Instructing a Mechatronics Course Aligning with TPACK Framework

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Abstract

In this paper, two separate lessons of a mechatronics course were selected. One lesson was on actuator technologies and applications. Another lesson was on sensor technologies and applications. For the actuator lesson, the instructor designed and implemented the instruction following the traditional approach. Then, the same instructor instructed the sensor lesson to the same student population. However, for the sensor lesson, the instructor designed and implemented the instruction following the TPACK (technological-pedagogical and content knowledge) framework approach. For the TPACK approach, before instructing the lesson, the instructor determined the technological, pedagogical and content knowledge and skills required to instruct the lesson effectively. Then, the instructor increased his/her self-efficacy on those knowledge domains as best as possible, and then instructed the lesson to the learners (students) accordingly. Appropriate assessment methods and rubrics were developed to assess the teaching and learning effectiveness and outcomes of each lesson. The assessment results for the TPACK approach were then compared to that of the traditional instruction approach. Results showed that the instructions designed and implemented aligning with the TPACK framework significantly increased the instructional quality of the instructor and the overall teaching and learning outcomes and effectiveness. The results can inspire instructing STEM courses especially the mechatronics course following the TPACK framework.

1. Introduction

Incorporation of educational technologies to promote effective pedagogy and teaching effectiveness is increasing rapidly [1]. Hence, educators need to learn and adjust with new educational technologies to teach successfully. However, educational technologies cannot be seen from standalone point of view. Instead, the application of technologies may have correlation with the pedagogy, subject matter, educator's attitude and aptitude, teaching goals, target learners, institutional supports, etc. This situation has inspired the creation of a new conceptual educational framework called the TPACK-the technological-pedagogical and content knowledge [2]-[5]. The intersections of the three constitutive knowledge domains of TPACK have also given birth to four additional knowledge subdomains such as the pedagogical content knowledge, technological pedagogical knowledge, technological content knowledge and technological pedagogical content knowledge [2]-[5]. Under the TPACK framework, educators need to have sufficient content knowledge of the specific discipline/topic, pedagogical knowledge to effectively teach the content to the learners, and the technological knowledge that is the knowledge and skills of appropriate educational technologies to be used to teach the content to the learners effectively [2]. The TPACK framework shows the status of technological, pedagogical and content knowledge of educators for a certain lesson, topic or course. Literature shows that the implementation of TPACK framework can make the three main knowledge domains complementary to each other that can provide a teaching and learning atmosphere that is more effective than that a single knowledge domain can provide alone [6]-[7]. Under the TPACK framework, educators can take most appropriate preparation to teach a particular topic, enable himself/herself to overcome the challenges of teaching the content that is pedagogically challenging and/or abstract in nature. Lessons instructed aligning with the TPACK framework can also increase student engagement, interest and motivation, and thus enhance overall teaching and learning effectiveness and outcomes [6]-[7].

However, the TPACK framework is still a theoretical framework, and successful implementation of this framework with regular educational activities in classroom environment is still not prioritized. Some preliminary works on TPACK implementation have been proposed [5]-[8]. However, those were not implemented with regular classroom activities. Instead, those were focusing on K-12 STEM education without showing any interests for college-level education [6]-[8]. Application of TPACK framework to college-level STEM education seems to be more necessary and promising. Especially, the efforts to apply the TPACK framework by educators to formally design the instruction of an engineering course such as a mechatronics course for mechanical engineering major and to instruct the course aligning with the TPACK framework are not observed. Mechatronics is itself a technology course. It is believed that incorporation of educational technologies maintaining proper correlation with pedagogy and content knowledge can greatly enhance the overall teaching and learning outcomes and effectiveness for mechatronics [3]. However, such efforts have not been made yet.

Being motivated by the state-of-the-art limitations of the application of the TPACK framework to the mechatronics course, the objective of this paper has been decided as to design the instruction of a mechatronics course aligning with the TPACK framework, implement the course in actual classroom settings, and investigate the suitability of the TPACK-based mechatronics instruction design on producing satisfactory teaching and learning outcomes and effectiveness. Thus, two research questions are adopted as follows:

(i) Whether it is feasible to design and implement the instruction for the mechatronics lesson fitting within the TPACK framework, and
(ii) Whether the TPACK-based mechatronics instruction design can significantly improve the instruction quality and teaching and learning outcomes and effectiveness.

