

6. Future Considerations

The overall results suggest positive learning experience among the students through this course. Although this course teaches the programming of LEGO Mindstorms robots, what the course aims to teach students is above the content knowledge that this course provides. This course is more or less a content-less course targets more on students' skill acquisition – skills that they need to be successful as 21st century citizen. All the targeted skills – collaboration/team work skills, communication skills, creative thinking, and critical thinking/problem-solving skills (4Cs) that the course focuses on are visible for students through the reflection of their learning experience. Although their prior experiences with group work both from their primary & secondary education, and college seem to be negative, having the positive collaborative learning experience through this course has changed their perception of collaboration. Follow up study on how their perception of collaboration will influence their performance in their future courses will help us understand the impact from this course better.

From the study, the other aim of the course to open their mind and interests in robotics and robotics technology and emhance students' technological literacy have appeared to be successful as well. One of the students also commented:

'I now find out robotics is an interesting tool because the way the course ended left me open minded about some things in the robotic field of life.'

One student in particular changed his major from Social Study – Criminal Justice to Engineering to pursue his career in Industrial Engineering because of his learning through the course. He expressed his learning:

'Finally, at the end of my first semester as a college freshman, I can say that this course has really opened my eyes up to the world and what is to be expected from this generation of college graduates. Innovation is what is going to drive the economy and the very way of life.'

I hope this course will continue to have such an impact on our students especially because our institution serves predominantly Black and Hispanic population of students and those are the population whose representation in STEM field needs to be increased.

This course happened to be a course that students feel uncertain about their learning adventure at the beginning of a semester. Sixty seven percent of students from Fall 2011 and Fall 2012 described that they did not know what they were going into at the beginning of the semester, and 78% of the students enjoyed the course. One student summarized the experience:

'When I first began the semester, I honestly believed that I was not going to enjoy my Robotics class. I began the class with the mentally of just doing what I had to do and leaving. The truth is, I learned many great things in this class and I enjoyed it very much.'

Although at times, the learning could be very frustrating as about half of the students expressed in their reflection, when they try to excel while having fun with their learning, the overall outcome becomes positive. The challenge for educators is to find the best way for each one of us to create such a fun learning experience for our students. Educational robotics is one of the best learning tools for creating such learning experience for students. This course is a course offered at an undergraduate institution; however, the author also teaches the same curriculum to grade school students. It might be interesting to study younger students' perception of their learning experience of 21st Century Skills through educational robotics in the future.

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