Training Undergraduate Engineering Students in Robotics and Automation through Model-Based Design Training: A Case Study at Assumption University of Thailand

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Abstract**—**Problem-based learning (PBL) is a student-centered pedagogy that originated in the medical field and has also been used extensively in other knowledge disciplines with recognized advantages and limitations. PBL has been used in various undergraduate engineering programs with mixed outcomes. The current fourth industrial revolution (digital era or Industry 4.0) has made it essential for many science and engineering students to receive effective training in advanced courses such as industrial automation and robotics. This paper presents a case study at Assumption University of Thailand, where a PBL-like approach was used to teach some aspects of automation and robotics to selected groups of undergraduate engineering students. These students were given some basic level training in automation prior to participating in a subsequent training session in order to solve technical problems with increased complexity. The participating students' evaluation of the training sessions in terms of learning effectiveness, skills enhancement, and incremental knowledge following the problem-solving session was captured through a follow-up survey consisting of 14 questions and a 5-point scoring system. From the most recent training event, an overall 70% of the respondents indicated that their skill levels were enhanced to a much greater level than they had had before the training, whereas 60.4% of the respondents from the same event indicated that their incremental knowledge following the session was much greater than what they had prior to the training. The instructor-facilitator involved in the training events suggested that this method of learning was more suitable for senior/advanced level students than those at the freshmen level as certain skills to effectively participate in such problem-solving sessions are acquired over a period of time, and not instantly.

Keywords**—**Automation, industry 4.0, model-based design training, problem-based learning.

I. Introduction

PBL is a learning pedagogy with its roots in the medical field. The introduction and implementation of PBL goes back to the 1950s in Canada at McMaster University, where dissatisfaction was found with traditional medical education practice due to its mostly lecture-heavy format and emphasis on memorizing fragmented biological information at the expense of developing problem solving skills necessary for a lifetime of practice and learning [1]. In addition to being implemented in many medical schools around the world, PBL practice has also found its way in other disciplines of knowledge, including engineering and technology [2]–[5].

In a PBL approach, learners are asked to solve a well-constructed problem intended to mimic or closely replicate a real-life situation, which is very different from a textbook only problem scenario. Students are divided into several smaller groups (each usually consisting of 8-10 participants) and are assigned an instructor who mostly plays a facilitator role during the problem solving process. Group members can discuss the various aspects of the given problem among themselves and may even discuss them with members of other groups. The primary goal of this problem solving exercise is to acquire new knowledge through the process of problem solving. It is best described by stating that the problem serves as a learning tool, and learning is the ultimate goal [3]. Thus, some generic skills are required of the participants in order to make PBL an effective practice. Some examples of such skills are teamwork, chairing groups, listening, recording, self-directed learning, and critical thinking [6].

There are certain well-recognized advantages and disadvantages of implementing PBL in a learning environment [6]. On the positive side, PBL is a student-centered learning approach where students actively participate in problem solving. It assists with integration of knowledge from various disciplines at the same time. PBL has been observed to increase motivation among learners promoting deep learning. This approach is constructive in nature; it helps effectively construct knowledge of a certain knowledge domain through the practice of problem solving. Wood [6] also mentioned some of the drawbacks or disadvantages of PBL. Human resources and other logistical requirements for implementing PBL tend to be more extensive than for traditional learning methods used in learning institutions. Students participating in a PBL session may be negatively impacted by a lack of role models among instructors (they may encounter tutors/ facilitators who cannot really teach well). Information overload is another concern with PBL - students can get overwhelmed with a load of information and face difficulties in filtering out relevant and useful information from a sea of knowledge. In summary, PBL pedagogy requires significant changes for both learners and educators of this method [1]. Nonetheless, certain benefits of implementing and practicing PBL as an instructional method are recognized through

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various published research and observations. In the short-term, students exposed to PBL tend to demonstrate a higher improvement in the understanding of concepts than those who were not exposed to this method [4]. Students from PBL curriculum also appear to have better knowledge retention [6], even though the focus of PBL is learning, understanding concepts, and application of concepts to practical problems. With an emphasis on learning in real-world contexts, students taught in PBL method can also easily see the connections between the subject matter and their own professional interests [2]. When employed in engineering programs, PBL method received mostly positive feedback from participants [2], [4], [7] while recognizing certain challenges and limitations similar to those mentioned above.

II. The Fourth Industrial Revolution (Industry 4.0 Or The Digital Era) And ITS Relevance To PBL Type Approach

Humankind is now experiencing the beginning of a new industrial revolution (often called the fourth industrial revolution or industry 4.0) [8], which is significantly different from all the others occurring in the past. In this digital revolution or digital era, a rapid shift is taking place, dictating how people in the near future will earn their livelihood, perform or delegate daily tasks, move around places, acquire education, and interact with other humans and non-human entities, etc. One of the predicted impacts of this era is that an alarmingly large number of traditionally secured and long-term jobs are going to be either completely lost or replaced by smart automation (robots) capable of performing many repetitive tasks without errors, fatigue, accidents, or complaints [8].

