

INTEGRATED 21ST CENTURY SCIENCE, TECHNOLOGY, ENGINEERING, MATHEMATICS (STEM) EDUCATION THROUGH ROBOTICS PROJECT-BASED LEARNING

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Abstract

Purpose of the study: To propose a new framework on integrated 21st century STEM education through Robotics Project-based Learning, and secondly, to outline a Robotics Project-based Learning curriculum in the perspective of integrated 21st century STEM education.

Methodology: Content analysis was carried out to design a new framework. Secondary data collection technique was used.

Main Findings: The proposed framework can identify itself with each STEM curriculum in Science, Technology, Engineering and Mathematics. Educational robotics as a tool to integrate the four disciplines through project-based learning.

Applications of this study: The proposed framework is applicable in 21st century learning environment using student-centered approach. 21st century skills are enhanced through collaboration, creativity, critical thinking and communication while students carry out robotics project-based learning.

Novelty/Originality of this study: A new pedagogy of STEM integration in Malaysia education system. Hands-on and minds-on activities through robotics project-based learning promote higher order thinking in students.

Keywords: STEM, Education, 21st Century, Robotics, Project-based Learning

INTRODUCTION

A nation's ability to maintain its global competitiveness within Science, Technology, Engineering, and Mathematics (STEM) fields is a critical issue. Since the past decade, STEM is an issue being discussed in the international arena in the 21st century workplace (Bell, 2010). In Malaysia, as well as other developed countries, the demand for graduates in STEM fields continues to grow at a relatively rapid rate; however, the supply of the STEM pipeline still reports a serious deficiency of graduates who pursue STEM courses. Thus, it is vital to minimize any gap between knowledge, skills, and attitude gained in school with the 21st century STEM competencies required by the future workforce capacity. The students in 21st century STEM learning environment need to enhance their creativity and critical thinking to make sure they can fully concentrate during the learning session in a perfect condition. The learner-centered approach is able to get rid of boredom; hence, accelerate the learning process (Marca & Longo, 2017; Hanipah Hussin, 2004). In a critical review reported by Jayarajah, Saat, and Rauf (2014), the researchers stated that little research has been documented to determine the effects of the integrated approaches among the STEM subjects on the students' achievement and the infusion between STEM disciplines. In order to bridge the gap between the previous research and practice, the challenges of addressing 21st century competencies in integrated STEM education can be alleviated by implementing Robotics Project-based Learning as an effort to achieve the standards. The educational robotics used in this study aims to improve the learning experience of people through the creation and implementation of activities, technologies and artifacts, where robots play an active role.

This paper proposes two questions about the conceptual framework:

1. How does the Robotics Project-based Learning satisfy the integrated 21st century STEM education needs?
2. How does the Robotics Project-based Learning bridge the gap between knowledge, skills, and attitude towards STEM disciplines?

Integrated STEM Education

Integrated STEM education is defined as the approach in teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning (Kelley & Knowles, 2016). Kennedy and Odell (2014) indicated that STEM education programs of high quality should include the integration of technology and engineering into science and math curriculum at a minimum. The benefit of integrating STEM education into all content areas is that it can provide students with informal practice especially to solve problems creatively in the future workplace.

21st Century Competencies

A systematic review was carried out by Dede (2010) on the various framework of 21st century skills or competencies. He concluded that all the 21st century skills frameworks are generally consistent with each other. Bernhardt (2015) concluded that although it is difficult to create a definitive list of 21st century competencies that comprehensively define 21st century learning, the reviewed literature illuminates the following key ideas: communication skills; technology integration; processing information from various forms of media; thinking critically, creatively, innovatively; problem solving; taking responsibility for self and community; and working collaboratively across disciplines (Sharifah Nadiyah, Faaizah, Hanipah, & Norasiken, 2015).

