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Evaluation of the 7E Model for Instructing a Mechatronics Topic

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Abstract

In this paper, the 7E (elicit, engage, explore, explain, elaborate, evaluate, and extend) instructional model was developed, implemented and evaluated for instructing a topic of the mechatronics course to senior students of mechanical engineering major. To do so, a topic (a force sensor design, development and testing) of the mechatronics course was selected to be instructed to the students in a regular classroom setting following the 7E plan. The instruction of the entire topic in a regular class period was divided into the 7 sequential stages of the 7E plan. Required activities to be performed by the instructor in each stage of the 7E plan for instructing the topic were determined. The instructor developed the instructional materials (lecture materials, handouts, prototype sensor system, etc.) as per the planned activities. The instructor taught the topic to 10 senior mechanical engineering students in the classroom setting in a 50-minute class period. An evaluation team consisting of 6 engineering students (3 senior and 3 graduate students) was engaged to observe and evaluate the instruction. The evaluation was made on three criteria: (i) instructional quality, (ii) instructional outcomes, and (iii) socioemotional attitudes of students. The instructional quality meant how effectively the instructor aligned the instruction with the 7 stages of the 7E model, which was assessed following a 7-point Likert scale by the evaluation team. Instructional outcomes meant how effectively the students learned the topic, which were determined by the scores of an examination (test) on the topic that the students attended at the end of the instruction. The socioemotional attitudes were assessed in terms of engagement and enthusiasm levels of the students following a 7-point Likert scale. The instructor taught the same topic to another group of senior mechanical engineering students (10 in number) in the same classroom setting following the traditional instructional approach (the instruction was not divided into the 7 stages of the 7E plan), and the instruction was evaluated by the same evaluation team following the same evaluation criteria. The results showed that instructional quality, instructional outcomes (test scores) and socioemotional attitudes improved by 23.67%, 8.85% and 24.52% on average respectively for the 7E model (plan) compared to the traditional instructional approach. The challenges and burdens that the instructor faced for designing and implementing the 7E model were investigated and necessary training and institutional support for the instructor were determined. The results can inspire and guide instruction design for engineering courses following the 7E model.

1. Introduction

1.1 Background and Motivation

The 7E (elicit, engage, explore, explain, elaborate, evaluate, and extend) plan or model is a powerful teaching tool [1]. It is a constructivist approach to teaching, which means that it is the learning theory as well as the learning philosophy where individual learners actively build or construct their own understanding and knowledge of the world through practical experiences and reflections, rather than absorbing related information passively [2]. The 7E model consists of seven (07) sequential stages or actions in teaching made by the instructor, which are elicit, engage, explore, explain, elaborate, evaluate, and extend [3]. The 7E model can be considered as a conceptual change model in teaching and it is a complete and comprehensive teaching tool [3]. An instructor while teaching under this model needs to initiate their teaching by eliciting true interests of the learners and end up their teaching by connecting it to a future extension or expansion of the concept [3]. The 7E stages can be implemented repeatedly within a single topic or within the entire course [3]. The 7E model can help instructors prepare their lessons aligning with the 7 stages, and thus this model can make instructors well prepared for their teaching and enhance their level of confidence in teaching [1]-[3]. It is expected that implementation of such a scientific instructional approach can enhance instructional outcomes, especially instructional outcomes of multidisciplinary topics as instructing these topics may require better planning and preparation [4]. Considering these potential advantages, the theoretical 7E model has created high interest in educators, especially STEM teachers [2]-[3].

