ROBOTICS AS A TOOL TO STEM LEARNING

Henry Goh
Institute of Teacher Education, Gaya Campus, Sabah, Malaysia
hryg@hotmail.com

Mohamad bin Bilal Ali
Universiti Teknologi Malaysia.
mba@utm.my

Abstract

Much has been written on the shortfalls in fully realizing the benefits of science, technology, engineering, and math (STEM) education. STEM is important, because it pervades every aspect of our lives. Nevertheless, STEM education is considered as hard, dull, and without emotional meaning. This article examines how the use of robotics in education benefits STEM learning and how teachers can get started with a robotics program in schools. In this study, students develop their building and programming skills teamwork, and presentation skills, as well as touch on STEM subjects school students using the LEGO NXT Mindstorm programmable reconfigurable robot, to observe and learn abstract physics concepts and to perform different designed activities. Students work in teams toward the common goal of developing logical and creative solutions to problems. The results of the study indicated that there was a statistically significant difference in overall perceptions of assessments in STEM Semantics Perception Data, STEM Career Interest Scales and in the interview sessions. It is hoped that this program may set the stage for the transformation of the Malaysian education system which aspires to ensure that every student in every school in every state achieves their full potential, as stated in the Malaysia Education Blueprint 2013-2025.

1.0 INTRODUCTION

The Malaysian Science curriculum for secondary schools aims at producing active learners, so students should be given ample opportunities to engage in scientific investigations through hands-on activities and experimentations (Ministry of Education, 2005). The educational system will entail changing the culture and practices of Malaysia's primary and secondary schools, moving away from memory-based learning designed for the average student to an education that stimulates thinking, creativity, and caring in all students, caters to individual abilities and learning styles, and is based on more equitable access. In other words, learning activities should be geared towards activating students' critical and creative thinking skills and not confined to routine or rote learning.

However, our children are still lacking; they are simply not 'world class learners' when it comes to mathematics and science (Crawford, 2001). Teaching science effectively in schools, particularly physics, is a challenge to teachers and has been of considerable concern for a very long time in Malaysian secondary schools (Lilia Halim *et al*., 2012; Salmiza Saleh, 2012). Mazur (1999) believes that a major problem with the conventional teaching method is that it places more importance on problem solving over conceptual understanding, which causes students to memorize "problem solving strategies" without understanding the concepts behind the manipulations.

Despite the increased investments in education, the statistics of classroom achievement in science are disheartening to say the least. According to the study by Trends in International Mathematics and Science Study (TIMSS), carried out by the International Association for the Evaluation of Educational Achievement (IEA), the general aptitude of Malaysian students in mathematics and science is not only below the international benchmarks, but is also on a declining trend (IEA, 2012). In terms of PISA (Programme for International Student Assessment), which is administered by the OECD Organisation for Economic Co-operation and Development (OECD) every three years to 15-year-olds, Malaysian students also fared below average in the 2012 results (OECD, 2013).

Strength in STEM-related skills is necessary to best prepare our students for success in the global workforce (Lantz, 2009). A stronger focus on science, technology, engineering, and math (STEM) education is the key to a country’s future (Francis-Poscente and Davis, 2013). However, many reports have shown that trends in STEM are alarming. The academic performance of students has stagnated and in some cases declined in STEM areas (Gonzalez and Kuenzi, 2012; Knezek, Christensen and Tyler-Wood, 2011). The avoidance of STEM areas for study and careers is also leading to less positive attitudes about careers in these areas (Knezek *et al*., 2013).

Many researchers have recognized the weaknesses in the methods of teaching and learning in Malaysia (Aziz Nordin, 2005; Chew, Noraini Idris & Leong, 2014; Nafisah @ Kamariah Md Kamaruddin and Nurul Qamar Hazni, 2005; Salmiza Saleh, 2011). Students fail to find meaning in the topics. There is a lack of or poor mastery of core and generic skills, as the schooling system in Malaysia is rather exam-oriented. To make matters worse, parents seem to be more concerned with the number of “As” that their children get rather than the development of the child’s deep understanding of knowledge and acquiring of skills (Burhanuddin Mohd Salleh, 2007).