In this paper, as an experiment basis, two topics of the mechatronics course were selected. One topic was instructed in one lesson. Hence, two topics were instructed in two separate lessons. One of the two lessons was selected randomly. Before instructing the selected lesson, the instructor determined the technological, pedagogical and content knowledge and skills required to instruct that lesson effectively. Then, the instructor increased his/her self-efficacy on those knowledge domains and then instructed the lesson to the learners. Appropriate assessment methods/rubrics were developed to assess the teaching and learning effectiveness and outcomes of the lesson. The assessment results were then compared to that when the same instructor instructed another lesson to the same student population without designing the instruction aligning with the TPACK framework (i.e., followed conventional or traditional instruction approaches). Results showed that the instruction designed and implemented aligning with the TPACK framework significantly increased teaching and learning outcomes and effectiveness, satisfaction and motivation of the students, and self-satisfaction, confidence and instructing abilities of the instructor. The results can serve as an inspiration or an illustration to instruction design for engineering courses following the TPACK framework.

The rest of the paper is organized as follows:
Section 2 presents related theories and concepts. Section 3 discusses related research works. Section 4 presents the development of the research setting, and section 5 presents the research design. Section 6 presents the research methods and procedures, and section 7 presents the research results and analyses. A general discussion is placed in section 8, and the conclusions and future work are presented in section 9.

2. Related Theories and Concepts

2.1 The TPACK Framework

Being inspired by the theories and concepts about the TPACK framework observed in [2], [4], [9]-[10], the underlying concepts of the TPACK framework are explained below. TPACK is a framework to understand and describe the kinds of knowledge needed by an instructor for effective pedagogical practice in a technology enhanced learning environment. This framework combines three kinds of knowledge: (i) content knowledge, (ii) pedagogical knowledge, and (iii) technological knowledge.

Content knowledge (CK) is “a thorough grounding in college-level subject matter” or “command of the subject” (American Council on Education, 1999). It may also include knowledge of concepts, theories, conceptual frameworks as well as knowledge about accepted ways of developing knowledge. For example, knowledge of a person about Math-algebra, ratio and proportion, statistics (mean, mode, median, range); Physics-energy, force, torque, mechanical advantage; Biology-cell, photosynthesis, etc. [9]-[10].

Pedagogical knowledge (PK) includes generic knowledge about how students learn, teaching approaches, methods of assessment, knowledge of different theories about learning, etc. This knowledge alone is necessary but insufficient for teaching/instructing purposes. In addition, a teacher (instructor) requires the content knowledge [9]-[10].

Technology or technological knowledge (TK) refers to an understanding of the way that technologies are used in a specific content domain. Most often refers to digital technologies such as calculators, computers/laptops, the internet, multi-media projector, sound, audio, visual system and software applications, experimental equipment, etc. TK does however go beyond digital literacy to having knowledge of how to change the purpose of existing technologies.

The correlation and intersections between the three knowledge domains can be illustrated using a popular diagram as shown in Figure 1. The diagram shows that TPACK is truly a combination of different knowledge domains, and there are some overlaps between the domains as well [9]-[10].

Pedagogical content knowledge (PCK) is knowledge about how to combine pedagogy and content effectively. This is about how to make a subject understandable to learners. PCK includes knowledge of what makes a subject difficult or easy to learn as well as knowledge of common misconceptions and likely preconceptions students bring with them to the classroom [9]-[10].

Technological content knowledge (TCK) refers to knowledge about how technology may be used to provide new ways of teaching the content. For example, digital animation makes it possible for students to conceptualize how electrons are shared between atoms when chemical compounds are formed [9]-[10].

Technological pedagogical knowledge (TPK) refers to the affordances and constraints of technology as an enabler of different teaching approaches. For example, online collaboration tools may facilitate social learning for geographically separated learners [9]-[10].

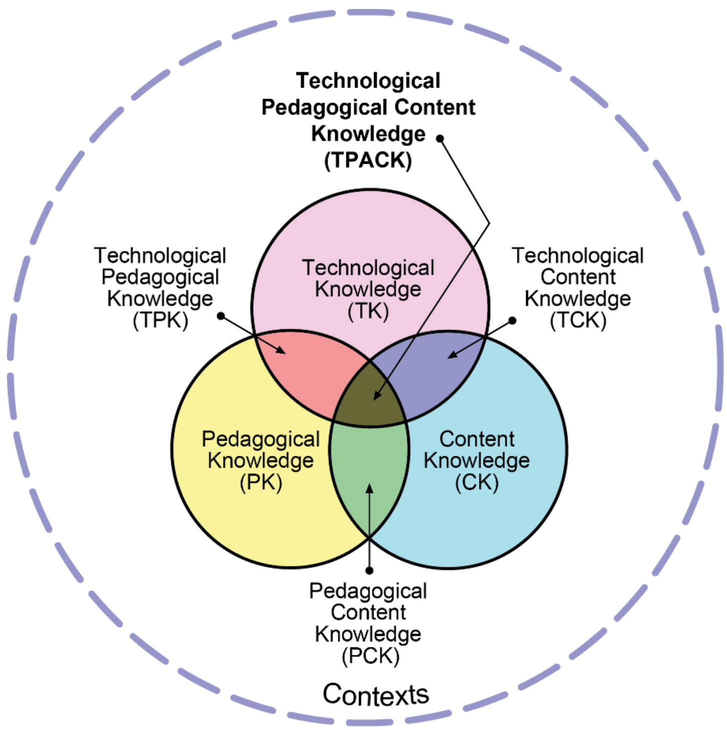

Figure 1. The correlation and intersections between different knowledge domains and subdomains of the TPACK framework [9]-[10].