However, despite having tremendous prospects and potential, the proposed 7E model remains a theoretical and conceptual model in instructional fields [5]-[8]. As the literature shows, fruitful and effective applications of this model in actual instruction design in educational institutions have not been reported. It is realized that comprehensive evaluations of the proposed 7E model in instruction design and implementation in actual classroom settings are required to prove this model effective and practical [9]-[10]. Teaching mechatronics is very complex because mechatronics is a multidisciplinary course and learners need to have background in different areas such as electronics, computer programming, mechanical engineering, electrical engineering, etc. [4]. An instructor needs to introduce connections among these areas to learners. Learning mechatronics is also time consuming as learners may need to perform troubleshooting and debugging while learning mechatronics. Classroom-based traditional approaches of teaching and learning pure theoretical concepts may not be effective to teach and learn mechatronics. An instructor may need to add some hands-on activities to make mechatronics teaching and learning active and experiential. The instructor may need to elicit the interest of learners in mechatronics, engage them in hands-on activities to explore information on the topic, explain the topic based on obtained information and connect the topic to real-world applications. Thus, preparing mechatronics instructions is difficult and time consuming for instructors. It is realized that preparing mechatronics instructions adhering to the 7E sequential stages of the 7E model may make instructions easy and prove it very effective [11]. However, the literature does not show the story of successful application of this model in instructing a mechatronics course or topics in mechatronics.

1.2 Objectives

Being motivated by the above scenarios, the objectives of this paper were to design the instruction of a topic in mechatronics aligning it with the 7 stages of the 7E model, implement the model in an actual classroom setting and evaluate the outcomes of the model by an independent evaluation team. In addition, another objective was to identify the challenges and burdens that instructors may face while designing and implementing the 7E model in actual classroom settings and propose necessary support for the instructors to overcome the situation.

1.3 Organization

The rest of paper has been organized in the following way: Section 2 analyzes 7E theories and concepts. Section 3 analyzes state-of-the-art related work. Section 4 presents the materials and methods of the research. This section introduces the participants selected to participate in the studies, the lessons developed for the instruction, the developed pedagogical approaches aligning with the 7 stages of the 7E model, illustrations of the selected mechatronic topic, research design, research procedures, and research results and analyses. Section 5 discusses various critical issues related to the research in the application of the 7E model. Section 6 presents conclusions and the future research work in this research direction. Then, the acknowledgement, references and appendices are presented.

2. 7E Theories and Concepts

The 7E model was first developed by Lawson (1995) and it was then narrated by Kanli (2007) [3]. Previously, it was a 5E model, then two new stages (elicit and extend) have been added to it, which resulted in the 7E model [3]. By 'Elicit', prior knowledge, understanding, familiarity and concepts of learners about the topic to be taught are brought in front of the learners. Statement of past learning, quick questioning and answering, brainstorming, etc. may be good approaches to realize 'Elicit' in instructing a lesson [3]. By 'Engage', the instructor tries to do something that can engage students in learning the topic. The main objective of this stage is to create interest and curiosity in the learners about the topic and draw their attention to the topic. The instructors may realize this stage by disclosing statistics or facts related to the topic, using engaging technologies, e.g., demonstration of relevant video clips, animations, etc. However, such engagement methods depend on the topic to be taught [4]-[5]. By 'Explore, the instructor pushes the learners to do something to know more about the topic. The learners actively participate in learning activities, investigate the topic, collect data and information, they may work in groups, etc. By 'Explain', the instructor tries to explain the information and findings that the learners obtained during the 'Explore' stage, especially the instructor explains if there is any critical concept. By 'Elaborate', the instructor may add more information to what the learners have explored and obtained, especially the instructor may discuss how the learners can apply their knowledge, skills, and expertise related to the topic to solve real-world problems [6]-[7]. By 'Extend, the instructor tries to encourage learners to think critically to add some innovative ideas to their existing knowledge and understanding so they can adjust and adapt in new and uncertain situations. By 'Evaluate', the instructor tries to evaluate their instructional outcomes. In this stage, the instructor tries to know how their instruction has improved knowledge and understanding of the learners. The instructor may apply various evaluation strategies such as conducting a brief test, self-reflection, etc. The instructor may use the evaluation results to modify their instructional approach in instructing next lessons [3]-[7].