In the new era of information technology and a knowledge-based economy, the grasp of science and technology among school students is important to produce knowledgeable and competent human capital with adequate capabilities and creativity to lead this nation in attaining developed nation status by 2020 (Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014). Robotics is one technology that allows teachers to build a STEM-specific curriculum around technology that is engaging to both male and female students (Whitehead, 2010). The uniqueness of using robotics as a fundamental teaching tool in content areas of STEM can offer additional educational benefits

1.1 Purpose

Robotics is a potentially rich source of meaningful learning activities (Adolphson, 2002; Eguchi, 2007). However, despite their growing popularity, currently, robotics activities are usually not found in regular classrooms or within the overall curriculum (Gura, 2011). This paper discusses the potential of using robotics to make learning relevant and stimulate new career paths possible by restructuring some standard cookbook physics experiments used in the classroom into a laboratory experiment module with robotics support, thus creating a natural, effective and tension-free learning environment.

1.2 STEM

STEM education is an interdisciplinary area of study that bridges the four disciplines of science, technology, engineering, and mathematics (Chew, Noraini Idris and Leong, 2014; Francis-Poscente and Davis, 2013). It is important to nurture STEM skills in order to maintain competitiveness in the global economy. Through STEM, students are taught through constructivist methods that aim to build content understanding and application of knowledge (Turner, 2013). In fact, in any country the strength of the STEM workforce is viewed as a strong indicator of the nation's ability to generate ideas towards the creation of innovative products and services (Chew, Noraini Idris & Leong, 2014). However, a report by President Obama's Council of Advisors on Science and Technology (2012) stated in 2008, only 23.6% of male students and 9.2% of female students when last enrolled at post-secondary institutions were enrolled in STEM fields (Figure 1).

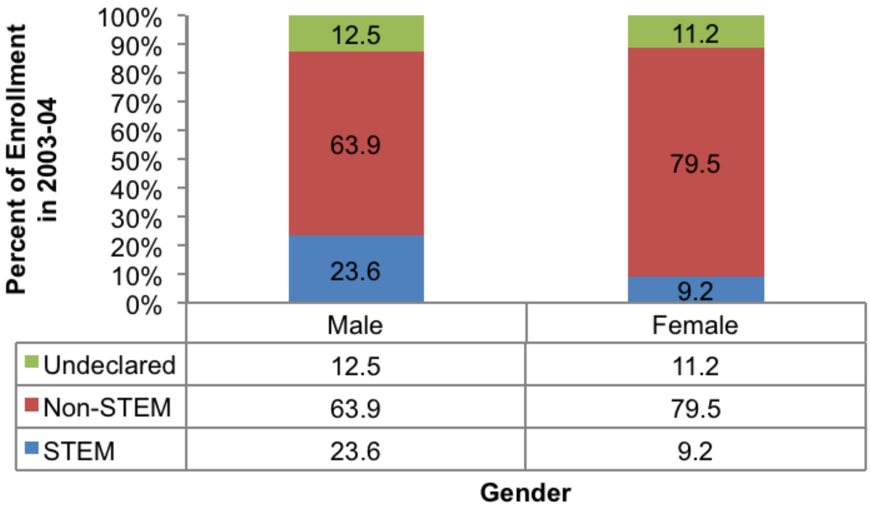
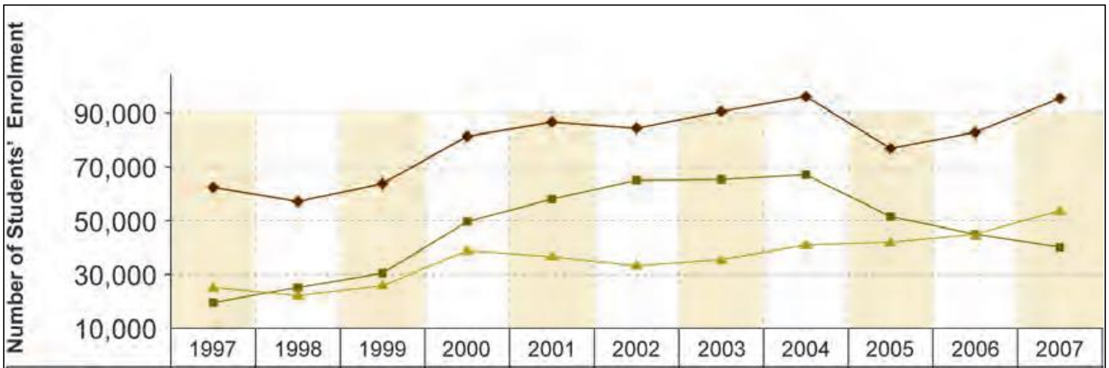


Figure 1 : Estimates of Enrolled Field by Gender

Source: President Obama's Council of Advisors on Science and Technology (2012)

While many would argue that a start has been made towards realizing STEM education within secondary schools, it is a far cry from actually planning, writing, and implementing an innovative, trans-disciplinary STEM program. A large majority of secondary school students fail to reach proficiency in math and science, and many are taught by teachers lacking adequate subject matter knowledge (Lantz, 2009).

