TechTeachers Support Series – Application of Robotics in STEM Education

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ABSTRACT

The millennials are natural users of digital technology. They expect to be engaged in their learning and do not do well being passive learners. Therefore, teachers who are tech-savvy has bigger chance to connect and make learning outcomes and activities relevant to millennials. However, not all teachers at school are aware of blending learning with technologies, and the majority still prefer rote learning. At school, robotics can become an interesting tool to teach difficult STEM concepts. This work aims to describe the perception of Malaysian school teachers on the application of robotics in teaching STEM subjects. Thirty teachers from fifteen high schools participated in a one-day robotics workshop that included basic robot programming hands-on and solving real robotics tasks. The post-training survey shows that the teachers well receive the idea that robotics as STEM tool (1) complements 21st century teaching and learning, (2) nurtures logical reasoning and creative problem solving, and (3) prepares students towards technology creation.

ABSTRAK

Generasi masa kini amat meminati pendekatan teknologi digital dan gemar mendalami pembelajaran secara aktif mengikut citarasa sendiri. Kini, informasi mudah dicapai dengan adanya internet, menjadikan pelajar kini tidak lagi bergantung harap dengan guru seperti waktu dahulu. Untuk itu, guru-guru perlu mengadaptasi pendekatan pembelajaran yang bersesuaian dengan informasi yang diterima, dan membuka minda pelajar dengan contoh dan aplikasi dunia sebenar. Dengan pendekatan pembelajaran aktif, pelajar-pelajar mempunyai kebarangkalian yang lebih tinggi untuk mendekati dan meminati subjek-subjek STEM. Bagi menyediakan guru-guru untuk berdepan dengan generasi pelajar yang celik teknologi, projek ini bertujuan memberi pendedahan aplikasi robotik dalam pendidikan STEM di sekolah. Kaji selidik yang dilakukan selepas bengkel robotik bersama 30 guru dari 15 sekolah menunjukkan guru-guru menyokong idea bahawa robotik sebagai alat pengajaran STEM (1) melengkap pengajaran dan pembelajaran abad ke-21, (2) meransang pemikiran logikal dan penyelesaian permasalahan dengan kreatif, dan (3) menyediakan pelajar ke arah rekacipta teknologi.

Keywords

STEM, robotics, 21st century teaching and learning, tech teachers
The demand for workforce that is able to implement new solutions and innovations towards sustainable communities economically, ecologically and environmentally is increasing (Capra, 2007; Dumont & Instance, 2010). Malaysia’s future economy health, in the dawn of the fourth industrial revolution (IR4.0), depends highly on the skills and knowledge of its workforce particularly in the science, mathematics, engineering and technology (STEM) disciplines. This workforce of tomorrow is in school today. Their K-12 education is preparing them to pursue their career of choice, and at the same time, they are feeding the nation’s talent pool to compete in the global economy. Unfortunately, there is a general consensus in the industry that current K-12 schools are not doing a good job in preparing students for the workforce. As a result, the number of high schoolers pursuing STEM subjects at school is rapidly declining, and this could be because of how STEM content and/or skill is being delivered at school.

An effective STEM course require integrated and multidisciplinary classroom focused on critical thinking and creative problem solving. The appropriate credential to be held by a STEM teacher would be a high qualification to teach project-based courses that include content from several STEM subject areas. In general, high school teachers in Malaysia do have the credentials to teach more than one subjects, for example the traditional math and science courses. However, with technology dramatically reshaping the career opportunities in the coming years, it is the multidisciplinary teacher who develop proficiency with the tools of technology and used it in their classroom that greatly impact the twenty-first century learning outcomes, i.e. building future professionals. Fig. 1 shows some of the envisioned characteristics of future professional include attainment of disciplinary knowledge, self-knowledge or self-awareness, innovation and creativity, critical thinking or civil literacy, responsibility and global awareness, and, communication and collaboration (Karjalainen et al., 2016).

Fig. 1: Characteristics of future professionals (Taken from Karjalainen et al. (2016)).

Teachers are hungry to use technology in their STEM classrooms but the serious lack of usage in our K-12 schools are largely due to lack of exposures to technologies. In some cases, the
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teachers are not even aware about the available technologies at all. Having students, or millenials, that are natural users of digital technologies, it is imperative for STEM teachers to engage with them in the classroom using technologies the students are familiar or excited with. One of the technology that is rising in popularity among youth of today is robotics.

