Integrated Robotics STEM Curriculum Towards Industry 4.0

Jiea P. Y.1, Hanipah H.2, Sharifah S.S.A3

1Institute of Technology Management and Entrepreneurship
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
2Centre for languages and Human Development,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
3Faculty of Information and Communication Technology,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
yeejiea@gmail.com

Abstract—In consideration of future employment in STEM domains, university graduates should be prepared to meet the demands of industry 4.0 – resulting from a fourth industrial revolution. Based on the technological concept of cyber-physical systems and the internet of things, it facilitates – among others - the vision of the smart factory. As a result, robotics education is faced with a large potential field of research, which ranges from the technical development and didactical students’ acceptance or the proof of concept of the terms of learning efficiency. This paper presents a conceptual framework to investigated which kinds of learning outcomes prefer in a robotics education in secondary school STEM curriculum. Building upon the results content analysis, a collaborative STEM curriculum using robotics as a platform was created within the collaborative competition environment. It is expected that the students exposed to the robotics curriculum in secondary school would continue to pursue the engineering course in university. Therefore, this is an important contribution towards a globalized and digitalized working world in terms of industry 4.0.

Keywords—industry 4.0; robotics; education; curriculum.

I. INTRODUCTION

In today’s world, it seems all students need to be equipped with STEM knowledge and the creative problem-solving skills necessary to be innovative and creative thinkers. The vision of “industry 4.0” is characterized by highly individualized and at the same time cross-linked production processes [1]. The digitalization of education system also means that learning becomes more collaborative. Recently, robotics education has built a track record in STEM education by providing resources that are engaging, familiar, and relevant to young learners so that teachers and facilitators can deliver high-quality, hands-on curriculum that encourages creativity and problem solving while strengthening the abilities and skills needed for students to be successful in the core classroom [2], [3].

The curricula at all levels in Malaysia are developed to address the needs of all students, regardless of race, socioeconomic and gender. The current curriculum design adopted by the Curriculum Development Division of the MOE, is a standards-based thinking oriented curriculum [4]. Students engage in learning experiences by thinking about and thinking with what they are learning. It is hoped that the findings of this study would spearhead the formal training of robotic education in the Malaysia education curriculum using Robotics curriculum to enhance integrative STEM education. By integrating educational robotics into the latest standards-based STEM curriculum, teaching tools, and appropriate hardware and software that can help turn to ordinary learning into dynamic, performance-boosting learning environments [3], [5], [6].

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The spotlight is now focus on how the learners learn and the how to design an effective learning environment. Parallel to this shift in pedagogy, the integrated STEM curriculum has emphasized the need for reform to modernise Malaysia STEM education.

II. LITERATURE REVIEW

Since 21st century, Malaysia economy moves from a manufacturing-based economy to an information and service-based economy, thus the demand for a workforce well educated in science, technology, engineering, and math (STEM) is growing. Unfortunately, the number of students who choose STEM fields continues to decline [7]. Research on integrative instruction that focuses on Science, Technology, Engineering, and Mathematics (STEM) is important, because the jobs of tomorrow are rooted in STEM fields. Although the written curriculum developed by the Ministry of Education (MOE) specifically states that STEM education includes three main components which are knowledge, scientific skills and scientific attitudes, however there is a gap between the aspired curriculum, implemented curriculum and examined curriculum [8]. The implemented curriculum does not reflect these three focus very well and the examined curriculum did not reflect this balance in integrative STEM education either. Educators are always searching the best pedagogy to improve students’ achievement, skills, and attitude toward learning STEM subjects, However, the current traditional curriculum is more teacher-cantered than learner rather than the learner-cantered.

In recent years, there has been a change in basic assumptions taking place, moving the emphasis from teaching to learning and a more student-centred curriculum especially in STEM subjects [9]. This change has impacted on the curriculum design process with a greater emphasis on the learning activities through project-based in terms of knowledge, skills and competencies within courses and modules [10], [11].

The objective of this paper is to propose a new integrated STEM curriculum using robotics as an agent to deliver the content and learning activities.