In Malaysia, the issues of declining students pursuing STEM related studies at secondary and tertiary level has been a growing concern (Chew, Noraini Idris & Leong, 2014; Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014). As shown in Figure 2, in general, there has been an increasing trend in the number of students' enrolment in first degree level in public institute of higher learnings in Malaysia from 1997 to 2007 for arts and technical courses. However, the number of students' enrolment in science courses has been on a decreasing trend since 2005 until 2007 (MOSTI, 2008).



Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Arts	62,528	57,587	64,092	81,914	87,482	84,311	90,925	96,581	76,935	83,354	95,969
Science	19,342	25,607	30,023	49,575	58,029	65,617	65,235	67,368	51,464	44,551	40,298
Technical	25,192	23,307	25,780	39,305	37,318	34,262	36,128	41,365	42,598	45,132	53,760

Figure 2 : Enrolment in First Degree Courses at Public Institutions of Higher Learning by Field of Studies (1997 – 2007)

Source: MOSTI (2008)

Therefore, better teaching methods are needed by educationists to make courses more inspiring, provide more help to students facing challenges, and to create an atmosphere of a community of STEM learners. We can engage students in real world applications of the principles of science and mathematics by infusing technology directly into math and science courses while melding science and mathematics concepts together. Robotics is a potentially rich source of meaningful learning activities (Adolphson, 2002; Eguchi, 2007). There is a potential for greater engagement and interaction between learners and the robots (Wang et al., 2010). Robotics is one technology that allows teachers to build a STEM-specific curriculum around technology that is engaging to both male and female students (Whitehead, 2010).

1.3 Robotic Education

Innovation in the use of technology can help to improve learning by enriching teachers' curriculum delivery and encouraging flexibility in pupil learning (UNESCO, 2014). However, the challenge is to exploit technologies within a pedagogically sound teaching and learning environment.

The Lego Mindstorms for Schools series' vision is to provide a powerful learning platform to enable students to cope with skills that are essential for success in the 21st century while its mission is to strengthen important problem-solving and social skills that are critical for success in further studies and further careers. These skills include problem solving, creative thinking, interpersonal communication and collaborative teamwork skills. We can engage students in real world applications of the principles of science and mathematics by infusing technology directly into math and science courses while melding science and mathematics concepts together. Students can engage in real world applications of the principles of science and mathematics by infusing technology directly into math and science courses while melding science and mathematics concepts together (Goh and Baharuddin Aris , 2007; Johnson, 2003; Perteet, 2005; Whitehead, 2010). Learning through designing, building and operating robots can lead to the acquisition of knowledge and skills in high-tech electrical, mechanical, and computer engineering areas that are in high demand in industry. It can promote development of systems thinking, problem solving, self-study, and teamwork skills. Involvement of students in robot activities can offer additional educational benefits (Johnson, 2003 and Verner & Ahlgren, 2004).

The field of robotics education has evolved tremendously over the past decade, largely because of the tremendous increase in computing power and the availability of an improved variety of sensors (Maxwell and Meeden, 2000). Educational robotics might be seen as a vehicle for new ways of constructionist thinking and a vehicle driving to new paths in constructionist learning (Alimisis *et al*., 2010; Demo *et al.*, 2012).

1.4 Theoretical Framework

Building upon Piaget's constructivist theories of learning, Seymour Papert developed a learning theory called constructionism (Alimisis, 2013; Mubin *et al.*, 2013). According to Papert (1971), in a technologically oriented educational system, children not only think and learn about the world, but also about the processes of thinking and learning, achieving for themselves the power to deal with whatever they experience. While Piaget's constructivism defines learning as the building of knowledge structures inside of one's head, Papert's constructionism, on the other hand, suggests that the best way to ensure that such intellectual structures form is through the active construction of something outside of one's head: that is, something tangible, something shareable (Stager, 2001).