The robotics field is developing at an incredible rate, and in the market, it shows no sign of slowing down. Playing an important role in the future, the industry is proposing robotics to be adopted into classrooms sooner than later. Building robots and learning to code require students’ higher scientific reasoning, critical thinking and creative problem solving, and the nature of attempting solutions through trial-and-error makes robotics projects more fun to work in groups (Khine, 2017; Leonard et al., 2017). Robotics projects require learning environments that are agile, student centred, having adaptive levels of challenge, and, value independence (Ortiz et al., 2015). The higher the complexity of a robotics problem, the higher the probability that the solution are derived from multidisciplinary perspectives. These attributes are in line with the STEM learning outcomes thus is it highly logical for STEM education to look at the utility of robotics in classroom applications.

Recently, several national initiatives have come together to draw attention on reforming the focus of the K-12 education. One of the strategy is to include more tech-savvy teachers that embrace the multidisciplinary aspects of the STEM subject areas and move away from rote learning. In support of this initiative, this work aims at a university-community engagement to transfer basic robotics programming and problem solving skills to secondary school teachers. The main agenda is to describe the experience and perception of the Malaysian school teachers on the application of robotics in teaching STEM subjects. The school teachers are then recommended to use the module prepared by the university to transfer robotics programming and problem solving skills to their school students.

(2) The mentors and mentees

The team of mentors were led by Dr. Zati Hakim Azizul Hasan, a senior lecturer at the Department of Artificial Intelligence (AI), Faculty of Computer Science and Information Technology, University of Malaya. The lead mentor’s main research field is intelligent robotics where she has been actively researching for over six years. She has also been lecturing the subject for over four years and her students are third year AI undergraduates at the faculty. Her team comprises of two postgraduate students currently pursuing a Masters and PhD degrees in intelligent robotics under her supervision and eight final year undergraduate students from her department who were former student in her intelligent robotics class. These students were highly competent in robot programming and were trained in two separate sessions in preparation for the robotics workshop with the mentees.

Additionally, the lead mentor is also a certified Master Trainer in Computational Thinking and Computer Science (CTCS) Teaching Certificate Programme, a certification programme recognized by the International Society for Technology in Education (ISTE). The certification
Sharin Best Practices in STEM Mentor-Mentee programme is an initiative by the Malaysian Digital Economy Corporation (MDEC) awarded to selected lecturers from several public universities in Malaysia. Following closely the ISTE standards, this programme specializes in teacher education programs on effective learning and teaching with technology. Since the programme’s inception in 2017, five CTCS Master Trainers at the University of Malaya (including the lead mentor) has trained over 240 teachers from primary and secondary schools, and matriculation centres from various peninsular areas in Malaysia.

It is from these CTCS trainings that the lead mentor developed knowledge about the serious gaps in STEM education in Malaysian schools. The invaluable experience gained in building her portfolio as teacher-trainer through the CTCS programme coupled with her passion in robotics inspired her to develop a STEM-robotics module with content and context suitable for high school audience, which she specifically utilised for this project.

The mentees for this work were teachers from fifteen secondary schools in the Klang Valley which are members of the University of Malaya’s UMCares Sekolah-Sekolah Sahabat. These schools were nominated and shortlisted by the District Education Office (PPD) of Petaling Utama who acted as the stakeholder for this project. These fifteen schools were from a list of about forty other secondary schools under the UMCares Sekolah-Sekolah Sahabat. The schools selected are listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1: List of participating schools</th>
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<tbody>
<tr>
<td>SMK (L) BUKIT BINTANG</td>
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<td>SMK (P) SRI AMAN</td>
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<td>SMK (P) TAMAN PETALING</td>
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<td>SMK BANDAR SRI DAMANSARA 1</td>
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<td>SMK BANDAR UTAMA DAMANSARA 2</td>
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<td>SMK BANDAR UTAMA DAMANSARA 3</td>
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<td>SMK BANDAR UTAMA DAMANSARA 4</td>
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<td>SMK DAMANSARA JAYA</td>
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<td>SMK DAMANSARA UTAMA</td>
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<td>SMK LA SALLE PJ</td>
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<td>SMK SEKSYEN 4 KOTA DAMANSARA</td>
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<td>SMK SEKSYEN 8 KOTA DAMANSARA</td>
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<td>SMK SRI PERMALTA</td>
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<td>SMK SULTAN ABDUL SAMAD</td>
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<td>SMK TAMAN DATO’ HARUN</td>
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In a briefing done with representatives from each school prior to the workshop, the need of limiting the total number of schools for this project was emphasized so each schools may nominate two teachers as mentees. For this pilot study, there were no pre-requisite fixed in joining the robotics workshop and the pre-survey done shows the mentees coming from various subject background of sciences (e.g. mathematic, physics, chemistry and biology), computer sciences (e.g. the old syllabus called information and communication technologies literacy
Sharing Best Practices in STEM Mentor-Mentee (ICTL), the new syllabus called basics of computer science (ASK) and design and technologies (RBT), and arts (e.g. history and the Malay and English languages).

