Robotics Education and Creativity

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Abstract

This paper reviews some of the author's literature and prior research into teaching creativity and reports the results of his EdD research project in this area. Seven common methods of fostering creativity were identified, and using Rasch Unidimensional Measurement Model computer program (Andrich, Sheridon & Luo, 2003), the level of difficulty of those methods were presented (N=124). Two examples of how some colleges foster creativity in technology were presented and improvements to their process were suggested. The teaching of robotics in an Educational Center in Singapore was analysed. The research was informed by Wakefield's (1992) Problem Finding and Solving Situations Model and Lumsdaine and Lumsdaine's (1994) Mindset Deployed at each Creative Problem-solving Process Framework. It is concluded that the teaching of robotics in education, when conducted in a guided framework, could be highly useful in fostering creativity and innovation.

Key words: Creativity, education, robotics

Introduction

The Importance of Technological Education and Creativity in Developed Nations

In developed nations such as the United States of America, many researchers have cited science-based technology as the main driver of economic growth (Conceicao, Gibson, Heitor & Sirilli, 1999; Wiggins & Gibson, 2003). Conceicao & Heitor (2002) went a step further and called for the accumulation and framing of knowledge and new discoveries for efficient retrieval and better competence building. They advocated the rapid proliferation of knowledge through the creation of a stimulating environment for innovation, and not through indicators such as the expenditure on research and development. Florida (2002) also supported this view when he developed a Cities Creativity Ranking and with it, he demonstrated that cities in the USA that have 'plug-and–play' communities tend to attract more creative and talented people and in turn are able to boost their economic dynamism. ('Plug and Play' communities refer to highly mobile, adaptive and educated people who flourish in digitally connected, livable cities) Other researchers in the USA examined the use of technology incubators within a university (Wiggins & Gibson, 2004), and the emphasis on fostering creativity in school through the use of collaborative and cooperative learning (Hillmann, 2004), in an attempt to enlarge the pool of creative talents working in the new economy.

In the United Kingdom and Scotland, there has also been an emphasis on creativity education in all levels of the education system. The rapid growth of the knowledge economy, coupled with the pervasive spread of technology, were cited as the main factors influencing their education systems to produce graduates capable of working in industries such as information technology, computing and engineering (Daines, 2001, Ofsted, 2003; Universities Scotland, 2003; The Arts Council of England, 2002). The United Kingdom has not only looked inwards to refine its educational system. They have also been involved in a series of discussions and workshops with developed countries such as Japan in the Far East, to share experiences and strategies to foster scientific creativity in their young people (Albone, 1998).

The educational scene in Japan, one of Asia's most developed nations, is not different. As far back as the mid 1990's, Japanese academics and educational researchers have understood the importance of developing a creative work force, and not just producing conforming and loyal workers (Keidaren, 1996). Deregulation, encouragement of diversity and an emphasis on creative thinking within the Japanese education system was called for, in an effort to nurture more creative human resources. More recently, the Government of Japan produced the 'Science and Technology Basic Plan (2001-2005)', which takes into consideration and adopts most of the proposals recommended by Japanese academics (Government of Japan, 2001). The Plan acknowledges that this is a 'century of knowledge' and that it is essential to create and use knowledge to have vitality from wisdom, to have an enlightened society through wisdom and that science and technology should be strategically used to achieve these aims (Government of Japan, 2001).

Singapore has recently been accorded the status of a developed nation. Its per capita GNP currently stands at US $28,620 while that of another developed nation, the USA, is US$29,340 (Lim, 2001). As a developed nation, Singapore faces challenges not only in sustaining its economic growth, but also it has to compete in the league of other developed nations. As Singapore is a small nation with few natural resources, it relies predominately on its human capital to generate and maintain its wealth. It too has identified that this 'new economy' is driven by new knowledge, and by discoveries in science and technology (Economist-Singapore, 2004). In order to produce workers capable of supporting the new economy, the Singapore government plans to fine-tune and employ its educational system as the key to developing graduates to be technically competent, creative, and entrepreneurrial to compete globally (The Remaking Singapore Committee, 2004). In a recent report, a senior minister in Singapore has even suggested releasing its government scholars into the private system in a bid to hasten the growth of inventors, innovators and entrepreneurs (Lee, 2004). As education plays an important role in moulding the thoughts, knowledge and eventually the character of a person, the making of a creative and technologically competent graduate must start by creating thinking and innovative schools and this will eventually pave the way for a learning and creative nation (Becker, 1998). Hence, this paper on creativity and applied sciences education, and in particular robotics education, is presented.