A big part of the fourth industrial revolution is the widespread adaptation of advanced technologies, such as: Internet of Things (IoT), Robots, Biotech & Smart Agriculture, Artificial Intelligence (AI), Machine Learning/ Deep Learning, Digital Currency, Autonomous Transportation, etc. Traditional Science, Technology, Engineering, and Mathematics (STEM) curriculums designed and implemented in the distant past without these technologies and consequential societal changes in mind will not be fully suitable for preparing the next generation of productive workforce. In addition, these STEM curriculums should also consider implementing new, effective learning methods and provide necessary tools in order to maintain their relevance and usefulness to industry 4.0 era.

Thailand has also recognized this future trend and formulated ‘Thailand 4.0’ – an economic model with the aim to relieve the country from several economic challenges resulting from the past older models of socio-economic development [9]. In this economic model, it is acknowledged that the transformative shift in economy will take place due to shift from traditional into ‘smart’ approaches with high value services offered by highly skilled workers. Smart Devices, Robotics & Mechatronics, IoT are among the recognized clusters for innovation and start-ups, while the targeted activities to accomplish this nation development goal include the strengthening of vocational training and education system.

When making hiring decisions for entry-level personnel for the workplace of the new digital era, visionary employers and organizations are unlikely to seek graduates with only stellar academic performance and certain theoretical and technical background. Rather, their ideal candidates would be individuals possessing a balanced combination of relevant academic background, satisfactory academic performance, and set of soft skills, such as: teamwork and collaboration, social skills and communication, priority/time management skills, documentation and organization, leadership, etc. One way of demonstrating such acquired skills is to provide evidence of meaningful participation in extra-curricular activities. However, PBL and similar learning approaches can offer students and soon to be graduates an opportunity to acquire and further develop the soft skills necessary for a lifetime of learning and success. With this thought in mind, PBL and similar learning methods may be considered very useful while teaching advanced level courses in automation, robotics, etc., which are directly related to operations in the organizations/factories of the industry 4.0 era.

III. Overview of the Model-Based Design Training at Faculty of Engineering, Assumption University

Assumption University of Thailand (AU) [10] is the first international university in Thailand, established originally in 1969. It currently has both a Faculty of Science and Technology and a Faculty of Engineering offering degree programs in Computer Science, Information Technology, Communication & Computer Networking, and Engineering with majors in Computer, Electrical, Mechatronics, and Aeronautical fields. The Faculty of Engineering, currently named Vincent Mary School of Engineering (VME), was established in 1990 with Electrical and Electronics departments. Computer and Telecommunications departments were added later on. Constantly anticipating the industry trends and needs, the faculty reorganized the undergraduate departments over the years to its current structure. A notable event was the introduction of Mechatronics Engineering, which is an interdisciplinary study field encompassing electrical, electronics, mechanical and computer engineering. According to the current curriculum, students majoring in Computer and Mechatronics tracks are those who get the most extensive exposure to subjects directly related to coding, robotics, automation, and their related applications.

AU engineering students and graduates receive their training through four key methods: 1) Formal training (through core curriculum study and related practical sessions in various laboratories), 2) Participation in external competitions where the students get to demonstrate their competence in robotics, automations, and related fields, 3) Field trips to companies and projects to further advance and complement their learning, and 4) Internships with companies/organizations where students receive real-world training related to their study disciplines for an extended period of time. To encourage and enable students in the senior and graduating classes to enhance their learning style and effectiveness, AU engineering faculty has introduced certain training programs through which students can complement their classroom and lab-based learning done mostly in the traditional lecture-format method. A recent addition of such training program is the 'Model Based Design Training' (MBT), which has certain similarities and differences with the PBL approach discussed earlier in this paper. Similar to the PBL approach, MBT has the following characteristics.

- The training is conducted with a student group consisting of 10 -12 students.
- MBT sessions feature an instructor who plays the role of a facilitator/guide during the problem solving part of the session.
- Students are provided a real-life problem/project; they are asked to solve the problem based on their earlier learning experience of fundamental knowledge related to the project.
- The problem solving session is collaborative, during which students employ general skills and aptitudes same as or similar to those applied in a typical PBL session.
- Students are expected to acquire further skills and new knowledge during this training session as they use critical thinking skills to approach the problem at hand.
- The MBT session is timed. Participants are expected to accomplish their problem solving goal within a specific timeframe.