Therefore, as students engage themselves in this learning environment while working with robotics, students are assigned tasks in which they must implement particular instructional goals. They learn to investigate, create, and solve problems, through themselves, through each other, and through experiences. Opportunities for construction could in principle lead to deeper changes in the learning. In addition, Papert's constructionism theory holds that children learn best when they use computers in a way that puts them in the active role of designer and builder (Harel, 2003).

2.0 METHODOLOGY

The study took place entirely in an urban secondary school in the state of Sabah, in Malaysia. The participants consisted of a non-random purposeful sample of forty-four sixteen-year-old Form 4 students or Year 10 of the school system in a fully government-aided school.

Students were introduced to the LEGO Mindstorm robot during the first session of the program. They then participated in a series of experiments involving the topic of force and motion in physics. It involves the integration of robotics into the context of real-life problem solving. The laboratory activities are designed to allow students to discover most of the physics principles underlying the experiments. There are also opportunities for students to design experiments and communicate their results. Each activity was designed to take a double period of eighty minutes to complete. The module was organized according to the attributes of hands-on activities where learners conduct experiments, analyze the resulting data, construct meaning and acquire understanding of the world in which they live.

Figure 3 shows an example of an activity in the module designed to encourage team-working and thinking skills. In this activity, students work in groups using suitable variables involving STEM fields, to record their experimental values in a table and plot a force against acceleration graph. They then, write brief explanations and construct the robots to justify their findings and suggest how to decrease the effect of the friction.

Two questionnaires, the STEM Semantic Survey and the Career Interest Questionnaire, both developed by Knezek, Christensen and Tyler-Wood (2011), were used in this research to unveil differences in the perceptions of students toward STEM disciplines. The questionnaires were carried out as a pre- and post-survey upon completion of the robotics education module.

Figure 5.1 : A robot on a friction compensated runway

1. Prepare a friction compensated runway as in Figure 5.1.
2. Put the robot on the runway.
3. Put the standing wall on the starting end of the runway.
4. Tie the robot to a slotted weight with a thread.
5. Support the thread with a pulley.
6. Start the experiment by hanging 20g of slotted weight on the thread.
7. Turn on the NXT and run the program. A sample program is shown in Figure 5.2.
8. Release the trolley to run down the runway.
9. The displacement of object will be recorded by the NXT.
10. Transfer the data into a table.
11. Calculate the acceleration of the robot.
12. Repeat the experiment with mass of slotted weight 40g, 60g, 80g and 100g.

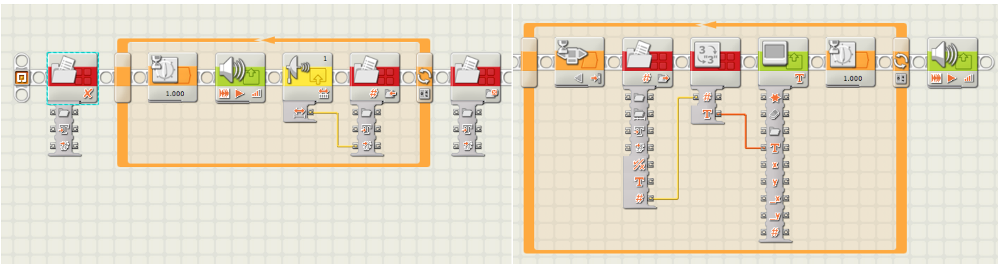


Figure 5.2: NXT Sample Program

Figure 3 : An Activity in the Module

The STEM Semantic Survey is a five-part questionnaire on science, technology, engineering, mathematics and career in STEM consisting of twenty-five questions. It uses adjective pairs such as "boring – interesting" and "unappealing – appealing" on a seven-point rating scale to assess perceptions of Math, Science, Engineering, Technology, and STEM as a Career. The Career Interest Questionnaire is a Likert-type (1 = strongly disagree to 5 = strongly agree) instrument composed of twelve items on three scales. Stephen, Bracey and Locke (2012) reported using the questionnaire to monitor students' interest in science as a college major and a career. The three scales measure the following constructs: perception of supportive environment for pursuing a career in science, interest in pursuing educational opportunities that would lead to a career in science, and perceived importance of a career in science. A formal structured interview to triangulate the information on the impact of robotics education on students' aspirations toward careers in STEM was also carried out.

3.0 RESULTS

The Wilcoxon test analysis in Figure 4 revealed that STEM perception levels in all the different fields were more positive after the implementation of the collaborative robotic activity ($z = -5.77$, $p < .05$). The results indicated that the participants' perceptions of STEM semantics increased as a result of their participation in the experiment, which suggested that the robotics program had positive effects on the participants.