Robotics Project-based Learning

Robotics project-based learning typically involves areas of constructivism, situated learning theory, cognitive psychology, and the concept of the integrated curriculum (Chen, Chang, & Tseng, 2015). Robotics building is an example of one ready opportunity for students to engage in 21st century learning. Educational Robotics for STEM is such an interdisciplinary environment which involves an understanding of related but different domains and involves participants from industry, academia and organizers of educational activities (Alimisis & Boulougaris, 2014; Nikitopoulou, 2017). Robotics project-based learning generally indicates positive effects on students' achievement (Chen et al., 2015; Sullivan & Umaschi, 2015). The effectiveness of robotics project-based learning in integrated STEM education is interdisciplinary and contain diverse content objectives within the context of hands-on activities to produce an artefact (Han, Capraro, & Capraro, 2014). Robotics project-based learning strategy has been found to be an effective integrated STEM education program which offers special educational leverage because it is a multi-disciplinary field involving a synthesis of much content knowledge, such as Mathematics and Physics, Design and Innovation, Computer Science and Programming (Afari & Khine, 2017; Analytis, Sadler, & Cutkosky, 2017; Angeli, 2018; Samuels & Poppa, 2017; Spolaôr & Benitti, 2017). The use of educational robotics as a curricula tool can bring the possibility of transmitting to the students the basics of technology and to give them another kind of human and organizational values (Ioannou, Socratous, & Nikolaedou, 2018). The keys to integrate 21st century skills into the classroom are an application, connections and participation; hence Robotics Project-based Learning provides an interdisciplinary platform to promote holistic human development.

METHODS

Content analysis was chosen as this research method utilizes a systematic approach to make valid and replicable inferences from the texts (Krippendorff, 2013). The aim of using content analysis in this research was to build a model to describe the phenomenon in a conceptual form. A summative content analysis is used, which involves counting and comparisons, usually of keywords or content, followed by the interpretation of the underlying context (Ernst, Ernst, & Tech, 2014; Krippendorff, 2004). Previous research was reviewed to abstract the key concept of Robotics Project-based Learning in the context of integrated 21st century STEM education. After the conceptual framework is built, the consequence step is to outline a Robotics Project-based Learning curriculum, which aimed to enhance the STEM education in school. The research work is in progress in which it will apply a pre-test and post-test quantitative data collection to investigate the effectiveness of the Robotics Project-based Learning in terms of students content knowledge in Science and Mathematics. On the other hand, a rubric is developed to assess the outcome of students' skills in robotics construction and design. While for the attitude construct, the S-STEM survey (Friday Institute, 2012) is used to measure students' interest toward multiple STEM disciplines, 21st century skills and interest in STEM careers (Unfried, Faber, Stanhope, & Wiebe, 2015).