3. Analysis of Related Work

The literature shows a great interest in research in 7E approaches. A representation of improvement of learners' cognitive skills and abilities on learning fluid statics following the 7E approach was presented in [1]. Improvement of knowledge in senior high school students due to the application of 7E-based instruction was investigated in [2]. Different stages of the 7E model have been explained in detail in [3]. In [5], the authors presented how the 7E model enhanced the effectiveness of learning chemistry. The authors found that the 7E model enhanced both learning subject matter and attitude in learning chemistry. In [6], the authors presented that the 7E model played an important role in helping students learn electromagnetism in a high school physics class. Similarly, the literature shows that the 7E model proved effective in instructing geography [7], virtual lab-based physics topics [8], computer-based chemistry topics [9], and basic physics topics [10].

The literature also shows efforts toward applying different instructional strategies in instructing the mechatronics course such as simulation-based mechatronics teaching approaches [11], industry-focused mechatronics teaching approaches [12], modular curriculum-based mechatronics teaching approaches [13], language neutral low-cost mechatronics teaching approaches [14], two-tiered project based mechatronics teaching approaches [15], teaching mechatronics infusing into robotics [16], problem-based mechatronics teaching approaches [17], virtual reality-based mechatronics teaching approaches [18], project-based mechatronics teaching approaches [19], hands-on activity-based teaching approaches [20], industry-focused multidisciplinary teaching approaches [21], agile methods in teaching mechatronics [22], teaching mechatronics using a common and versatile platform [23], and so forth. However, as far as it is known, no one has applied the 7E approach to teach mechatronics at college level and evaluated the approach adequately. Recently, an initiative was taken to instruct mechatronics topics following the 7E plan [28]. However, the initiative needed substantial evaluations addressing its challenges and burdens, generalizability and possibility of generating misconceptions and misrepresentations. This paper aims to address these limitations.

4. Resources, Materials and Methods

4.1 Participants: learners and evaluators

Twenty (20) mechanical engineering senior students enrolled in a mechatronics course were selected to participate in the research. Those students were called the 'learners' for this research study. The students were randomly divided into two learner groups, each consisting of 10 learners. In addition, 3 senior engineering students and 3 engineering graduate students were selected to serve as observers and evaluators of the research study. They formed a team called the 'evaluation' team. The evaluation team members participated in the study voluntarily.

4.2 The mechatronic topic and the classroom

As part of the instruction of the mechatronics course, the instructor selected a topic to be instructed following the 7E model. The topic was the design, development and testing of a force sensor. The instructor planned to instruct the topic in a 50-minute class period in a classroom plus lab instructional setting.

4.3 Pedagogies

The instructor planned to follow two distinct pedagogical approaches to instruct the selected mechatronics topic: (i) 7E model instructional approach, and (ii) traditional instructional approach. In the 7E model instructional approach, the instructor divided the entire activities of the instruction into 7 divisions to be implemented sequentially during the instruction and aligned each division with each stage of the 7E model [3]-[6]. However, in the traditional instructional approach, the instructor did not divide the entire activities of the instruction into 7 divisions and did not align the instruction with the stages of the 7E model sequentially. Instead, the instructor followed the instruction design for the topic that the instructor received from another instructor who was not aware of the 7E model. The traditional instructional approach might eventually include all or some of the activities that the instructor planned for the 7E model, but the activities were not clearly and intentionally divided into the 7 sequential stages of the 7E model [1].

4.4 Research design

The research methodology was observation of the instruction by the evaluators and comparison of instructional outcomes between two different pedagogies (7E model instructional approach, and traditional instructional approach) by the evaluation team. The pedagogical approaches were the independent variables, and the instructional outcomes were the dependent variables.

4.5 Instructional materials and resources

For the 7E instructional model, the instructor divided the entire instructional activities into the 7 stages of the 7E model [1]-[3], as Fig.1 demonstrates. Based on the instructional framework presented in Fig.1, the instructor delivered the entire lesson content using PowerPoint slides for the 7E model pedagogy. The instructor also developed handouts on the topic to be printed and distributed to the learners. The instructor also developed paper worksheets that the learners needed to use during the instruction. In addition, the instructor developed a working prototype of a force sensor system, as Fig.2 illustrates. It was not a lab class. However, the instruction included demonstration of the force sensor prototype to add active and experiential learning experience to the instruction. The instructor also developed test questionnaires for the learners, as Appendix A shows. In addition, the instructor developed an assessment scheme that the evaluation team used to assess the socioemotional attitudes (e.g., engagement, enthusiasm) of the learners during the instruction, which Appendix B shows [24]-[25].