Analysis of overall paired pre-post data in Figure 5 from the school students on the Career Interest Scales Survey revealed a significant difference ($z = -3.90$, $p < .05$). The mean of the ranks in favour in the pretest was 11.98, while the mean of the ranks in favour in the posttest was 14.07, indicating a more positive perception after the implementation of the robotics experiment module. Therefore, it can be inferred that the students have developed a positive increase in STEM beliefs and STEM interests, thus leading to positive aspirations toward careers in STEM.

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
RANK PRE	44	132.4773	15.73396	90.00	162.00
RANK POS	44	158.6591	8.83161	136.00	175.00

Ranks

		N	Mean Rank	Sum of Ranks
RANK POS - RANK PRE	Negative Ranks	3[a]	3.00	9.00
	Positive Ranks	41[b]	23.93	981.00
	Ties	0[c]		
	Total	44		

a. RANK POS < RANK PRE
b. RANK POS > RANK PRE
c. RANK POS = RANK PRE

Test Statistics[b]

	RANK POS - RANK PRE
Z	-5.673[a]
Asymp. Sig. (2-tailed)	.000

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Figure 4: Pre-Post STEM Semantics Perception Data

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
RANKPRE	44	47.8636	6.93689	19.00	60.00
RANKPOST	44	53.9545	5.31323	36.00	60.00

Ranks

		N	Mean Rank	Sum of Ranks
RANKPOST - RANKPRE	Negative Ranks	8[a]	18.81	150.50
	Positive Ranks	35[b]	22.73	795.50
	Ties	1[c]		
	Total	44		

a. RANKPOST < RANKPRE
b. RANKPOST > RANKPRE
c. RANKPOST = RANKPRE

Test Statistics[b]

	RANKPOST - RANKPRE
Z	-3.897[a]
Asymp. Sig. (2-tailed)	.000

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Figure 5 : Pre-Post of All Items of Career Interest Scales

As for the interview sessions amazingly, the respondents were in favor of the module because according to them, it was effective and the engaging nature of the activities had improved student attitudes toward STEM disciplines and increased the likelihood that they would explore STEM disciplines. Some of the examples of feedback are:

S01: "I like my physics class".
S02: "… enjoy going to science lessons.
S03: "I would like to learn more about robots."
S04: "Science is one of the most interesting school subjects."
S05: "Physics lessons are interesting and exciting with robotics."

Apart from that, attitudes toward STEM career interest choices had become more positive after the implementation of the robotics program. There was an increase in satisfaction in students' perception of STEM careers after the program. The students' responses were not much different from their answers in the questionnaires. Some of the statements from the students include the following:

S01: "I would like to be an engineer when I leave school".
S02: "I wish to have a career in a science-related area".
S04: "A job related to robotics would be interesting".
S05: "If I do well in mathematics classes, it will help me in my future career".

Interestingly, one student even answered:

S03: "When I leave school, I would like to work with people who make discoveries in science".

It is worth mentioning that students described their participation in the program positively because, as they reported, it revealed the different careers and job possibilities involving STEM subjects.

4.0 CONCLUSION

Findings of the research have shown the potential for integrating educational robotics into the teaching and learning of physics. The overwhelmingly positive results from students involved in successful physics activities and the quality of their work indicate that the use of robotics has tremendous potential to offer learning experiences to students. In addition, this study was an initial step toward what could be a lifelong development of educational STEM programs, supporting the expansion of STEM programs and enlarging the pipeline of future STEM degree recipients. Students gained from the opportunity to learn about robotics, mathematics, science, technology, and engineering in a motivating way.

Better teaching methods are needed by teachers to make courses more inspiring, provide more help to students facing mathematical challenges, and to create an atmosphere of a community of STEM learners. Rigid lecture-and-test models of learning are failing to challenge students to experiment and engage in informal learning (Nagel, 2013). It is imperative that teachers integrate STEM standards by incorporating emerging technologies and new media in their classrooms and learn how to adapt curriculum, identify correlations with national standards, and promote the relevance of using robotics to STEM education (Johnson *et al.*, 2013). It is hoped that in light of these findings, more support and attention will be given to the use of educational robotics in order to promote STEM literacy among students in Malaysia. More research will be needed to better understand the long-term benefits of robotic education on students (Loh *et al.*, 2013) and set the stage for the transformation of the Malaysian education system.

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