III. METHODOLOGY

A conceptual framework for Integrated Robotic STEM curriculum is designed in this study as a guideline for curriculum development as in Fig. 1. The new framework focuses on using educational robotics in STEM learning as an outcome while capitalizing on the acts of workplace readiness as versioned in Industry 4.0.

The curriculum is designed based on the following principles:

1. Provide learning objectives and examples of learning modules for various robotics concepts
2. Present a comprehensive set of competencies based on these concepts for effective robotics understanding
3. Promote a set of competencies for using robotics concepts to teach or reinforce cocurricular concepts (programming, engineering design, math, science, etc.)
4. Offer flexibility across academic level or robotics experience.

Table I. Existing Stem Frameworks

<table>
<thead>
<tr>
<th>Components</th>
<th>Application of Integrated STEM Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving</td>
<td>Explore, explain, elaborate, evaluate</td>
</tr>
<tr>
<td>Communication</td>
<td>Formulating, communicating</td>
</tr>
<tr>
<td>Creativity</td>
<td>Design and construction, Design evaluation,</td>
</tr>
<tr>
<td>Reasoning</td>
<td>Creativity, Share, Process, Generalise, Apply.</td>
</tr>
<tr>
<td>Design</td>
<td>Five comprehensive core engineering design processes: Problem scoping,  Idea Generation,</td>
</tr>
<tr>
<td>Real world: Industry 4.0</td>
<td>Five comprehensive core engineering design processes: Problem scoping,  Idea Generation,</td>
</tr>
</tbody>
</table>

Fig. 1. Conceptual framework of integrated STEM curriculum [12]
The objective of this paper is to propose a new integrated A conceptual framework for Integrated Robotic STEM curriculum using robotics as an agent to deliver the knowledge, skills and competencies within courses and learning activities through project-based in terms of curriculum design process with a greater emphasis on the STEM subjects [9]. This change has impacted on the teacher-cantered more student-centred curriculum especially in achievement, skills, and attitude toward learning STEM.

IV. ANALYSIS

The new STEM frameworks integrates the existing framework from Science 5E Instructional Model [14], Technological literacy framework [15], PISA Mathematical Literacy [16], Engineering Design Challenge [17], and Robotics Experiential Learning [18], which allows students to scope, design, create, evaluate, review and improve their solutions:

![Curriculum development cycle model](image)

Fig. 2. Curriculum development cycle model [13]

<table>
<thead>
<tr>
<th>Existing Framework</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science 5E Instructional Model</td>
<td>Explore, explain, elaborate, evaluate</td>
</tr>
<tr>
<td>Technological Literacy Framework</td>
<td>Communication, problem solving, creativity, and thinking skills in a meaningful context</td>
</tr>
<tr>
<td>PISA Mathematical Literacy</td>
<td>Formulating situations mathematically, Employing mathematical concepts, facts, procedures and reasoning, Interpreting, applying and evaluating mathematical outcomes</td>
</tr>
<tr>
<td>Robotics Experiential Learning</td>
<td>Experience, Share, Process, Generalise, Apply.</td>
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</tbody>
</table>
### V. RESULTS