Methods of Fostering Creativity

There are broadly seven methods of fostering creativity, with three supporting items each (Teo, 2006). The seven methods are: (i) teach the skills and attitudes of creativity, (ii) teach the creative methods of the disciplines, (iii) develop problem-friendly classrooms, (iv) induce prior knowledge and experience, (v) employ different types of problems, (vi) provide multi-disciplinary/hands-on projects, and (vii) have a creativity enhancing lesson plan.

Each method has three supporting items. Supporting items are auxiliary methods of fostering creativity for the main method. The three items are arranged in increasing levels of difficulties, as per the processing requirement of Rasch Measurement Model. A copy of the questionnaire, together with the supporting items, can be found in Appendix 2. Each item is considered in two perspectives, the attitudinal perspective (ideally, this is what I should do) and the behavioural perspective (this is what I actually do). Hence, as there are a total of twenty-one supporting items with two perspectives each, the total number of perspectives is forty-two.

Results of the Measure of Methods of Fostering Creativity

This paper only presents the results of the Measure of Methods of Fostering Creativity. The rationale for the use of the Rasch Measurement Model viz a viz the use of the Likert Response Categories and the True Score Theory, and how the data were collected and analysed can be found in my research thesis (Teo, 2006, pp.67-122). The data were collected using 42 items and obtained from 124 participants (lecturers). All the items listing the methods of fostering creativity fitted the Rasch Measurement Model satisfactorily. The attitudinal perspectives (ideally, this is what I should do) are easier to accomplish for all items than their behavioural perspectives (this is what I actually do). These results are in agreement with the conceptual design of the questionnaire and thus support the model of methods of fostering creativity used. The Global

Statistics for the methods of Fostering Creativity are given in Table 1 (Appendix 1).

The results of the Methods of Fostering Creativity Scale are shown in Table 2 (Appendix 1).

These results mean that valid inferences could be made from the scale and it was inferred that:

(1) The easiest method of fostering creativity was to *Develop a problem friendly classroom* (both attitude and behavioural-wise);
(2) The hardest methods of fostering creativity were providing students with *Different types of problems* (attitude-wise) and *Teaching the skills and attitudes of creativity* (behavioural-wise);
(3) It was easier to hold any ideal attitude about fostering creativity than to actually implement the method, for all 21 items of the scale.

Technological Education and Creativity

Several researchers and engineering lecturers in recent years have attempted to inculcate creativity in students through the use of engineering projects (Blicblau & Steiner, 1998; Court, 1998; Dekker, 1995; Hirose, 2001).

In Australia, Blicblau and Steiner (1998), engineering lecturers from Swinburne University of Technology, Melbourne, used the final year projects of engineering students as a platform for the students to demonstrate their creativity. Projects required the students to apply engineering principles and concepts to solving real-life engineering problems and thus help the students to improve 'their understanding, motivation and creativity' (Blicblau & Steiner, 1998, p.44). Student projects like the human powered hydrofoil and the wheelchair guidance system were selected and quoted as examples of creative products. Blicblau and Steiner's (1998) research papers did not mention of any specific validated creativity test used to assess or determine creativity in the student's project. The determination of the creativity level of the student's project is illustrated as follows:

> *Human-powered hydrofoil (HPH) - This project aimed to demonstrate the feasibility of a human-powered hydrofoil concept, as demonstrated by prototypes produced by the Swedish Trampofoil company. Slow-motion replays of the motion of the craft revealed that the new HPH exhibited forward motion generated from the lift of the rear wing and the flexing of the fork by the rider. Although based on a previous idea, the project reflected many creative engineering skills* (Blicblau & Steiner, 1998, p.47).