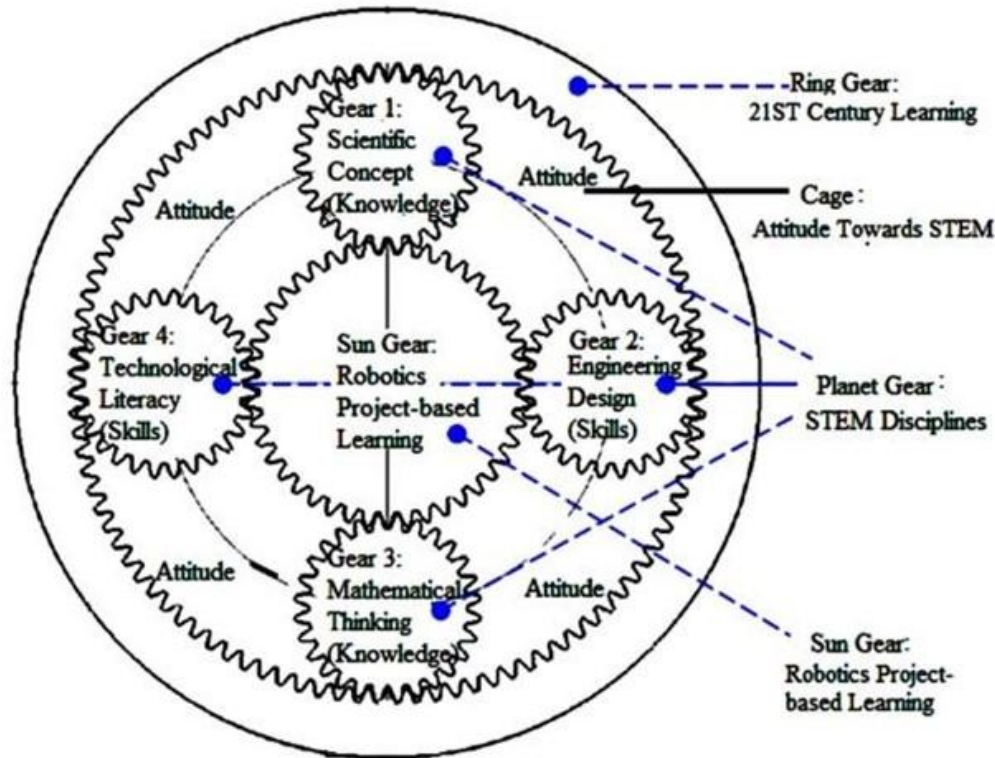


Figure 1. Sun Gear: Robotics Project-based Learning

RESULTS

The first objective of this study is to build a strategic conceptual framework using integrated STEM disciplines. Figure 1 illustrates the proposed planetary gear system conceptual framework of integrated STEM education through Robotics Project-based Learning, which seeks to propose such a comprehensive approach in the context of 21st century learning. This framework describes the integrated STEM disciplines in terms of knowledge, and attitudes which the students should master to succeed in work and life in the 21st century.

In engineering, a planetary gear is one of the epicyclic gears, which is a gear system consisting of one or more planet gears, revolving about a central sun gear. The planetary gear is a widely used industrial product such as automation system with outstanding power transmission efficiencies. The image presents a planetary gear with four planets, in this case, is a scientific concept, thinking, and technological literacy.

The sun (central) gear is illustrated as Robotics Project-Based Learning. The outermost gear which is the ring gear that meshes with each of the planet gears is considered as a 21st century classroom. The four disciplines of STEM are applied in the classroom to embed 21st century skills in students. In order to complete this system, the planet gears are held to a cage or carrier that fixes the planets in orbit relative to each other. Thus, the cage in this design is described as the integrated STEM education. In a simple planetary setup, input power turns the sun gear at high speed. The planets, spaced around the central axis of rotation, mesh with the sun as well as the fixed ring gear, so they are forced to orbit as they rolls (Cooley, & Parker, 2017).

In Figure 1, Robotics Project-based Learning is the common practices within the four STEM disciplines and are bounded in the 21st century classroom. The advantages of planetary gears are only realized if the individual planets carry nearly equal load. Thus, this framework proposes the equality of each STEM discipline and the harmony among them towards an effective 21st century STEM classroom.

Based on the conceptual framework in Figure 1, this study then outlined an integrated 21st century STEM competencies in Robotics Education as in Table 1. Table 1 explain the matrix of STEM disciplines and the outcomes expected through Robotics Project-based Learning in the aspect of content knowledge, skills and attitude. The robotics tools proposed in this framework is LEGO® Mindstorms Education and its compatible software. LEGO® Mindstorms Education is used as it is more user-friendly and is able to serve students' needs from primary schools up to high school levels (Afari & Khine, 2017; Danahy et al., 2014; Savard & Freiman, 2016).

DISCUSSIONS

The proposed framework emphasizes the equality of the four STEM disciplines and other components driven by the Robotics Project-based Learning. The following explanation describes the conceptual framework for integrated STEM education and will also serve as a frame for the core concept of the paper.