2.2 Mechatronics

According to [11], mechatronics is the approach aiming at the synergistic integration of mechanics, electronics, control theory, and computer science within product design and manufacturing, in order to improve and/or optimize its functionality.

3. Related Research Work

3.1 TPACK Implementation

Innovation on design and implementation of TPACK framework in education is an active area of research. A few recent works on TPACK framework have been reported in the literature though the volume of research works on the TPACK framework seems to be too little as compared to the expected volume. In [2], Mishra and Koehler presented the fundamentals of the technological pedagogical content knowledge. Ferdig highlighted the assessment of technologies for teaching and learning, and also emphasized on the understanding of the importance of technological pedagogical content knowledge in [3]. In [4], Mishra and Koehler also discussed the ways of confronting the wicked problems of teaching with technology with respect to the TPACK framework. In [5], Schmidt et al. focused on the development and validation of an assessment instrument for preservice teachers with respect to the technological pedagogical content knowledge framework. In [6], the authors attempted to build trust in robots in robotics-focused STEM education under the TPACK framework in middle schools. Recently, Mallik et al. examined the variations in the TPACK framework for teaching robotics-aided STEM lessons of varying difficulty [7]. Rahman et al. explored the dynamic nature of the TPACK framework in teaching STEM using robotics in middle school classrooms [8], and so forth.

3.2 Mechatronics Course and Instruction Design

Efforts towards development of mechatronics course for engineering students are very active as informed through literature. Holden attempted to develop a simulation centered mechatronics course [12]. In [13], the authors defined multiple industry sectors' workforce needs for educated mechatronics technicians and the evolution of these programs from traditional technical programs in electronics, mechanical, electromechanical, automation and advanced manufacturing technology associate degrees to more integrated mechatronics programs. In [14], a modular curriculum development project created by a four year university in the mechatronics engineering technology field was described. In [15], the authors described the mechatronics curriculum of their university, the language-neutral teaching approach for mechatronics, and usage of low cost technology demonstrator for studying the key elements of mechatronics including system dynamics, sensors, actuators, and computer interfacing. In [16], the author presented the two-tiered approach to teaching mechatronics. The student teams were first given small-scale projects that targeted specific competencies required by the more involved actual class project which was the second tier. After completing the first-tier projects, student teams taught the rest of the class what they learned, and shared the materials they developed.

In [17], the author provided the methods and approaches of infusing mechatronics and robotics concepts in engineering curriculum. In [18], the authors presented the approaches of implementing problem-based learning in a senior/graduate mechatronics course. In [19], the authors showed how virtual software and hardware environment can provide enhanced learning opportunities for mechatronics engineering technology majors. The project-based approach of teaching mechatronics was presented in [20]. Development of a senior mechatronics course for mechanical engineering students was described in [21]. In [22], the authors presented the development of an introductory mechatronics course for the students who had completed their second year at the community college and planned on pursuing a bachelor's degree in an engineering field. In [23], the authors investigated the use of agile methods enhancing mechatronics education through the experiences from a capstone course. In [24], Consi proposed a versatile platform for teaching mechatronics that considered a middle-ground approach seeking a compromise between free-form and set-piece projects that maximized exposure to core mechatronics concepts while minimizing peripheral tasks, importantly, preserving a good measure of creativity, and so forth.

However, implementation of the TPACK framework with mechatronics course for college-level STEM education did not receive priority yet.

4. Development of the Research Setting

A regular semester-long senior-level mechatronics course offered to mechanical engineering students was selected. The author was the sole instructor of this course in a fall semester. The course was taught in traditional classroom settings that contained a whiteboard, marker pens, erasers, tables and chairs for students, computers on student tables, multi-media projector with a computer, a white screen, a TV monitor, lighting, electrical power outlets, internet services, etc. In total, 22 students attended the course. The number of male and female students were almost equal. This was the first mechatronics or similar type course to the selected students. The course focused on understanding the basic concepts and practices of mechatronics. Major topics included electronic interface between mechanical world and computer software, actuators, sensors, common mechanical and electrical applications, system response, integrated circuits, and microcontrollers for embedded systems. It was a lecture-based course of 3 credit hours, but the course also included 6 lab practices. Hence, the students needed to build hardware and perform computer programming to run the hardware for their lab sessions. In addition, the instructor provided relevant hardware devices to the student groups so that the students could get some opportunity to perform some classroom activities through building physical mechatronic devices. Sometimes, the instructor demonstrated various pre-built mechatronic systems or commercially available mechatronic systems such as a robotic system to the students as a part of his/her instruction. For this course, student outcomes were evaluated through assignments, periodical tests, lab reports, final tests, design projects, etc. This course and the classroom environment were used as the research setting for the proposed research study.