The above comments, though made by the consensual agreement of a few assessors, may not be reliable due to a lack of clear creativity assessment criteria. The use of a validated creativity test instrument such as Besemer's (1998, 2000) Creative Product Analysis Matrix (CPAM), in addition to the expert/assessor's comments, will help to improve the reliability of the findings.

In the United Kingdom, at the Mechanical Engineering Department, Imperial College, the UK Royal Academy of Engineering, Court (1998) described how creativity in engineering design can be improved through the experiences learnt while undertaking an interdepartmental project. The main obstacle cited was the students' preconception that engineering should be an intellectual activity involving deductive and mathematical (logical) thinking. This rigid approach to thinking consequently impeded the students' ability to solve an open-ended design problem which needed a creative input (Eder, 1996). Fostering of creativity in the engineering students was done using a turbo-generator as a design project and providing the students with support in reforming problems, attempting alternating design solutions and exploring relevant unknown background knowledge (Fisher, 1994). The turbo-generator project was further broken down into ten sub-projects undertaken by teams of students. A novel solution or approach and an appropriate balance between creative and technical inputs were sought in all projects. Students were taught some techniques such as brainstorming to help them to generate more creative ideas. The results showed that while all students can and do make creative contributions, some students are better at generating radical ideas while others can identify very good adaptive solutions. The ideas generated have to be carefully considered before adoption so as to arrive at maximum design effectiveness.

Court (1998)'s method of improving creativity relied heavily on the inherent creative requirement present in an engineering design project. Students were only taught one method to generate creative ideas; the brain-storming method. While creative ideas were generated and the project was quite successful, the reasons for teaching only the brain-storming technique to the students and not a variety of other programs designed to enhance creativity, such as the use of Six Thinking Hats (consideration of the problem under six different scenarios namely, intuitively, cautiously, exploratory, factually, beneficially and realistically), and Fishbone diagram (a structured method of looking at cause and effect, given a problem) were not discussed. The exposure of students to more creativity programs coupled with the use of an engineering design project would make this study more complete.

In Singapore, studies on the teaching of creativity have been done mainly with students and teachers from elementary schools, primary schools or secondary schools (Fatt, 2000; Tan, 2001, 2000). In a recent study conducted with 95 beginning and 116 experienced elementary school teachers, a significant number of the teachers felt that project-based activities are an effective means to foster creativity in schools (Tan, 2001). Reviews of the publications of overseas researchers done earlier also supported this claim.

In the LEGO Education Center Singapore, a series of technological products and concepts are introduced to school-aged students. Typically, seven-year old students work with Basic Mechanical Components such as Levers, Gears, Pulleys Axles and Structures, eight to nine-year old students' work with Simple Powered Mechanisms, ten to eleven-year olds, Mechanical Engineering, and Robotics are taught to students above eleven-year olds. Lessons are conducted in a problem friendly, 'play and make' manner. A lesson framework that revolves around the concept of Connect, Construct, Contemplate and Continue is used. Such lesson framework requires students to think about the project that they are about to make (Connect), make it using LEGO bricks (Construct), discuss and evaluate their creations (Contemplate) and continue to work and improve on their creations (Continue). While there have not been any known studies done in the two Centers in Singapore investigating into the ability of such a framework and process in fostering creativity, overseas studies done by Shelfield Hallam University and MIT with students working with LEGO bricks have suggested such benefits. Other frameworks that offer circumstant-ial evidence and support of the learning process used in LEGO Education Center are Lumsdaine and Lumsdaine's (1994) Mindset Deployed at each Creative Problem-solving Process Framework and Wakefield's (1992) Problem Finding and Solving Situations Model.

Lumsdaine and Lumsdaine's (1994) Mindset Deployed at each Creative Problem-solving Process Framework

Lumsdaine and Lumsdaine (1994) postulated that in creative problem solving, the Detective (and analyzer)'s mindset are called upon initially to define the problem. Following that, the mind engages the Explorer and Artists' mindset to facilitate idea generation. This continues until the stage of solution implementation, where the Producer's mindset is used. Figure 1 (Appendix 1) shows the problem-solving mindset (in bold) deployed at each creative problem solving stage.