From the perspective of conducting a robotics workshop, it was initially encouraging to elicit from the pre-training survey, that almost half of the mentees have had teaching experiences in computer science-based subjects as shown in Fig. 2. However, having computer science-based subjects teaching experience does not justify the competency in programing. Length in teaching computer science-based subjects also did not reflect competency in programming. This is overly populated in the pre-training survey conducted on mentees familiarity in coding using any popular programming language (see Fig. 3) and mentees familiarity using popular robot programming platforms (see Fig. 4). Only a handful of mentees have beginner or intermediate competency in programming, and/or basic experience in using popular robotics platforms. The majority of mentees are not familiar with programming or robotics platforms.

Fig. 2: Pre-training survey results on 30 mentees familiarity in teaching ICT-based subjects

Fig. 3: Pre-training survey result on 30 mentees familiarity in coding
Since the majority of the mentees do not have much familiarity with coding, a decision was made to pair mentees from each school to support each other upon their return from the workshop. The approach to pair mentees for the robot programming workshop; called pair programming, as the name suggests, is the act of programming in a two-person team at a single computer. One team member is usually the driver, who controls the keyboard and manoeuvres the mouse, and the other is the navigator, who keeps an eye out for issues and minds the way everything fits into the bigger picture (McDowell et al., 2002). Learning how to code is a challenging endeavour for many beginners, and pair programming has been shown to improve confidence, satisfaction and test scores in comparison to coding as an individual (Ghobadi et al., 2017). In the pre-training survey done, the proposal to work in pairs was well received by the mentees as they initially perceive programming a robot an overwhelming task for beginners.

(3) Methodology and activity outlines

This section describes the resources, module inspiration and the activities conducted for the mentor-mentee workshop.

3.1 Acquisition of resources

There were two main resources secured in the preliminary stage, one is monetary funding awarded by the UMCares to hire research assistant for module development and testing, support workshop supply and materials, venue preparation, as well as food and beverages for trainers and workshop participants. The other is borrowment (in kind) of fifteen EV3 Lego Mindstorm robots under the Memorandum of Agreement (MoA) signed between the University of Malaya and SASBADI SDN. BHD.
3.2 The EV3 Lego Mindstorm and Python Programming

The EV3 from Lego Mindstorm is one of the most popular robot education kit in the world since it’s released in September 2013. It is a lego set with a variety of flexible joints powered by a single programmable brick which hosted the ARM9 CPU running Linux. The disadvantage of this robot (and many other manufactured robot kit) is its costs. The cost for an EV3 unit ranges from RM2,000 to RM2,500 for the core set and inclusion of the expansion set can amount up to RM1,000 or more. Fig. 5 shows on the left, the EV3 basics and on the right the EV3 built for mentees to use. The EV3 basics comprised of two large motors, two small motors, touch and ultrasonic sensors all connected to a programming brick in the middle. The basics were extended with two wheels and simple body design for workshop usage.

![Fig. 5: The EV3 basics on the left and on the right the EV3 built for the workshop](image)

The EV3 set comes with the Lego Mindstorm EV3 Home Edition (see [www.ni.com/labview](http://www.ni.com/labview)), a visual programming platform. This allow the robot programs or codes in EV3 to be written using blocks instead of lines. However, the need for specific software is not budget-savvy and at times limit coding versatility. Alternatively, one programming language that is open source (free), has a syntax similar to the English language and is easy to learn is Python. Python is currently the top choice for web development, machine learning, data mining, data science, automation and embedded systems programming. It is reported as the fastest growing programming language for fintech companies in high-income countries such as the United States, Germany, United Kingdom and Canada, to name a few.