5. Research Design

Two independent topics from the mechatronics course syllabus were randomly selected: (i) actuator technology and applications, and (ii) sensor technology and applications. Two topics were taught in two separate lessons in two days in a week in two separate conditions. Class duration was 50 minutes for each lesson.

For the actuator lesson, the instructor planned to instruct the lesson following the ordinary traditional manner. For the sensor lesson, the instructor planned to design the instruction following the TPACK framework. Hence, it is seen that there were two instruction conditions: (i) instructing the actuator technology and applications lesson following the traditional instruction method (called "*traditional instruction method*"), and (ii) instructing the sensor technology and applications lesson following the TPACK framework method (called "*TPACK instruction method*). The aim of the research was to implement the above two conditions, assess overall outcomes of each of the conditions using appropriately designed and executed assessment rubrics, and compare the outcomes between the two conditions. Hence, the independent variables were the instruction methods (traditional vs TPACK), and the dependent variables were the overall teaching and learning outcomes and effectiveness.

6. Research Methods and Procedures

In a week, the instructor instructed the actuator lesson following the traditional method. Here, the ordinary traditional manner means that the instructor needed to use all the classroom facilities, provide lecture materials to the students, instruct through power point presentation and also write on the whiteboard when and where it was necessary to provide ideas about advanced actuation technologies to the students. For actuator applications, the instructor needed to explain the DENSO robotic platform shown in Figure 2 where the electrical motors were introduced as the actuators to perform prospective manipulation tasks. The instructor needed to use the robotic platform as a teaching tool to explain how the actuator technologies could be used to perform real-world activities. As the ordinary instruction model, before the start of the lesson, the instructor needed to superficially check whether or not (i) the robotic platform with all accessories was in its original location, (ii) all the educational resources as mentioned above were in respective locations in the classroom, (iii) the instructor was well-prepared to instruct the lesson and provide class materials to the students, etc.

Figure 2. The DENSO robotic platform used by the instructor as a teaching tool to teach the concepts of actuator and sensor technologies with possible real-world applications to the selected students for the mechatronics course.

One day after the lesson, the instructor evaluated the overall teaching outcomes. The evaluation was based on (i) responding a rubric by the students as given in Appendix A, and (ii) a formal test of the students on the lesson. The instructor briefly explained the meaning of each question set in the rubric in Appendix A so that the students could comprehend each question properly. For example, the question 3 in the rubric might mean how the students perceived the content knowledge of the instructor. It might not be the actual verification of the instructor’s knowledge. Instead, it might be the students’ perception of the instructor’s knowledge. It is true that the students were not expert on the subject matter, and hence it might not be so easy for them to assess the subject matter knowledge of the instructor. However, the students might be able to perceive the content knowledge of the instructor based on some salient features such as the fluency level of the instruction, confidence and synergy in the instruction, logical propagation, body language of the instructor, answering questions asked by the students, etc.

On another day in the same week, the instructor instructed the sensor lesson. For the sensor lesson, the instructor needed to use the same robotic platform as shown in Figure 2 as the teaching tool to explain the real-world applications of various sensor technologies. In addition to the traditional manner as above, the instructor needed to identify the actual requirements of his/her own knowledge and skills on the three knowledge domains and all subdomains of the TPACK separately. The instructor needed to write down those requirements, analyze the requirements separately, and analyze how those requirements were interrelated with each other for the selected lesson. The instructor also needed to investigate whether he/she was ready to fulfill all of the requirements before he/she could start to instruct the lesson. To understand his/her own readiness, the instructor needed to briefly conduct a formal self-efficacy assessment on the TPACK framework for the lesson following a 5-point Likert scale [6]. Based on the self-efficacy results, the instructor also needed to perform some self-training and self-practice sessions to enhance his/her self-efficacy on the knowledge and skill requirements for the lesson.

