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Inculcating Problem Solving and Analytical Skills in STEM Education Practices: The CRYsTaL Initiatives

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The Malaysia Education Blueprint 2013-2025 has put a lot of emphasis on transformation in Science, Technology, Engineering and Mathematics (STEM) education to equip students with significant skills to compete in the global job market. The success of the Government Transformation Program, the National Science Policy and National Transformation 2050 have also been linked to STEM education to instil creative and innovative human capital in sustaining economic development and improving life quality in society especially in the era of industrial revolution 4.0 and IoT (Internet of Things). The aim of this study is to explore an alternative teaching and learning method based on STEM education practices especially in programming and automation systems, to enhance problem solving and analytical skills among undergraduates and school students initiated in the CRYsTaL program. This program provides an interdisciplinary, hands-on approach to teaching programming language and introduces key concepts in mathematics and science while allowing the students to have hands-on experiences with various electronic devices and components. This exposure allows students to experience real world applications and exposes them to technology not currently introduced in many primary and secondary school classrooms. The method used is based on a qualitative study using semi-structured techniques that includes individual interviews, proposal presentation and demonstration observations. The design of this study is based on a sub-type of descriptive-longitudinal case study. The population in this study involved the fifth cohort of about 36 students from technical schools in Malaysia. Although this is less than conclusive, the result of the finding indicates that the methods employed are generally effective to make an impact in promoting problem solving and analytical thinking skills.

Key words: *STEM Education, Programming and Automation systems, Problem solving and analytical thinking skills, National Transformation 2050.*

Introduction

The school curriculums currently is progressing beyond a typical focus on basic competency in core subjects. It is now focused to promoting understanding of the content at much higher levels by integrating the 21st century skills into all subject areas (MOE, 2016). The societies in the 21st century are now living in a high-technology and internet-based environment.

The characteristics of this environment include access to an abundance of information and rapid changes in the technology tools that require more than average thinking skills and content knowledge. The problem solving and critical thinking skills that promote creativity and innovation, communication and team work are essential to prepare students for the future. The action plan as emphasized by the Education Ministry emphasised that education should appear as Key-Stage standard instead of merely grade-based standards. The global market is now making the technology far more competitive and in order to compete, students should be properly educated so that they are competent in the STEM fields that drive innovation in this new age. STEM education emphasizing on engineering education and the idea of integrating these four main areas is relatively very new to Malaysia (Bunyamin & Finley, 2016, Thomas & Watters, 2015).

Through various research studies have found that STEM education is able to develop problem solving and critical thinking skills, promote student-centred learning, cultivate team work and communication skills (Sanders, 2009 and Stohlmann & Moore, 2012). A STEM education puts more emphasize on hands-on investigation and collaborative problem-solving and it should incorporate the theory and practices of science and mathematics education into technology and engineering education (Satchwel & Leopp, 2002). Thus, integrated STEM education can be complimented by fundamental teaching and learning approaches such as project-based, problem-based, inquiry-based and theme-based learning (Apedoe et al., 2008). In addition, it is also been found that effective practices in science and mathematics education provides insight into effective practices in STEM education. Zemelman, Daniels & Hyde (2005) list ten best practices for teaching math and science among which are: use manipulatives and hands-on learning; discussion and inquiry; use a problem solving approach and integrate technology.

The New Malaysian Curriculum

The KSSM (Curriculum Standard for Secondary Schools) was recently introduced by the Ministry of Education in 2016. Some schools throughout the country had already executed this curriculum by offering the two new subjects; Fundamental Computer Science and Design and Technology. In this new curriculum, the students are expected to learn to use the latest technology and to be conscious and embrace the impact of technological changes. With the new curriculum, the students should also be able to think creatively by participating in a learning environment that simulates the mind to improve quality of life through problem solving ability. With the 21st century skills, these students are also expected, not to be just recipients or users of the latest technology introduced, but involved in the innovation and invention of products and able to provide innovative ideas (MOE, 2016). The domains that describe the required technical competencies for the students is listed in Table 1 below.