Robotics education serves as a new education tool that emphasizes on the holistic development of students; thereby, helping the students and the nation to fulfil its National Philosophy of Education, which emphasizes in nurturing individuals holistically through physical, emotional, spiritual, intellectual, and social development that ultimately produces balanced citizens. This pedagogy not just focuses on building up intellectual skills, but also serves as a perfect learning environment that allows for physical development through hands-on experiment, social skills, group discussions, and solving problems with their teammates. Now is the right time that the implementation of robotic curriculum be taken into consideration in the education development in Malaysia so that all students can benefit from such an enjoyable and meaningful learning process.

Table 1: The Integrated 21st Century STEM Competencies in Robotics Education

STEM Disciplines	Content Knowledge	Skills	Attitude
Scientific Concept	Gearing system, distance, speed, acceleration, momentum, force	<ol style="list-style-type: none"> 1. Calculate the ratio 2. Determine the distance, speed, and acceleration, momentum and force in a problem 	Enhance the attitude and interest towards science
Technological Literacy	Programing languages contextualize the process of cause and effect through algorithms	<ol style="list-style-type: none"> 1. Use the programming 2. Change the variables in the existing program to experience the effects 3. Create original program for robot 	Develop the students' consciousness towards importance of technological literacy
Engineering Design	Steps in engineering design to create a project and to solve a problem	<ol style="list-style-type: none"> 1. Construct the robot and reconstruct the robot 2. Reflect on the engineering design process 	Motivate the students to apply engineering design in problem solving
Mathematical Thinking	Robotics components such as bricks, gear, tires, etc. possess a variety of mathematical qualities.	<ol style="list-style-type: none"> 1. Measuring the variables and calculating the physical quantities 2. Test hypotheses using statistical method 3. Share findings quantitatively 	Enhance the attitude and interest towards mathematics
Project-based Learning (PBL)	Integrating the scientific concept, technological literacy, engineering design and mathematical thinking to complete a project in 21st century learning environment	<ol style="list-style-type: none"> 1. Complete the project within the duration given 2. Reflect and share findings 	Collaboration Interest towards STEM career

Planet Gear 1: Scientific Concept

The science learning process emphasized more development of communication through enquiry, conceptualizing, reasoning, and problem solving.

Scientific literacy will empower students to become responsible citizens in a rapidly changing world in which we live and will prepare students for effective participation in the decisions and actions that take place in their homes, their communities, and their entire world.

Gear 2: Engineering Design

Engineering design provides the ideal STEM content integrator by encouraging students to explore all the stages across the curriculum. [Moore et al. \(2014\)](#) proposed a model of STEM integration centered on engineering design that attempts to identify the components of integrated curricular that can capitalize on engineering to enhance learning in multiple disciplines. Engineering design is an approach for delivering STEM education creates an ideal entry point to include engineering practices into existing secondary curriculum.

The Ring Gear: 21st century learning environment

If an educator wants to make their instruction more career relevant and practical for their students to prepare them for workplace readiness, they need to know which essential skills will be transferable across different fields of work in the 21st century. The 21st century learning environment aims to prepare the students with 21st century competencies for needs in future and to equip students with an internationally competitive edge.

The cage: Integrated STEM Education

The cage in the planetary gear system represents the integration of interdisciplinary curriculum where rigorous academic concepts are coupled with real-world lessons as students apply Science, Technology, Engineering, and Mathematics in contexts that make connections between school, community, work, and the global enterprise; thereby, enabling the development of STEM literacy and with it the ability to compete in the new era.

STEM Attitude

The relationship between students' achievement and students' attitude is well documented. Likewise, students' attitude towards a subject will be reflected by their interest levels in the classroom. Students' attitude and interest towards 21st century STEM competencies can be measured through a survey in integrated STEM education ([Han, 2017](#); [Unfried et al., 2015](#)). By combining Project-based Learning with integrated STEM disciplines, it can increase effectiveness, generate meaningful learning and influence student attitudes in future career pursuit.