Here, "self-efficacy" may mean the perceived abilities and skills of the instructor assessed by himself/herself before instructing the lesson for the fulfillment of the requirements of each knowledge domain and subdomain and their intersections under the TPACK framework for instructing the lesson [8]. Note that arranging the self-training and self-practice sessions by the instructor does not mean that the instructor did not receive proper training/education on mechatronics, and thus he/she was unable to instruct the mechatronics course especially the selected topic. Instead, the self-training and practices may here mean the reviewing of the instructor's knowledge and skills required for the topic, doing some rehearsals so that he/she can deliver the instruction fluently, examining the readiness of himself/herself and of the teaching materials including the robotic system so that the instructor can use them in the desired ways in the desired times during the lesson, etc. During the self-training and practices, the instructor also tried to understand the interrelations between the knowledge domains. In fact, the instructor was highly trained on mechatronics. The little self-training and self-practices were added on the top of the instructor's prior knowledge and expertise that made the instructor well-prepared and ready to instruct the selected lesson with synergistic awareness in the TPACK domains and subdomains.

One day after instructing the sensor lesson following the TPACK framework, the instructor evaluated the overall teaching and learning outcomes using the same evaluation methods applied earlier for the actuator lesson instructed in traditional manner.

In addition to above evaluations of lesson outcomes through responses to rubrics and formal tests, the instructor utilizing his/her experience in the classroom environment during his/her instruction of the lesson, made some qualitative assessments on the overall classroom performance and environment for both the actuator and the sensor lessons. Hence, the overall combined evaluations could get the benefits of applying the mixed method evaluations and analyses that might be helpful for crosschecking the results between the qualitative and the quantitative methods via triangulation [25].

7. Research Results and Analyses

The required knowledge and skills of the instructor for each TPACK knowledge domain and subdomain perceived by the instructor for instructing the sensor lesson following the TPACK framework are given in Table 1.

Table 1. Requirements of the instructor to fulfill and gain self-efficacy in different knowledge domains and subdomains of the TPACK framework before instructing the sensor technologies and applications lesson following the TPACK framework

TPACK domains/subdomains	Requirements to be fulfilled by the instructor before he/she instructs the sensor technologies and applications lesson successfully
CK	• Knowledge on different types of sensor technologies and their working principles • Functions of different sensors • Knowledge of determination of appropriateness of using different types of sensor technologies for different purposes and contexts • Limitations of each type of sensor technologies, etc.
TK	• Knowledge of operating the robotic tool to illustrate the definitions and applications of different sensors incorporated with the robotic platform • Knowledge, familiarity and abilities to use different classroom facilities and resources such as whiteboard, marker pens, eraser, tables, computers, multi-media projector, white screen, lighting bulbs and switches, electrical power outlets, internet services, TV monitor, etc.
PK	• Knowledge of determining the sequence and duration of delivering the lecture/instruction such as determining the portions of verbal lecture, writing on the board, showing in the projector, demonstrating with the robotic tool, etc. • Desired body language, eye contact, questioning and answering techniques, etc. matching with different instruction phenomena • Evaluation and assessment approaches such as tests, assignments, etc.
TPK	• Planning the pedagogy for the lesson and checking whether the planned pedagogy was appropriate to use in the concerned technology-enhanced environment, or the vice versa
TCK	• Analyzing whether the available technological facilities and resources were sufficient and appropriate to explain the content knowledge

PCK	• Analyzing whether the planned pedagogy seemed to be appropriate to explain the concerned content knowledge clearly and properly
TPACK	• Analyzing whether the instructor was able to realize the relative importance of and interconnection between each of the knowledge domains • Analyzing how the instructor could compensate his/her lack of self-efficacy in one knowledge domain by another domain • Analyzing how the lack of self-efficacy in one domain could impact another domain, etc.

Figure 3 shows the perceived self-efficacy scores for different knowledge domains and subdomains assessed by the instructor one day before instructing the sensor lesson. The results show that the instructor was not well-prepared to instruct the lesson because he/she had limitations in many knowledge domains and subdomains. The self-efficacy scores were very low especially for the knowledge subdomains that involved intersections between two knowledge domains such