Table 1: The domain that describes the required technical competencies for the students

Domain	Description
Design Appreciation	To be appreciative of any designs that could be improved or develop new designs that are better, cost effective and efficient
Application Technology	Learning and applying technology in a variety of designs discipline.
Manufacturing Products	Development of designs or products that are more efficient based on better design process.
Evaluation of Product Designs	Putting emphasis on human values in learning to ensure that the product able to solve individual and community issues while being competitive

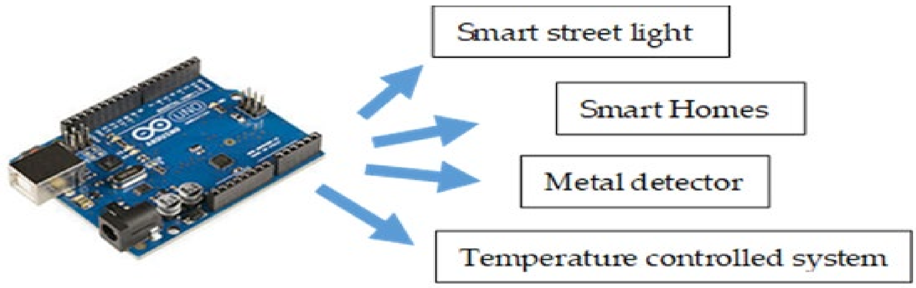
The CRYsTaL Program

CRYsTaL is an acronym for CReative Youths Through innovAtive Learning. This program was initiated by a group of lecturers at the Faculty of Engineering and Built Environment (FKAB) and Faculty of Information Science and Technology (FTSM), University Kebangsaan Malaysia (UKM) in 2009. The main objective of this program was initially to provide an opportunity for secondary school students to explore their interest in science and technology courses in a more interesting and out-of-the classroom approach. The intention was to address the issue of the declining number of students pursuing the science stream. Simultaneously, the concept was also to bring knowledge in smart technology to teenagers in Malaysia regardless of their background so that they are inspired to develop smart systems to solve problems around them.

The Crystal initiative is focused on providing real learning experience using microcontroller-based boards in the development of automation systems. Students aged 15 to 17 were first trained based on structured modules under the guidance of lecturers, students and technical staff from UKM. The complete program was conducted between 3 to 5 months based on the four main phases. When the industrial revolution 4.0 and IOT (Internet-of-Things) were first given attention, the program was found to be more relevant as the revolution emphasized on the wider use of automation technology. In tandem with the challenges of a more complex new technology, knowledgeable and skilled human resource development that can compete globally could be emphasized accordingly.

The main device used in this program is the development board Arduino based on ATMega 328P microcontroller. This is an open-source electronics platform based on relatively easy to use hardware and software. It is also known as Embedded Computing Platform which is an interactive system where hardware and software can interact with the environment (Bender 2012). Various smart and autonomous projects could be developed as shown in Figure 1 below and this would allow the students to design real world applications and expose them to programming and technology which is not taught in secondary school classrooms (Hoffer, 2012; Irshad, 2017).

Figure 1. Projects using Arduino



The approach observed in the Crystal program is based on the STEM education practices shown in Figure 2 below. This 4 month program employs the practical teaching and learning method where the path of knowledge flows from the lecturers and technical staff to the university undergraduates (as mentors) to the school students as shown in Figure 3 below. The main device used in this program is the microcontroller and the open-source software package for the program development. The outcome of the program is that the students are able develop a proof of concept prototypes based on their ideas to solve problems within the community.