In terms of robot programming, Python is ubiquitous. With slight modification, it can run on most robotics platforms such as Lego Mindstorm, Raspberri Pi, Arduino, GoPiGo and others. Coupled with its ability to perform complex data analysis, which could come from various robot sensors such as camera and range finders, the potential for innovative robotics solutions is endless. For these reasons, Python is chosen as the programming language in this project not only for mentees’ exposure, also for the versatility for the module to be adopted on other robotics platform of choice after the workshop. As far as the mentor’s best understanding, this project is also the first kind of robotics training that utilizes Python on top of the EV3 Lego Mindstorm platform in this country.
3.3 Module and workshop activities

The training module is developed in two parts, the first is an introduction to Python programming and the second is an introduction to robot programming using Python. The goal of the module is to train the mentees the basics to control a mobile robot with two wheels differential drive robot equipped with ultrasonic and touch sensors. Understanding these basics is important in producing algorithm to allow the robot to navigate safely in its environment, a feat required for any autonomous agents. The outlines of both modules are described in Table 2 and coding samples from Session I and II are shown in Fig. 6 and Fig. 7 respectively. Fig. 8 shows several activity photos taken during the workshop.

<table>
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<tr>
<th>Session I</th>
<th>Introduction to Python programming</th>
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<tr>
<td>1.0</td>
<td>Python and Jupyter Notebook on Windows installation</td>
</tr>
<tr>
<td>2.0</td>
<td>Package installation</td>
</tr>
<tr>
<td>3.0</td>
<td>Python 'Hello World'</td>
</tr>
<tr>
<td>4.0</td>
<td>Variables, strings, numbers</td>
</tr>
<tr>
<td>5.0</td>
<td>Lists and looping, tuples, numerical lists</td>
</tr>
<tr>
<td>6.0</td>
<td>While loops and user inputs</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Session II</th>
<th>Introduction to robot programming</th>
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<tbody>
<tr>
<td>1.0</td>
<td>The robot setup</td>
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<tr>
<td>2.0</td>
<td>Controlling the motor</td>
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<td>3.0</td>
<td>Programming the differential drive kinematics</td>
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<td>4.0</td>
<td>Logical tests and decision making</td>
</tr>
<tr>
<td>5.0</td>
<td>Sensors control</td>
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</tbody>
</table>

Table 2: Description of materials for Session I and II

```python
import math
speed=100
turn_speed=100
def distance_to_rotation(distance):
    # return the degree of wheel turning
cir_of_wheel=math.pi*56.0
rotations = distance/cir_of_wheel
return rotations*360.0
def direction_to_rotation(angle):
    # Point turn is used
    # return the degree of wheels turning
cir_of_wheel = math.pi*56.0
dia_of_robot_circle = 137.0
cir_of_robot_circle = math.pi*dia_of_robot_circle
dist_wheel_need_to_travel = cir_of_robot_circle*angle/360.0
rotations = dist_wheel_need_to_travel/cir_of_wheel
return rotations*360.0
```

Fig. 6: Sample coding for Session I
A common use of the ultrasonic sensor is range finding. An ultrasonic pulse is generated in a particular direction and if there is an object in the path of this pulse, parts of the pulse will be reflected back to the transmitter as an echo. Based on this concept and the Session II materials
to perform sensor calculation on the robot, the mentees have to work with their partners to implement basic obstacle avoidance algorithm for their respective EV3 (Lu, 2016; Mac Thi et al., 2018). The mentees are encouraged to inquire and discuss with other mentees, do own research using materials available on the internet, and get assistance from the team of mentors to work on the task. Each group presented their finding and this activity marks the end of the workshop (see Fig. 9 for closing photo).

3.4 Mentoring at school

Within one week after the completion of the workshop, the mentees were asked to complete a post-training survey. One of the question posed was if the mentees were interested to run the module again, this time at their school with them as mentors. Mentees from SMK Sri Permata responded and a session was held at their school within two months after the workshop at the University of Malaya ended. Fifteen students aged 13 years old participated and due to time constraints, they were divided into two groups, each working on one robot set. The majority of the students have no programming experience except for two to three students who have done some basic block based programming. None of them have used an EV3, more so an EV3 programmed using Python. The university mentors prepared two EV3 units and helped the teachers in guiding the students through the module. Some of the photos during the three hours session are shown in Fig. 10.