Integrated 21st century STEM in Robotics Education

In order to achieve the second objective of this study, the literatures were analyzed and concluded to bridge the gap between integrated STEM education and 21st century competencies in the aspects of content knowledge, skills and attitudes. 21st century competencies are essential for students to succeed as civilized citizens in a globalized, technology-enhanced modern world, which includes employability in highly-skilled career ([Hanipah et al. 2016a](#)) especially in STEM field. By integrating the STEM curriculum through robotics education, institutions are able to prepare young people with higher-order abilities to deal positively and productively with 21st century global challenges ([Chen et al., 2015](#); [Eguchi, 2015](#); [Eguchi, 2018](#)). In the competencies outlined in Table 1, Robotics Project-based Learning is the common practices within the four STEM disciplines and are bounded by the 21st century competencies. Robotics education serves as a new education tool that can emphasize on holistic development of students in STEM, thus helping students and the nation to fulfil its National Philosophy of Education. Project-based learning allows students to go through a process of inquiry, collaborative learning engaging students to complete a project or solve a problem in a STEM classroom ([Razali, Noor, Ahmad, & Shahbodin, 2017](#); [Sharifah Nadiyah, Faaizah, Hanipah, Norasiken, & Mohd Hafiez, 2014](#)).

CONCLUSION

The elements of the 21st century learning outcomes are skills, knowledge, and attitude to enable students to achieve success in work and life. In summary, the integration of Science, Technology, Engineering, and Mathematics curriculum through Robotics Project-based Learning provides a magnificent cross-curricular learning, by underlying the practices on the foundation of the 21st century competencies. Since Malaysian education is aiming at making STEM more appealing to students and indirectly inviting more students to pursue their studies in STEM-related areas to fulfill the workplace demand, more emphasize should be given for integrated STEM education in Malaysia ([Malaysia Education Blueprint 2013 - 2025," 2013](#)). However, the problems associated with this framework include installation costs for robotics devices, and more importantly, lack of sufficient time for the teachers to learn new technology due to their hectic schedules. Despite these problems, our current research shed light on the potential of Robotics Project-based Learning to significantly influence the design and facilitation of learning experiences, and teachers' professional development, ([Hanipah, Hussin et al. 2016b](#)) and the education policy makers to implement robotics curriculum in primary and secondary schools.

The challenges of this research on integrated curriculum occur at various stages of development and in various domain-specific areas. They are (1) the content proficiency dimension, (2) the process or product research dimension, and (3) the epistemological concept dimension. If these three research-based approaches can be synthesized, then the aim to design an integrated curriculum through Robotics Project-based Learning can be achieved. The proposed conceptual framework hopefully would build a research agenda that will, in turn, inform the STEM stakeholders to realize the full potential of Robotics Project-based Learning as the best practice in the 21st century classroom. The recommendation for the

educators when using this framework is to identify the basic themes and concepts that incorporate multiple curriculums when designing the Robotics Project-based instruction to meet the 21st century competencies. By using this proposed framework, it is believed that the integrated STEM education in the 21st century learning environment could be enhanced.

LIMITATION AND STUDY FORWARD

One challenge that emerged from the designed integrated STEM education is the necessity for appropriate learning activities in such a way that might achieve the learning outcomes to fulfil the needs of knowledge, skills and attitude. The design of the curriculum should consider carefully the social interactions happening in classroom and should offer a more socially sensitive program ensuring equal opportunities and participation for all the students in all levels. The future work suggested is, we need to integrate Science, Technology, Engineering and Mathematics in a well-thought robotics curriculum that will trigger students' curiosity and enthusiasm in learning. On the other hand, the applicable integrated STEM curriculum should transform the students to be more conscious and mindful while engaging in problem solving and in other creative activities. This highlights the challenge for integration of STEM concepts across each phase of conceptualization. We must provide a comprehensive support for teachers' learning not only for the content of the robotics and STEM disciplines, but also for the needed pedagogy of enactment.

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