Figure 2. STEM education practices

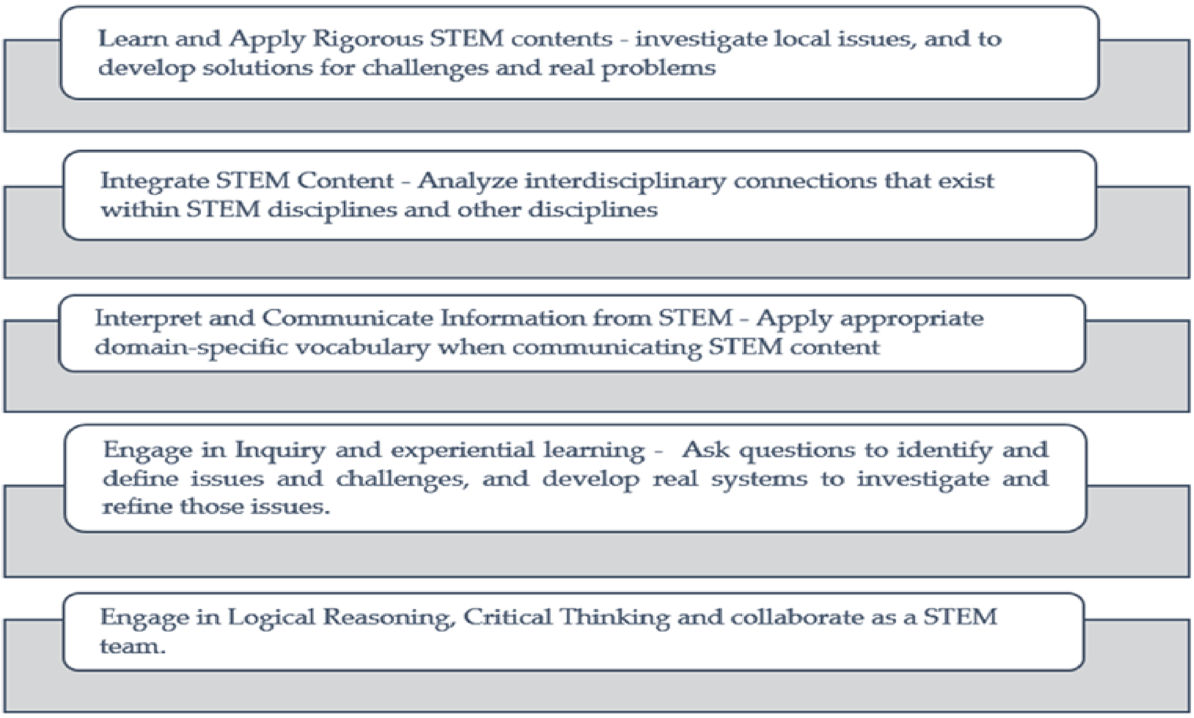
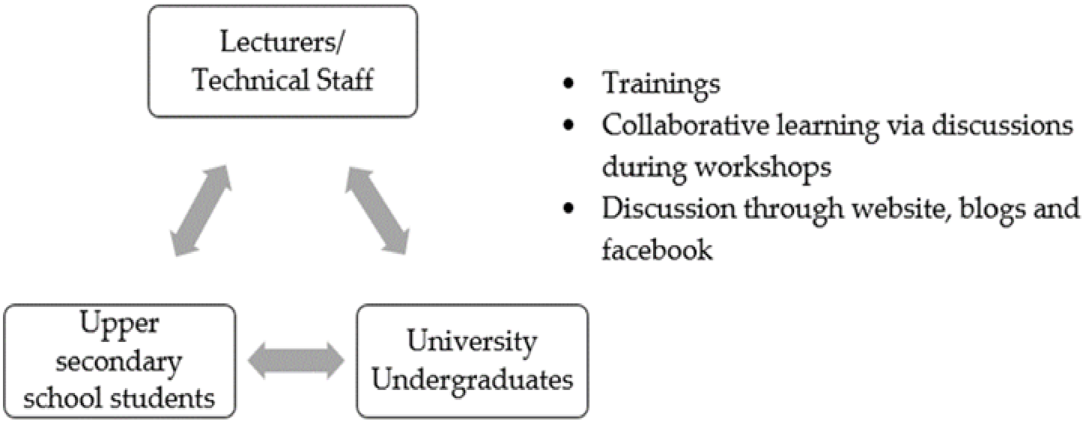


Figure 3. The Program structure



This paper discusses the impact of the Crystal program in inculcating problem solving and critical thinking skill among youths via STEM education practices as employed. Among the questions investigated in this study are:

1. Is the approach use in this program aligned with the domain set by the Ministry of Education?

2. What are the main considerations for implementing STEM education using the manipulatives and hands-on learning; discussion and inquiry and use justification of thinking?
3. Can the school students apply problem solving and analytical thinking skills in engineering design process and product development?

Methodology

This study was conducted on 36 secondary technical school students from Selangor, Kedah, Terengganu, Melaka, Johor, Pahang, Negeri Sembilan and Penang. There were 22 undergraduates, 8 technical staff and 10 lecturers from the engineering faculty involved to guide and motivate the students. In this study, a qualitative method was established using semi-structured techniques that includes individual interviews, proposal presentation and demonstration observations. The design of this study is based on a sub-type of descriptive-longitudinal case study. The program is separated into four main phases with the appropriate STEM education practices as described below.