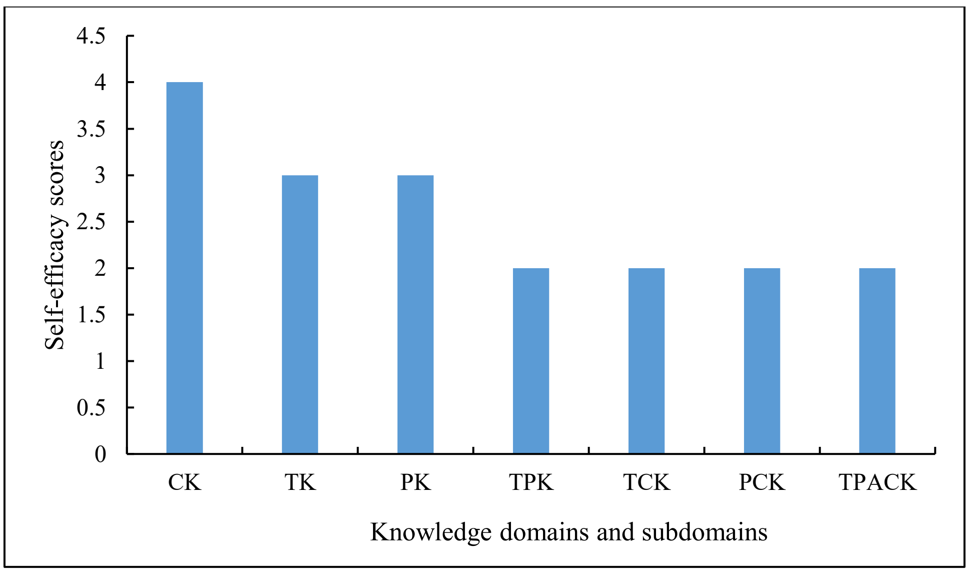

Figure 3. Self-efficacy scores (out of 5) for different knowledge domains and subdomains assessed by the instructor one day before instructing the sensor lesson.

as TPK, TCK, PCK, and the overall TPACK. This happened because the instructor might be able to prepare him/her for the CK, TK, and PK as standalone knowledge domains. However, the interrelations between the domains were usually ignored unless those were assessed and analyzed under the TPACK framework. It is thus posited that such transparency of self-efficacy in the knowledge domains and subdomains is the prime benefit of the TPACK framework. In fact, the TPACK approach created an opportunity to pinpoint such limitations beforehand, and provided an opportunity to improve his/her self-efficacy. The instructor worked hard to reduce the gaps in his/her self-efficacy and then instructed the lesson as scheduled.

Figure 4, based on Appendix A, shows how the participating students evaluated the efficacy level of the instructor in some knowledge domains after they had attended the lessons. The figure shows that the instructor could achieve satisfactory efficacy levels in the knowledge domains for the sensor lesson as assessed by the students because the instructor improved his/her efficacy based on the information of Figure 3 (self-efficacy) before he/she instructed the sensor lesson under the TPACK framework.

Figure 4 also compares the efficacy of the instructor on some knowledge domains for his/her instruction between the actuator lesson (instructed following traditional method) and the sensor lesson (instructed following the TPACK framework). The efficacy of the instructor on the knowledge domains for the actuator lesson was significantly lower than that for the sensor lesson. It is logical because the instructor was not aware of such domains when he/she designed/planned the instruction following the traditional approach. However, the instructor was well-prepared with and aware of the knowledge domains under the TPACK framework, which ensured high efficacy of the instructor on those domains. The analyses of variances (ANOVAs) showed that the variations in the efficacy scores between the actuator and the sensor topics were statistically significant ($p<0.05$). The results thus prove the superiority of the TPACK framework over the traditional approach in terms of enhancing instructor's abilities and improving overall instruction quality. Variations in efficacy scores between the students were statistically nonsignificant ($p>0.05$), which indicates the generality of the results.

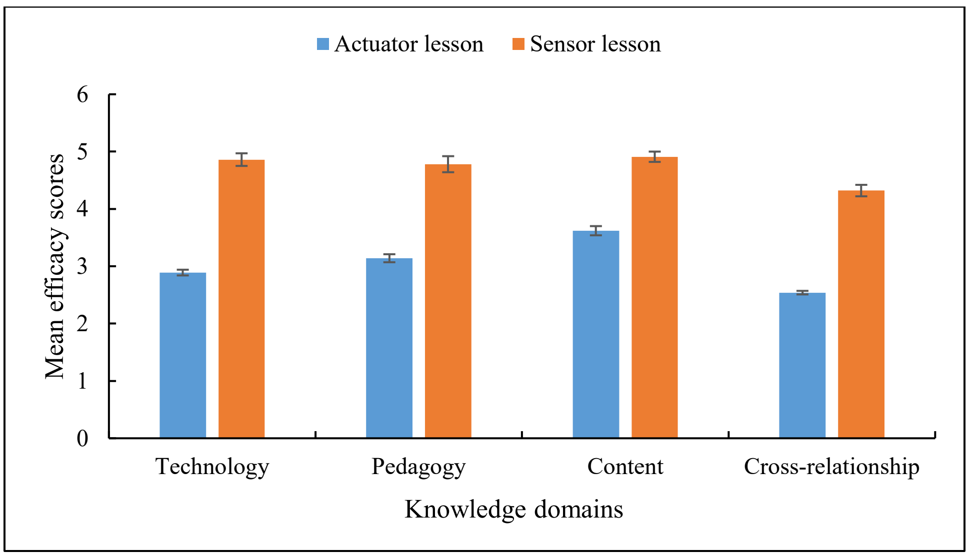

Figure 4. Comparison of the efficacy levels (out of 5) of the instructor assessed by students on some knowledge domains for his/her instruction between the actuator lesson (instructed following traditional method) and the sensor lesson (instructed following the TPACK framework).