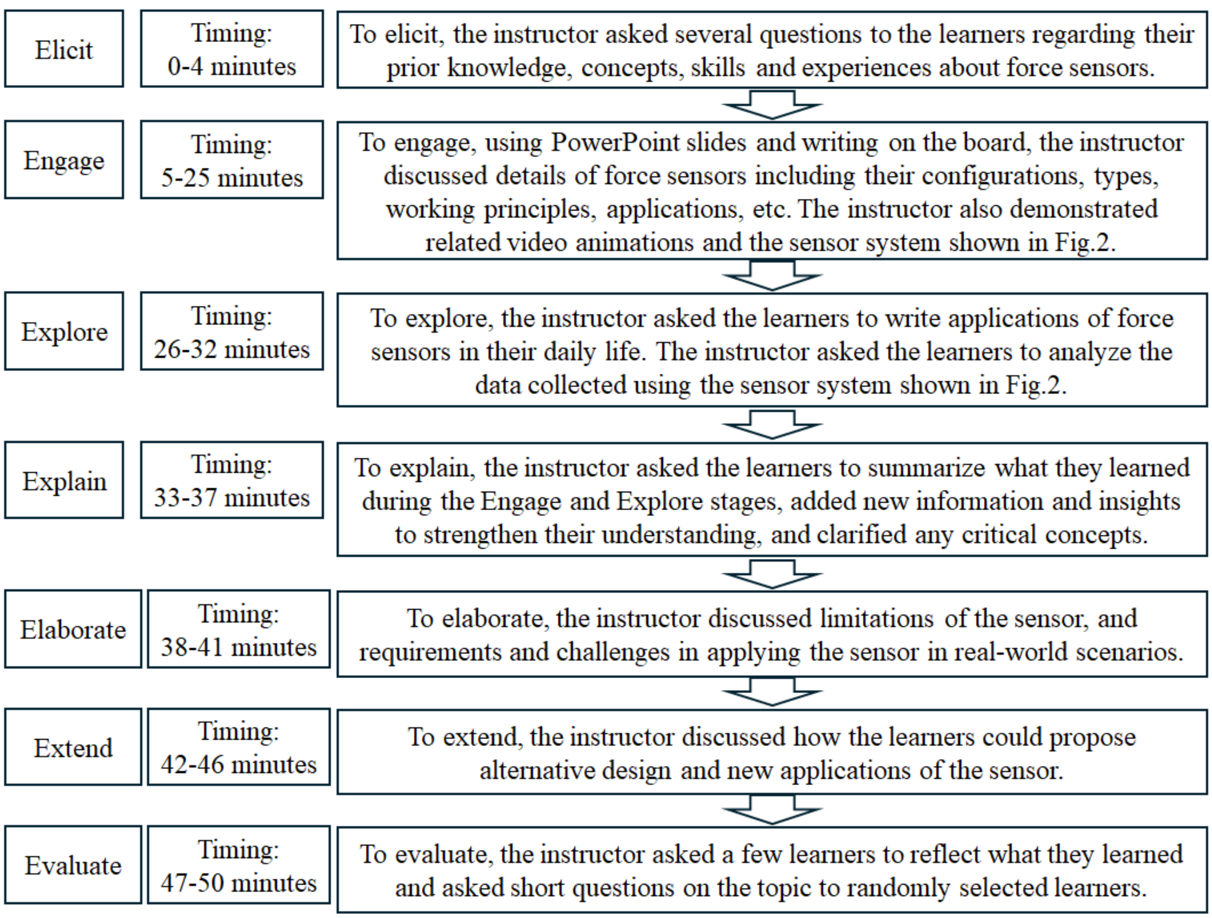

Figure 1. The instructional framework developed based on the 7E model. The framework shows what activities the instructor performed at different stages of the 7E model sequentially in the specified time durations.