Fig. 10: Activity photos taken during mentoring at SMK Sri Permata
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(4) Activity outcomes and survey analysis

As shown in Fig. 2, Fig. 3 and Fig. 4, the majority of the teachers who participated as mentees for the workshop do not have competency in programming nor familiarity with any robotics platforms. As a consequent, it did take longer time to get them to familiarise with programming/robotics environment. Nevertheless, once they were able to grasp the concept and run basic codes, they were eager to follow through the robotics programming and problem solving challenge. They gained a lot of confidence and joy at discovering new tech-skills. Some of them, particularly those from physics and add-maths were able to utilize theoretical concept and calculation better than computer science-based teachers. Together, they made good combination when solving robotics tasks. As much as they were showing high interest during the workshop, many were not interested to pursue robotics beyond the workshop due to lack infrastructure at school (most of the schools do not have any robot hardware ready). Those who were not from STEM-based subjects responded negatively to commit to mentoring beyond the workshop, thinking it would not benefit them in their classroom. The post-training survey shows that the teachers well received the idea that robotics as STEM tool can (1) complements twenty-first century STEM teaching and learning, (2) nurtures logical reasoning and creative problem solving, and (3) prepares students towards technology creation.

In comparison to the workshop held for the teachers at the University of Malaya, the school students were able to grasp the programming aspect of the training much faster albeit having
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no programming exposure prior to the training at school. Interestingly, the students were able to create new functions not part of the hands-on module provided and combined them in interesting ways that solved the robotics problems efficiently. The students showed that with some guidance by their teachers, they were able to break down the robotics problems, looked for patterns and abstract the problems into several level of difficulties, some purely mathematical or physical problems, some purely logical problems, some purely automation tasks, and some a combination of each of these elements. Then, they brainstorm collectively in their respective groups to propose different solutions to each problems. Most of the times, their solutions were an outcome of tried and errors. Above all, they showed much joy throughout the activities and were welcoming of further robotics challenges (in future sessions) when asked at the end. In conclusion, robotics has tremendous potential as a tool to advocate and facilitate STEM learning at school and the school teachers should be equipped with relevant technological skills to fasten the skills transfer to students.

(5) Conclusion and future outlook

The biggest obstacle to run this program is occupying proper robotics hardware at schools so schools can apply robotics as an alternative tool to teach students about STEM. The EV3 Mindstorm is the state-of-the-art in robot education but very costly, around RM2,500 - RM3,500 per unit for a full-spec unit. Some schools which engaged with industry supplier mentioned that the training is not free and parents must pay up to RM80/2hour/weekend. Since the module prepared for this project is generic and could go onto any robotics platform, schools can look at alternative and cheaper solution to acquiring proper robotics hardware. As a summary, the following are some feedback from the mentees based on the post-training survey collected:

- The mentees appreciate the mentoring effort by the university, enjoyed the module and training. However, the constraint in time (prescheduled commitment at school) made many reluctant to commit to mentoring session at school beyond the workshop.
- Mentees indicated lack of robotics hardware at school as obstacle in progressing further in applying robotics in STEM education.
- Mentees indicated their students will benefit from mentoring program. Video shows case study done at SMK Sri Permata (students engaged and enjoyed the 3-hour session)
- Mentees in consensus that teachers equipped with technological skills is a MUST in the twenty first century teaching and learning
- Mentees in agreement that the application of robotics in STEM education is worth investing at school level due to the many benefits towards producing future workforce, which include:
  - Robotics contribute towards technology creation
  - Robotics improve logical reasoning and problem solving
  - Robotics skills is a MUST have skills for current school students
In the future, lead mentor is considering to opening up this program to any highly interested teachers (selection not necessarily from computer science-based teachers). Also, considering the added value non-computer science teachers have over computer science-based teachers (theoretical considerations in solving robotic tasks), project leader would like to propose science, technology, engineering, arts and mathematic (STEAM)-based robotics challenges in the future. In showcasing the versatility and compatibility of the robot-STEM module produced from this project, the project leader is working towards acquiring low-cost robots to be considered in future TechTeachers robotics outreach workshops.

Acknowledgement

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References


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