Figure 5 shows the comparison of the test scores between the actuator lesson (instructed following traditional method) and the sensor lesson (instructed following the TPACK framework). Here, it is assumed that obtaining higher test scores is an indicator of better teaching and learning outcomes and effectiveness. If so, then the results prove the superiority of the teaching and learning outcomes and effectiveness for the lesson instructed following the TPACK framework over the lesson instructed following the traditional approach. It is believed that the superior instruction design/plan, proper resources allocation, enhancement in instructor's self-efficacy on different knowledge domains and subdomains, and the instructor's realization of potential cross-relationships between different knowledge domains and subdomains under the TPACK framework resulted in such better teaching and learning outcomes. ANOVAs showed that the variations in the test scores between the actuator and the sensor lessons were statistically significant ($p<0.05$). The results thus prove the superiority of the TPACK framework over the traditional approach in terms of teaching and learning outcomes and effectiveness. Variations in the test scores between the students were statistically nonsignificant ($p>0.05$), which indicates the generality of the results.

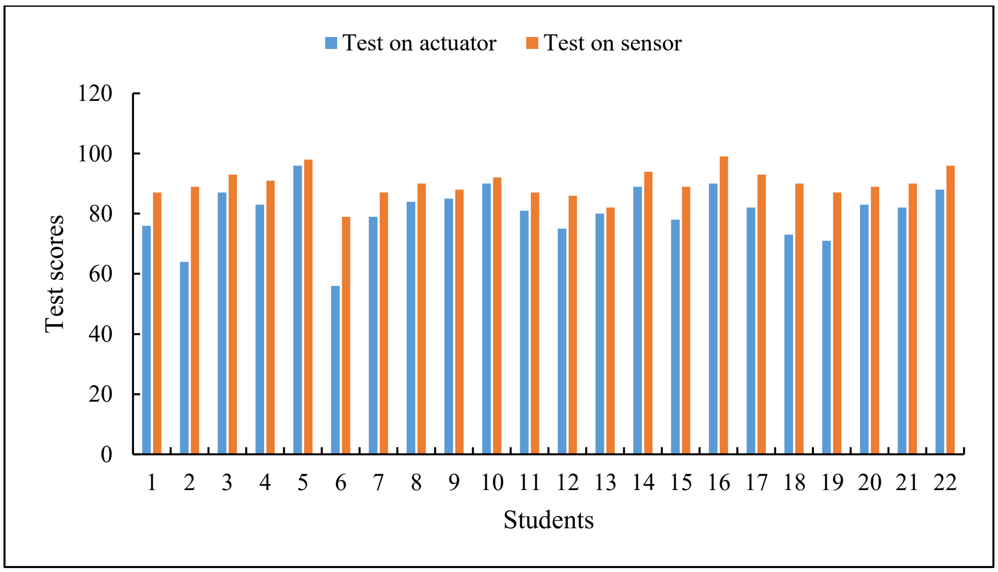

Figure 5. Comparison of test scores (out of 100) between the actuator lesson (instructed following traditional method) and the sensor lesson (instructed following the TPACK framework).

The qualitative evaluation results based on the instructor's experience showed that the students seemed to be more satisfied, pleased, engaged and motivated during the lesson instructed following the TPACK framework over the lesson instructed in traditional method. The instructor based on his/her experience believed that the well-planned lesson under the TPACK framework resulted in better motivation, satisfaction and engagement in the learners over the traditional instruction. All those might produce better learning outcomes for the TPACK case as reflected in Figure 5. Likewise, better motivation, satisfaction and learning outcomes of the learners might result in better satisfaction and confidence in the instructor as well because the instructor found his/her success in teaching and thus achieved desired teaching outcomes for the TPACK case. Furthermore, it is realized that there is a good agreement between the qualitative assessment results as above and the quantitative results presented in Figures 4 and 5. Such combination and agreement in results between qualitative and quantitative evaluation justify the effectiveness of mixed method benefits, and help crosscheck the results via triangulation [25].

Finally, all these results are sufficient to answer the adopted research questions as follows:

(i) It is feasible to design and implement the instruction for the mechatronics course fitting within the TPACK framework, and
(ii) The TPACK-based mechatronics course instruction design/plan can significantly improve the instruction quality and teaching and learning outcomes and effectiveness.