According to the research done by Herrmann (1996) using over half a million people, he found that 7 percent have a single brain dominance, 60 percent have double dominance, 30 percent have triple dominance and only 3 percent have quadruple dominance (Lumsdaine & Lumsdaine, 1994). Hence, a person with a single brain dominance, such as dominance in solution implementation mindset, will have good organisational skills but weak idea generation and weak analytical and solution finding abilities. The implication of this finding is that since the majority of people have triple brain dominance or less, as individuals, they have not fully utilised their creative potential.

The lesson framework used in LEGO Education Center of Connect, Construct, Contemplate and Continue, may be viewed as a step towards achieving that objective. Connect can be considered as a means to think and define the problem, hence the Explorer and Detective mindset. The Construction of a product, especially when it is used to solve a given problem, can be considered as using the Artist and Engineer mindset, as described by Lumsdaine & Lumsdaine (1994). During the Contemplation stage, the Judge mindset is used to evaluate all the possible solutions or creations presented. Upon receiving all information, knowledge and judgements made about the creations, the Continue stage allows better creations to be produced. This leads to the arrival of a better solution, otherwise known as the Producer mindset. Hence, it can be considered that the framework used in LEGO Education Center may be a means to develop more brain dominance in students, leading to better creativity.

Wakefield's (1992) Problem Finding and Solving Situations Model

Some researchers like Wakefield (1992) point out that professions such as the arts attract persons with divergent mindsets and the science profession attracts persons with convergent mindsets. This claim seems to be generally supported by Lumsdaine and Lumsdaine's (1994) research involving 848 engineering students from the University of Toledo. The research showed that the typical profile for engineers are people who have a strong preference for analytical thinking and least preference for thinking which involves feelings and people (Lumsdaine & Lumsdaine, 1994, p.82).

Wakefield (1992) went a step further and developed a fourfold classification of problem situations based on the works of other researchers such as Getzels and Cskszentmihalyi (1976) and Dillon (1982). He explained how classification of problems and solutions into Open and Closed types can lead to different thinking being deployed to solve them. An open problem type of question leading to an open type of solution calls for Creative Thinking to be deployed. He proceeded to define Creative Thinking as a meaningful response to any situation which calls for finding a problem and solving it in one's own way (Wakefield, 1992, p.3). Wakefield's (1992) problem finding and solving situations are presented in Figure 2.

In the LEGO Education Center, as mentioned, the one-hour classes are designed to follow a lesson plan revolving around the 4 Cs. As a prelude to the Construction stage, practical problems relating to the topic introduced during that lesson are presented. Where possible, Open-ended problems leading to Open-ended solutions are presented. Where this is not possible, then Closed problems leading to open-ended solutions will be deployed. Such problems may involve students in 'solving a car park traffic congestion problem' using robotics and microprocessor based technology. Solving such problem facilitates Divergent and Creative thinking. Divergent thinking is a key component to Creative Problem solving (Teo, 2006).

Summary

Out of the seven methods of fostering creativity identified in this paper, *Using lesson plans focusing on creativity* and *Multi-disciplinary, hands-on projects* are directly deployed during Robotics learning at LEGO Education Center. Other methods that are indirectly deployed are: (i) Developing problem friendly classroom, (ii) Using prior knowledge, and (iii) Using different types of problems. The scale of the Methods of fostering Creativity, based on the Rasch Unidimensional Model computer Program (Andrich, Sheridon & Luo, 2003) was presented. The easiest method of fostering creativity was to *Develop a problem friendly classroom* (both attitude and behavioural-wise) and the hardest methods of fostering creativity were providing students with *Different types of problems* (attitude-wise) and *Teaching the skills and attitudes of creativity* (behavioural-wise).

Robotics Education in LEC covers Basic Mechanical Components such as Levers, Gears, Pulleys Axles and Structures, Simple Powered Mechanisms, Mechanical Engineering and Robotics. The lesson Framework of teaching robotics used in LEC, namely Connect, Construct, Contemplate and Continue was compared to Lumsdaine and Lumsdaine's (1994) Mindset Deployed at each Creative Problem-solving Process Framework. It was found that there are similarities in both frameworks, implying that robotics education involves Creative Problem Solving Process. It was also pointed out that Robotics lessons in LEC facilitate the use of Creative and Divergent thinking, components of thinking as identified by Wakefield's (1992) Problem Finding and Solving Situations Model. Hence, robotics education when conducted in a guided framework could be highly useful in fostering creativity and innovation.