The MBT program at AU engineering faculty is different from PBL in one way though. PBL sessions are conducted in multiple student groups whereas the MBT described here currently consists of a single group of students participating in a 2-day training and problem solving session. The training session is conducted periodically during the academic year. Each session involves a fresh new group of students without any prior exposure to an MBT session. Regardless of this difference, the assignment/problem provided during an MBT session serves as a tool to help student acquire further knowledge and skills, which is the ultimate goal here. The MBT session at AU engineering faculty takes place over 2 days. Day 1 of the session involves providing some basic level training to participants in Arduino [11] and Simulink/ MATLAB [12]. Arduino is an open source electronics training platform with both hardware and software components and it is widely used all over the world to build electronics projects and applications. The platform has a microcontroller capable of reading instructions in various forms, and turning the instructions into desired outputs. This is accomplished using Arduino programming language and the Arduino Software (IDE). Simulink is a graphical programming language tool for modeling, simulating, and analyzing multi-domain dynamic systems. It is developed by MathWorks [12] and supports system-level design, simulation, automatic code generation, and testing and verification of embedded systems. Participants spend 3 hours on Arduino basic training, and 3 hours on Simulink basic training on Day 1 of the event. The reason for including Arduino and Simulink in the MBT program is to ultimately integrate these two to solve an industrial/real-life problem.

Day 2 of the MBT session includes offering basic training on integrating Arduino and Simulink during the first half of the day. Following this, participants are then handed over a real-life project, during which they would apply their prior knowledge of programming, automation, robotics, as well as the fundamentals of Arduino platform and Simulink to make the project assignment work. Since its first introduction in June 2019, AU engineering faculty has conducted two MBT sessions until now. The most recent event was held during October 6-7, 2019. This event featured a design challenge asking participants to design the controller function of a fully working vending machine which dispenses a selection of drinks and snacks upon receiving proper payment from a customer. The design requirement included a set of six distinct inputs and three possible outputs for the vending machine to operate properly.

TABLE I
THE 14 QUESTION SURVEY AND SCORING SYSTEM FOR THE MODEL BASED DESIGN TRAINING PROGRAM

Session	Survey Questions			Possible Responses (Recorded on a scale of 1 to 5)
	Question Category	No.	Focus Area/Topic of Assessment	
Day 1 (Basic Training)	Incremental Skills Assessment	1	Skill Development on Arduino Usage	1. Indifferent 2. Very little compared to before attending 3. More than before attending 4. Considerably more than before attending 5. Absolutely greater than before attending
		2	Skill development on MATLAB/Simulink Usage	
		3	Software tools provided for Arduino	
		4	Software tools provided for MATLAB/Simulink	
		5	Programming skills for MATLAB/Simulink	
		6	Programming skills for MATLAB/Simulink	
		7	Arduino and MATLAB/Simulink operations skill for industrial application	
		8	Arduino and MATLAB/Simulink integration skill	
Day 2 (Integration and Project/ Problem Solving)	Incremental Knowledge Assessment	1	Knowledge Development on Arduino architecture	
		2	Knowledge Development on MATLAB/Simulink structure	
		3	Programming knowledge on MATLAB/Simulink	
		4	Knowledge on MATLAB/Simulink problem solving	
		5	Knowledge on Arduino integration with MATLAB/Simulink	
		6	Programming with MATLAB/Simulink operations in industry sector	

IV. Assessment of Participants' Learning and Perception of the MBT Program

Mills and Treagust [5] mentioned that within the engineering examples of PBL, the evaluations undertaken had been almost entirely along the line of student interviews or responses to open-ended questions. AU engineering faculty took the same qualitative approach in order to evaluate the effectiveness of the MBT session. Participants were asked to complete a survey consisting of 14 questions and a 5-point scoring system. Details of this survey questions and scoring system are provided on Table I. The survey questionnaire is designed to assess the entire 2-day session consisting of required basic training, and problem solving using prior knowledge. The first eight questions (for Day 1) ask students to assess their own incremental skills upon receiving the basic training, whereas the remaining six questions (for Day 2) are used to determine students' incremental knowledge upon attending the problem solving session and applying prior knowledge to successfully completing the design challenge.

V. Results and Analysis from the Survey Following the MBT Session

Responses from the participant survey following the October 2019 MBT session were gathered and analyzed. There were a total of 11 participants in this MBT session. Out of these 11 participants, 10 responded to the first eight questions created to assess students' incremental skills following the basic training. For the next six questions assessing students' incremental knowledge after the problem-solving session, there were eight respondents. The participants' responses to the 14 questions are shown on Table II.