**TABLE II. New Robotics STEM Curriculum Framework**

<table>
<thead>
<tr>
<th>Skills and processes</th>
<th>SCIENCE</th>
<th>TECHNOLOGY</th>
<th>ENGINEERING</th>
<th>MATHEMATICS</th>
<th>ROBOTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigating and scoping</td>
<td>Engage</td>
<td>Investigating and defining</td>
<td>Problem scoping</td>
<td>Exploring and identifying</td>
<td>Engage</td>
</tr>
<tr>
<td>• Create interest and stimulate curiosity</td>
<td>• Critique needs or opportunities for designing, and investigate materials, components, tools, equipment and processes to achieve intended designed solutions</td>
<td>• Understanding the boundaries of a problem</td>
<td>• Identify a (real world) problem based on a theme or context of interest to students - current popular topic, issue of concern or interest from community, work or study</td>
<td></td>
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</tr>
<tr>
<td>Planning and designing</td>
<td>Planning and conducting</td>
<td>Generating and designing</td>
<td>Constructing and Design</td>
<td>Formulating and planning</td>
<td>Apply</td>
</tr>
<tr>
<td>• With guidance, plan and conduct scientific investigations to find answers to questions, considering the safe use of appropriate materials and equipment</td>
<td>• Design a user interface for a digital system (ACTDIP018)</td>
<td>• Model development</td>
<td>• Formulate a mathematical model to address the question (involves translating from the real-world setting to the domain of mathematics, making simplifying assumptions, choosing variables, estimating magnitudes of inputs etc)</td>
<td>• Apply what was learned to similar or different situations</td>
<td></td>
</tr>
<tr>
<td>Design and Development</td>
<td>Explore</td>
<td>Developing mental models</td>
<td>Create</td>
<td>Employing and applying maths</td>
<td>Experience</td>
</tr>
<tr>
<td>• Provide experience of the phenomenon or concept</td>
<td>• Develop stronger mental models that ultimately make students better software engineers.</td>
<td>• Carry out the plan; create the design.</td>
<td>• Employ mathematical concepts, facts, procedures and reasoning (reasoning, argumentation, manipulation and computation) to solve the problem in the</td>
<td>• Do the activity</td>
<td></td>
</tr>
<tr>
<td>Analysing and explaining for Implementation</td>
<td>Explain</td>
<td>Producing and implementing</td>
<td>Redesigning and Reconstructing</td>
<td>Interpreting and evaluating</td>
<td>Process</td>
</tr>
<tr>
<td>• Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon</td>
<td>• Select appropriate materials, components, tools, equipment and techniques and apply safe</td>
<td>• Review first design</td>
<td>• Interpret and evaluate the mathematical outcomes (interpretation, justification, and explanation) and</td>
<td>• Analyse and reflect upon what happened</td>
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VI. DISCUSSION

Developing a new curriculum requires large efforts, resources, and involves several changes. The first step including selecting one of the two curriculum frameworks or merging the both; rewriting and state the related curriculum documents; retraining the teachers in the integrated curriculum structure; rewriting new textbooks for possibly all grades; and providing substantial professional development course to allow school districts to coordinate pedagogy. Long-term investment in developing and refining their own robotics STEM programs has caused states, school districts, and teachers to modify their existing curriculum frameworks and have attempts to adopt national or state content standards and frameworks.

To outline the learning activities based on an integrated STEM curriculum, the selection of a topic within the curriculum for the application of educational robotics is a very important step to ensure that learning outcomes relate directly to the curriculum. The course syllabus could be modified to suit the robotics related activities but without deviating away from the objectives of the course. Next, a clear set of learning outcomes must be derived from the STEM syllabus and aligned with the STEM curriculum as a guide in the process of constructing the robotics project which will be the basis for the activities. To design the robotics projects and specification, the project requirements must be defined in a way that its completion would fulfil the learning outcomes. In addition, the requirements must resemble a real-world problem which clearly defines the type of new knowledge to be learned, whether this new knowledge comes at the core of the curricula, and what existing knowledge is necessary for students to get involved in the robotics project.

As some of the projects including a robotics competition, a set of well-defined competition rules is included. The rules and regulations must include project themes, winning criteria, and other related terms. Finally, the assessment method for learning outcomes is design based on the Taxonomy Bloom. Assessing the learning outcomes of the integrated STEM curriculum using educational robotics is not an difficult task. The teacher can easily determine that through interviews or presentations, or even using traditional examinations.

VII. CONCLUSION

More Malaysian schools are now geared towards 21st century learning environment with emphasis on more active student-centred learning applying Higher Order Thinking Skills (HOTS) in curriculum, assessment, and co-curricular activities, and the utilisation of Information, Communication and Technology.
In the integrated STEM curriculum, whether learning about robots or learning with robots, it is essential that a robotics lesson provide an introduction to the key areas of STEM while focus to insight the students’ engagement and exploration in the multidisciplines study. It is important that the curriculum allow for single activity or lesson plans as well. To allow for this, the robotics curriculum should allow entry points at various stages in the overall academic curriculum. By no means, robotics STEM curriculum is a new silver bullet for 21st century education, nor is it intended to replace the existing science and mathematics curriculum, it is another entry in the teachers’ toolbox with the aim to prepare the STEM workforce and STEM literate society for the real world in Industry 4.0.

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REFERENCES