8. Discussion

The sensor lesson was instructed after the actuator lesson. Hence, it may be apparently thought that the students gained more experience about the mechatronics subject matter and with the instructional approaches of the instructor for the sensor lesson than that for the actuator lesson, which might help the students achieve better test scores for the sensor lesson over the actuator lesson. It may be true that the experience of the students in subject matter and familiarity with the instructor's approaches for the sensor lesson might impact the learning outcomes. However, it is assumed that the impacts of the application of the TPACK framework on the learning outcomes were heavier than that due to the experience and familiarity. A separate systematic study may be needed to determine the relative contributions of the TPACK framework and of students' experience and familiarity with the subject and its instructor [26].

Very obvious things such as familiarity with TV, light switches, etc. in Table 1 were spelled out under the TPACK framework. This is logical. It does not mean that the instructor does not know what a TV is or what a light switch does. Instead, it means that the instructor makes him/her fully aware of and familiar with all the required facilities for the lesson beforehand. This is the potential advantage of the TPACK framework. If an instructor instructs without following the TPACK framework, it does not mean that the instructor does not have technological, pedagogical and content knowledge and skills for the lesson. Instead, it may mean that the knowledge and skill requirements may not be fully understood by the instructor, the instructor may not have a comprehensive checklist and awareness of all the knowledge and skill sets, and the synergy among the knowledge and skill requirements may be unclear to the instructor. The TPACK framework helps the instructor specify each requirement very clearly (even if some may be minor) in a more formal and exclusive way beforehand that may make the instructor's preparation more complete, comprehensive, synergistic and well-organized [27].

There were several limitations of the presented studies. For example, the requirements to be fulfilled by the instructor for different knowledge domains and their intersections as given in Table 1 to instruct the sensor technologies and applications lesson successfully could be determined and analyzed more appropriately. In fact, it may need further research to determine these requirements appropriately, and the success of the TPACK framework largely depends on such determination. However, the instructor/author did not get much time and opportunity to conduct such research. The instruction of each lesson could be videotaped and analyzed by the instructor/author [28]. This could enable the instructor to make formal observations on his/her own teaching. The observation results could help the instructor improve his/her instruction quality. However, it was not done.

9. Conclusions and Future Work

Two separate lessons of a mechatronic course were selected. One lesson was on actuator technologies and applications [29]. Another lesson was on sensor technologies and applications [30]. For the actuator lesson, the instructor designed and implemented the instruction following the traditional approach. The same instructor instructed the sensor lesson to the same student population. However, for the sensor lesson, the instructor designed and implemented the instruction following the TPACK framework. For the TPACK method, before instructing the lesson, the instructor determined the technological, pedagogical and content knowledge and skills required to instruct the lesson effectively. Then, the instructor enhanced his/her self-efficacy on those knowledge domains and requirements, and then instructed the lesson to the learners accordingly. Appropriate assessment methods and rubrics were developed to assess the teaching and learning effectiveness of each lesson [31]. The assessment results for the TPACK approach were then compared to that of the traditional instruction approach [32]. Results showed that the instructions designed and implemented aligning with the TPACK framework significantly increased the instruction quality and self-efficacy of the instructor and also enhanced the overall teaching and learning outcomes and effectiveness. The results can inspire the educators and education decision makers to design instructions of STEM courses especially the mechatronics course following the TPACK framework.

In the future, more research will be conducted to determine the technological, pedagogical and content knowledge and skills required to instruct the lesson effectively. Actions plans will be taken to remove or reduce the limitations of each lesson implementation. External evaluators and observers may be invited to evaluate the lesson implementation so that more fair and unbiased evaluation of the instruction quality and lesson implementation outcomes can be obtained. The instructions will need to be videotaped for analysis by the instructor and others, which may increase instruction quality and hence the learning effectiveness. The presented approach will be implemented with more STEM courses such as control system [33], communication system [34], system design [35], etc. to understand the generality of the proposed TPACK model. The scope and definition of the *traditional instruction method* will be defined more clearly. Better evaluation rubrics will be developed and validated before using in the evaluation processes in practices. The results will be benchmarked for generalization [36].

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Appendix A

Student's Name Code:

1. How was the use of educational technologies by the instructor ("Technology")? (circle one)

   1 (worst) 2 3 4 5 (best)

2. How was the pedagogy (way/approach/presentation of teaching) of the instructor ("Pedagogy")? (circle one)

   1 (worst) 2 3 4 5 (best)

3. What was the level of content knowledge (knowledge of subject matter) of the instructor ("Content")? (circle one)

   1 (least) 2 3 4 5 (most)

4. How clearly could you realize any inherent relationship among educational technologies, pedagogy and depth/level of knowledge of the instructor in the subject matter towards successful teaching ("Cross-relationship")? (circle one)

   1 (least) 2 3 4 5 (most)