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APPENDIX 1

Table 1: Global Statistics for Methods of Fostering Creativity

ITEM-PERSON INTERACTIONS

	ITEMS		PERSONS	
	Location	Fit Residual	Location	Fit Residual
Mean	0.00	0.12	-1.27	-0.15
SD	1.21	0.89	0.61	1.10

Notes

(1) The item means are constrained to zero by the measurement model.

(2) The means of both item and person fit statistics are 0.12 and –0.15. The standard deviations of both item and person fit statistics are 0.89 and 1.10. As the item and person fit statistics have means near zero, and standard deviations near one, they indicate that the data fit the Rasch Measurement Model very well.

(3) The standard errors are to two decimal places, so numbers are given to two decimal places.

Table 2: Methods of Fostering Creativity and their Level of Difficulties

Methods	Attitude Difficulty (logits)	Behaviour difficulty (logits)
B1. Teaching the skills and attitudes of creativity		
B2. Teaching the creative methods of the	- 0.73	1.6
disciplines (subjects)	- 1.14	0.64
B3. Developing problem friendly classroom	- 1.75	0.46
B4. Using prior knowledge	- 0.44	1.49
B5. Using different types of problems	+0.01	1.35
B6. Using multi-disciplinary, hands-on projects	- 0.83	0.90
B7. Using lesson plans focusing on creativity	- 1.06	-0.50

Notes

1) The difficulty values of each method were taken as the average of three supporting items in each perspective
2) Items with the smallest value (in logits) are the easiest to perform and items with the largest values are the most difficult ones to perform.

Figure 1: Mindset Deployed at each Creative Problem-solving Process

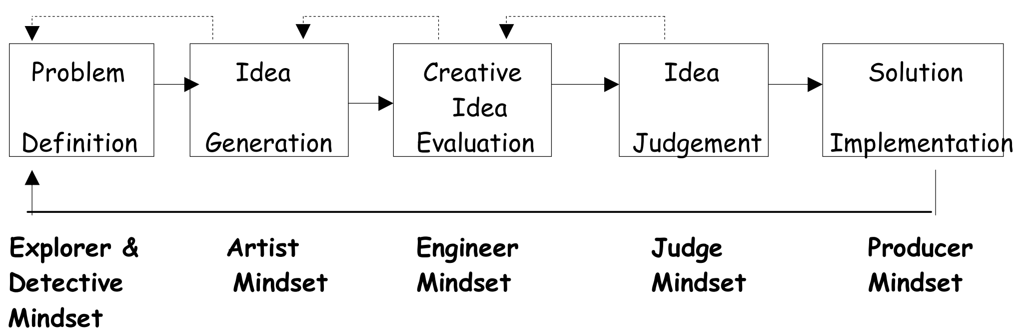
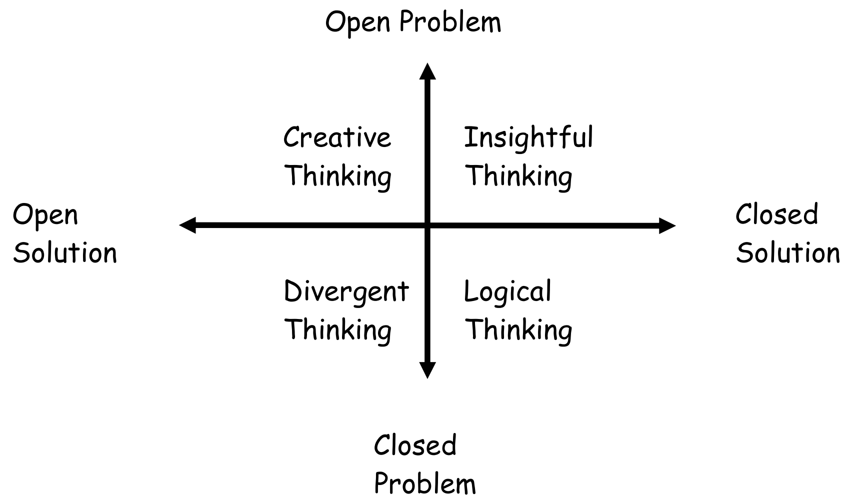