For the traditional instructional approach, the instructor performed some of the actions of the 7E instructional model as the above, but the instruction was not divided into the 7 sequential stages of the 7E model purposefully following the illustration of Fig.1. Instead, the instruction was designed in such a way that the instructor first explained what a force sensor was, how it was configured, what it did and how, and then demonstrated the force sensor prototype. More specifically, the traditional instructional approach did not directly include elicit, elaborate, extend and evaluate actions because these actions are usually not performed carefully in traditional instructions. Instead, the traditional instructional approach focused mostly on the engage, explore and explain actions because such actions are usually performed by instructors in traditional instructions. It is to note that the traditional instructional approach might eventually include some of the activities or actions included in the 7E model, but the activities were not clearly, directly and intentionally aligned with the 7 stages of the 7E model [1].

The instructor needed about 30% more time to design the instruction following the 7E model than the traditional instructional approach. The instructor also needed to put more effort (approximately 25% more) to design the 7E model-based instruction for the topic than the traditional instructional approach.

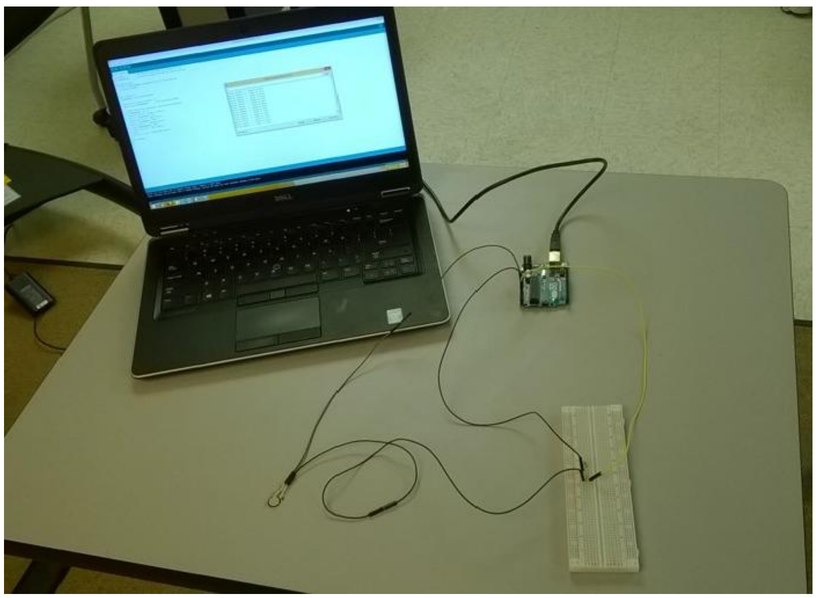

Figure 2. The force sensor system developed to instruct this topic to the learners of the mechatronics course.

4.6 Research procedures

There were two phases of the research procedures. In the first phase, the instructor instructed the selected force sensor topic to the first group of learners (10 learners) following the 7E teaching approach in a classroom plus laboratory setting. The duration of the teaching and learning period was 50 minutes. The instructor tried to strictly maintain the time duration for each 7E stage as per the plan in Fig.1. The evaluation team members observed the instruction, and individually assessed the instructional quality of the instructor following a 7-point Likert scale as illustrated in Appendix C. Here, the instructional quality means how effectively the instructor aligned the instruction with the 7 stages of the 7E model. Then, the instructor conducted a written test to evaluate the learning outcomes of the learners based on questionnaires developed by the instructor as shown in Appendix A. Each evaluation team member then evaluated each answer sheet for determining the learning outcomes of the learners. The evaluation team members also individually assessed the level of engagement and enthusiasm of each learner based on their observations on the learners during the instruction following the 7-point Likert scale shown in Appendix B.

In the second phase of the study, the instructor instructed the sensor topic to the other group of learners (10 learners) following the same procedures as the above, but the instructor followed the traditional instructional approach [20]. The evaluation procedures for the instructional outcomes for the traditional instructional approach were the same as that applied to the instruction that followed the 7E model.