A training session was organized in Phase 1 for the students to become familiar with the devices used and they were taught how to program the microcontroller based on the structured module and hands-on lessons in the laboratory. They were then given some smart systems problems to solve. In these problems, they would need to write programs and develop the basic hardware circuit to control simple applications, for example a water level pump system and a traffic light control system. In this phase, the students were expected to understand basic program writing and the important input and output processes were made visible for them to learn. They would also need to demonstrate that their system was functional.

In this 3-day training session, there were 40 school students involved and they were divided into a group of two. The sessions were delivered by the lecturers and each group were guided by at least one university undergraduate student to assist whenever the school students needed to investigate and explore other alternative connections or programming styles for better understanding. Each group was provided with a toolbox that consists of one microcontroller board, some basic outputs devices like LEDs and LCD, some sensors, a multi-meter and other basic tools, a traffic light module, a robot base with two motors and a motor driver. At the end of the training session, the group of students were given a challenge, that is, to develop a line tracking robot and to compete to find the fastest robot to finish the given track.

In Phase 2, the students are given a theme and they conduct a study on what the problems are that are associated with the given theme and propose a smart or automation system that could resolve the identified problem. As what are required in the STEM practices, they would need to perform analysis and synthesize some STEM information to derive the solution. They would then present their proposal in front of a panel, comprises of lecturers and technical staff from UKM. The objective of this session is for the panel to give views and suggestions on the proposed project. This session had also provide a good feedback on the students' ability to collect and analyse information and proposed technological solutions.

In Phase 3, the students would be focusing on designing and developing the project. The STEM education practices observed in this stage are that the students evaluate, select, and apply appropriate systematic approaches and appropriate technology in the design process and they apply STEM content to construct creative and innovative ideas. They would also share ideas and work effectively with a STEM focused multidisciplinary team to achieve a common goal. They need to be able to perform troubleshooting procedures to solve problems in hardware interfacings and solve programming bugs. Dealing with more complex applications requires more difficult programming process. Tracking down which lines of code need to be adjusted to compensate for this and modifying it could be a very time consuming task. Hence, the students were faced with very stressful challenges in this phase and this tested their problem solving and analytical thinking skills.

In Phase 4, or at the end of the program, the students would need to demonstrate their proof-of-concept prototypes. They are expected to be able to deliver effectively the STEM contents of the prototypes developed and demonstrate an understanding on the developed solutions to the identified problems. The list of projects developed are shown in Table 2 below. The activities conducted in all the 4 phases are as shown in Figure 4 below, and the summary of STEM education practices for each stages is shown in Table 3 below.

Table 2: List of Developed Projects for proof of concept

Title	Description	Identified problems
OKU-D	A system that able reads the ID card of a disabled person and allow him/her to park in the designated parking lot for the disabled.	The disabled people are usually denied of their rightful parking space in the shopping malls or office complexes.
Page Turner	A system that allows disabled person to turn a page of a book	The disabled people have problems in reading physical books or the quran due to the

	automatically.	difficulties in turning pages.
Green Smart Feeder	A system that able to assist disabled people to automatically monitor the pet food and feed their pets.	The disabled people have difficulties to ensure their pets have enough food and a proper feeding time.
Smart Dustbin	A dustbin that opens automatically if a nearby person is detected.	The disabled people faced difficulties to open the lid of dustbins that are provided in the common areas.
Smart walking stick	A system that assist visually impaired people to move around safely.	The visually impaired people faced hardship to move around safely.
Limitless artificial hand	A system to assist amputees in their daily chores.	The disabled people especially amputees faced difficulties in accomplishing their daily chores.

Fig. 4 . Various activities executed in the 4 phases

Table 3: Summary of STEM Education practices observed in the 4 Phase

Phase	STEM Education Practices
Phase 1 (3-days) Workshop on Training the students using the development board and writing programs	• The students learned and acquire the knowledge on the fundamental concepts on programming and automation systems based on hands-on and investigative approach. • The students understand the interdisciplinary connections that exist within STEM and other disciplines
Phase 2: (1 week) Students conduct studies and present a proposal on automation systems that able to solve identified problems based on specific themes.	• The students analyse interdisciplinary connections that exist within STEM and other disciplines • They would apply integrated STEM and other disciplines as appropriate to answer complex questions, to investigate local issues, and to proposed solutions to those problems. • The students identify, analyse, and synthesize appropriate STEM information • The students will be engaged in critical reading and writing of technical information. • The students evaluate and integrate multiple sources of information.
Phase 3 (3 months) Design and development of the proposed system.	• The students evaluate, select, and apply appropriate systematic approaches in the design process • The students apply STEM content to construct creative and innovative ideas. • Share ideas and work effectively with a STEM focused multidisciplinary team to achieve a common goal • Listen and be receptive to ideas of others • Identify and understand technologies needed to develop solutions to the problems - perform troubleshooting process • Apply technology strategically
Phase 4 (2-days) Presentation and demonstration of the prototypes as proof of concept.	• Communicate effectively the STEM contents on the prototypes developed • Demonstrate an understanding of STEM content to develop solutions to the identified problems. • Demonstrate an evidence-based opinion or argument