Figure 2: Wakefield's (1992) Problem Finding and Solving Situations



Notes

1) Closed Problems with Closed Solutions refer to problems that are well defined, clearly formulated and could be solved through known procedure. The answers are also clearly defined and have agreed-upon standards.
2) Open Problems with Closed Solutions refer to problems that are poorly defined and have solutions that are specifically and clearly defined.
3) Open Problems with Open Solutions refer to problems that are poorly defined, difficult to formulate and have solutions that are also difficult to formulate a criterion for.
4) Closed Problems with Open Solutions refer to problems that are well defined, clearly formulated and could be solved through known procedure, but have solutions that are difficult to formulate a criteria for.

APPENDIX 2

The Questionnaire to Measure the Fostering of Creativity

The numerical response sought for are as follows:

Your Response	The numbers to be assigned
All the time	6
Most of the time	5
Some of the time	4
A few times	3
Once	2
None	1

Main Item B1: Teach the skills and attitudes of creativity			Ideally, this is what I should do	This is what I actually do
1	Item 01-02	I share stories about the lives of creative people and/or inventors during my contact with my students.		
2	Item 03-04	I explain the creative process (techniques and/or attributes to be creative) during my contact with my students.		
3	Item 05-06	I discuss with my students how to employ creative techniques in their daily lives.		

Main Item B2: Teach the creative methods of the disciplines (subjects)			Ideally, this is what I should do	This is what I actually do
4	Item 07-08	I teach subject-specific problem investigative skills to my students.		
5	Item 09-10	I teach subject-specific idea(s) and/or solution(s) generative skills to my students.		
6	Item 11-12	I teach my students how to effectively generate subject-specific ideas, evaluate them and to iterate the whole process, until a creative solution is arrived.		

Main Item B3: Develop problem-friendly classroom			Ideally, this is what I should do	This is what I actually do
7	Item 13-14	I provide opportunities for all students to offer their views in class.		
8	Item 15-16	I provide constructive feedback on all views offered by students.		
9	Item 17-18	I facilitate the class to provide constructive feedback on views offered by their fellow classmates.		

Main Item B4: Prior Knowledge - elicit or facilitate creativity by controlling information to be released, prior to the students working on the assignment.			Ideally, this is what I should do	This is what I actually do
10	Item 19-20	Students doing my assignments will find that all the knowledge needed to solve them had been taught in class.		
11	Item 21-22	I set well-defined assignment requiring the students to do some research on their own.		
12	Item 23-24	I set ill-defined assignment requiring the students to do some research on their own		

Main Item B5: Employ different type of problems for the students to solve so as to foster creative thinking.			Ideally, this is what I should do	This is what I actually do
13	Item 25-26	I set problems that lead mainly to a close-solution (single correct answer).		
14	Item 27-28	I set closed- problems that lead mainly to open-solutions (multiple responses). This problem has a well-defined initial state but a less well defined end-state leading to a few possible solutions.		
15	Item 29-30	I set open- problems that lead mainly to open-solutions (multiple responses). This problem has few clues for solution procedures, and has less definite criteria for determining its solution(s).		

Main Item B6: Multi-disciplinary, hands-on projects. e.g., design/build engineering project, simulation, sociodrama.			Ideally, this is what I should do	This is what I actually do
16	Item 31-32	In doing their project assignment, students need only produce a sketch of their idea(s) on paper.		
17	Item 33-34	In doing their project assignment, students have to develop a functional project.		
18	Item 35-36	In doing their project assignment, students have to develop a reliable and fully functional project. This condition is normally attained by subjecting the product through a reliability test giving rise to a number of engineering revisions (changes).		

B7. Lesson plans – how classes activities are planned and conducted			Ideally, this is what I should do	This is what I actually do
19	Item 37-38	Class activities are planned in tight accordance to the subject syllabus.		
20	Item 39-40	Class activities are conducted in tight accordance to the subject syllabus plan.		
21	Item 41-42	Subject syllabus is used as a guide and class activities are conducted a way that requires students to alternate between thinking logically and thinking divergently.		