From the survey responses on participants' incremental skills development (first eight questions of the survey), between 60% and 80% of the respondents to these questions reported that their incremental skill level handing Arduino and Simulink/MATLAB was absolutely greater than what had been prior to the basic training (score level 5). Between 20% and 30% respondents indicated that their incremental knowledge level was considerably more than what had been prior to attending the basic training (score level 4). Only one respondent from the basic training session indicated that his/her incremental skill level following the basic training showed little improvement compared to the level of skill prior to the training (score level 2). No responses were seen for score level 1 and level 3 for this part of the session. Rest of the questions (six out of 14) were responded to by eight participants out of 11. This is the part which tried to assess the participating students' incremental knowledge level of the subject matters upon completion of their assigned project. Between 50% and 62.5% of the respondents to these questions indicated that their incremental knowledge level following the problem solving session was absolutely greater than that prior to participating in the session (score level 5). Between 25% and 37.5% of the respondents indicated that their incremental knowledge level of Arduino, MATLAB/Simulink, and integration procedures and how to apply these to industry situations was considerably more than the level they had had before the session (score level 4).

TABLE II
PARTICIPANTS RESPONSES TO THE SURVEY QUESTIONNAIRE

No.	Question Details (Focus Area/Topic of Assessment)	# of Responses for Each Score				
		Score 1	Score 2	Score 3	Score 4	Score 5
1	Skill Development on Arduino Usage	0	1	0	3	6
2	Skill development on MATLAB/Simulink Usage	0	0	0	3	7
3	Software tools provided for Arduino	0	0	0	3	7
4	Software tools provided for MATLAB/Simulink	0	0	0	3	7
5	Programming skills for MATLAB/Simulink	0	0	0	3	7
6	Programming skills for MATLAB/Simulink	0	0	0	2	8
7	Arduino and MATLAB/Simulink operations skill for industrial application	0	0	0	4	6
8	Arduino and MATLAB/Simulink integration skill	0	0	0	2	8
1	Knowledge Development on Arduino architecture	0	1	1	2	4
2	Knowledge Development on MATLAB/Simulink structure	0	0	1	2	5
3	Programming knowledge on MATLAB/Simulink	0	0	0	3	5
4	Knowledge on MATLAB/Simulink problem solving	0	0	2	1	5
5	Knowledge on Arduino integration with MATLAB/Simulink	0	0	0	3	5
6	Programming with MATLAB/Simulink operations in industry sector	0	0	2	1	5

There were also responses received for score level 2 and level 3. Around 12% of the respondents indicated that their incremental knowledge level was more than before, but not considerably or absolutely higher than what they knew prior to the problem solving session. Similar to the first part of the survey, only one participant indicated that his/her incremental knowledge was very little compared to the level of knowledge prior to the problem solving session.

Overall, 70% of the responses under incremental skill level assessment and 60.4% of the responses under incremental knowledge level assessment entered a score of 5 (maximum) to the questions asked about the MBT session. This outcome might seem to be biased towards mostly positive responses, but it is not unusual given the prior experience of other engineering students participating in such sessions [2], [4], [7]. Similar to those participants, AU engineering students appreciated the fact that the MBT sessions allowed them to make a connection between theoretical learning and real-life, industry related problems. They were also able to make good use of their soft skills (collaboration, critical thinking, time management, problem solving, analyzing) in order to complete the assignment in hand within specific timeframe and other design constraints. There are some limitations of this study which needs to be acknowledged. Firstly, MBT at AU is a relatively new method of training implemented only recently. As such, number of training sessions and corresponding participants is still relatively small in order to assess MBT's usefulness over a medium to long-term period. Further sessions and a larger sample size of participants would be beneficial in establishing a long-term trend. The instructor-facilitator responsible for the MBT sessions observed and commented that this type of learning approach is suitable for rather advanced/senior level student participants due to the need for applying significant level of generic skills (soft skills) to solve the problem in hand. Such generic skills have been observed to develop among AU students gradually over a period of time and practice. MBT has potential to benefit freshmen and sophomore level students as well, but these students may not be able to realize the full benefit of MBT sessions if some minimal level of required soft skills is not present at the time of the participation in these sessions.

VI. Conclusion and Final Thoughts on the MBT Program at Assumption University

During the year of its initiation, the MBT program at the AU engineering faculty has shown potential to benefit its students concentrating in robotics and automation by enabling them to make a connection between theoretical knowledge and practical world problems. The observed benefits of conducting the MBT session are similar to those resulting from PBL-type sessions used elsewhere, without some of the challenges and constraints faced by practitioners of PBL. Logistical requirements to conduct an MBT session are much less extensive that that of a typical PBL approach. The AU engineering faculty is currently looking into expanding the MBT sessions by increasing its frequency, as well as exploring other advanced level STEM subjects to make MBT a part of those courses. It is expected that by expanding the MBT in such manner, the faculty and students can benefit from increased interactions with more industry partners and exposure to a larger set of real-world practical problems. Furthermore, the effectiveness of MBT may be assessed more precisely and objectively with larger number of sessions and participants than AU currently has.

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