Results and Discussion

All of the groups who participated in this program successfully completed their proposed projects and were able to discuss the constraints in their design process. Periodic observations were made on the activities conducted during the 4 month program. Their approaches in identifying the challenges, exploring ideas, planning and developing engineering design, testing and evaluate their prototypes as well as presenting their solution as a team was commendable. Table 4 below lists the identified technological constraints and problems that were solved by the students.

Table 4: List of Developed Prototypes for proof of concept

Title	New technology involved	Identified technological & Engineering problems that was solved
OKU-D	• The students are able to implement the programming codes and established the interfacing for new devices, mainly the barcode reader and the motion sensor.	The barcode reader was found to be very challenging to program due to insufficient information on the device purchased and the unavailable relevant libraries in Arduino IDE programming.
Page Turner	• The students are able to implement the programming codes and established the interfacing for new devices, mainly the motors and gears and provide a proper timing.	The students need to solve problems on the speed of the motors and the movement of the gears. These problems results in more pages were turned at one time.
Green Smart Feeder	• The students are able to implement the programming codes and established the interfacing for new devices, mainly the appropriate sensors, actuators, motors and the mechanical devices.	The problem were discovered on the mechanical part of the system, whereby it was difficult to maintain the correct amount of food to be dispensed.
Smart Dustbin		The students are faced with the problem to design their interfacing circuits and select the appropriate sensors to be used in their respective projects.
Smart walking stick		
Limitless artificial hand		

The first observation was made during the training session. All of the students had not had any experience working on the Arduino board and programming language. However their enthusiasm and excitement were visible when they were seen exploring and investigating alternative techniques to write the programs and to connect the input and output components. These students have demonstrated their ability to learn and acquire knowledge on the fundamental concepts of programming and automation systems using a hands-on investigative approach. This result is determined from the interview sessions where 80% of students could explain their understanding about the programmes they had written.

The second observation was conducted during their proposal presentation. It was evident that the students were actively engaged in critical reading and understanding the technical information that they gathered. These students were able to identify, analyse and synthesize appropriate STEM information and use this information to propose creative and innovative ideas in their products. The subsequent observations were made during the product design and development phase. Based on the products that they were working on, the students were given the guidance to effectively evaluate, select and apply the systematic approach in the design and development process. They could be seen sharing ideas and working effectively within a team to achieve a common goal. It was obvious that they were receptive to ideas from within the group members and their mentors. For example, the group who were designing and developing the project named OKU-D. They needed to use a device that could read the disabled person ID card. The group members studied all the related devices to be used and presented their findings in the group and discussed the limitations and the strengths of these devices. They came to agreement and worked closely to resolve problems within the time frame.

The last observation was made during the product demonstration. The students were able to present and communicate the STEM content on the proof-of-concept prototypes that they have developed. Based on the question and answer session, they were able to demonstrate an understanding of the STEM content based on the identified problems. Based on interviews and verbal feedbacks, it was interpreted that these students exhibit strong determination and worked very closely in a team to complete their projects successfully.

Finally, the schools were encouraged to compete in innovation and invention competitions. It was found that two products, the OKU-D and the page turner had won several competitions at national and international level. The OKU-D won gold medals in the South Korea World Innovation Invention and Canada invention competitions respectively. These awards were given based on the innovativeness, demonstrated creativity, and originality of idea. They were also evaluated on the quality of presentation and clarity of idea. In addition, the criteria for the award also emphasized the problem solving strategy.

Conclusion

Based on the results presented, the approach used in this program supported the domains as listed by the Ministry of Education, especially in technology application and evaluation of product designs. The hands-on program based on discussion, inquiry and an investigative approach has been effective to inculcate problem solving and critical thinking skills. The acquired skills were evident in the way the students applied them in the design process and product development.

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