In both phases, neither the evaluators nor the learners (students) knew whether the instructor followed the 7E or the traditional instructional approach. The evaluators did not need to ask questions to the learners verbally or directly to evaluate the instructional outcomes. Instead, they evaluated the learners based on learner responses and their observations on the learners during the instruction sessions. In both phases, the instructor instructed the topic to the learners in such a way that the correct answers to the questions shown in Appendix A were embedded in the instruction and it was possible for the learners to know the answers to the questions set in Appendix A clearly.

4.7 Research results and analysis

The results shown in Fig.3 (based on responses to questionnaires set in Appendix C) compare the instructional qualities between the 7E instructional model and the traditional instructional approach. The results show that the instructor was highly capable of aligning the instructions with the 7 stages of the 7E model for the 7E model-based instruction. This is logical because the instructor ensured it when designing the instruction. The results proved the effectiveness of the instruction design following the 7E model. On the other hand, the assessment results show that the instructor was somewhat able to align the instruction with the 7 stages of the 7E plan for the traditional instructional approach as well. This is because the instructor did not purposefully align the instruction with the 7E stages for the traditional instructional model. However, the instruction indirectly and eventually addressed the stages of the 7E model because the traditional instructional approach was also a well-designed approach though it did not purposefully and consciously align with the 7E stages. This is why the assessment scores for the traditional instructional approach were low, but not zero [1]-[2]. On average, the instructional quality for the 7E model was 23.67% better than that for the traditional instructional approach, based on Fig.3. The results of paired *t*-test showed that the assessment scores between the two pedagogical approaches were statistically significant ($p<0.05$), which indicates the superiority of the 7E model over the traditional instruction model.

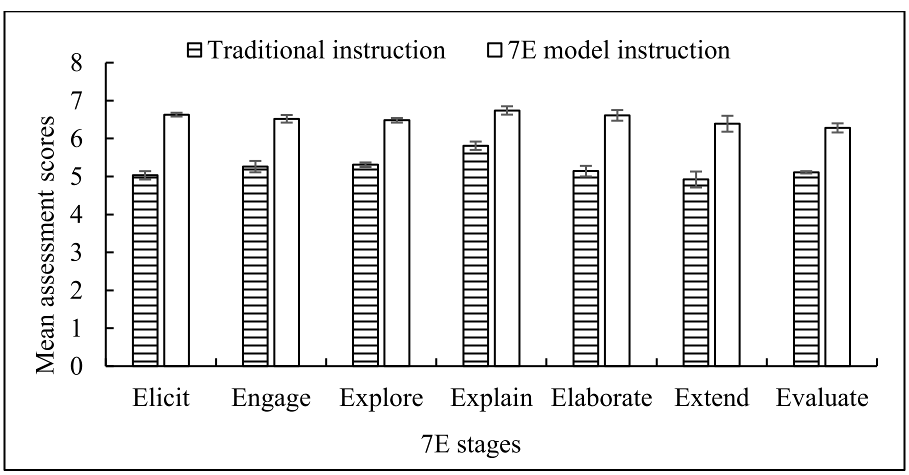

Figure 3. Assessment scores of instructional qualities between the 7E instructional model and the traditional instructional approach.

The results in Table 1 (based on responses to questionnaires set in Appendix A) show the mean test score for each question (standard deviation in parenthesis) between the two learner groups. On average, the test scores for the 7E model were 8.85% better than that for the traditional instructional approach, based on Table 1. A paired *t*-test conducted on the test scores between two learner groups showed that the test scores between the two groups were statistically significant ($p<0.05$). The results clearly show that the instructional outcomes significantly improved for the 7E instructional model compared to the traditional instructional approach. It can be noted that the instructional outcomes for traditional instruction were also satisfactory, but the 7E instructional model produced higher learning outcomes [6]. It happened because the traditional instructional approach was also a good instructional approach that indirectly and eventually addressed the stages of the 7E model partly, but the 7E instruction model addressed the 7 stages of the 7E model more clearly and purposefully [7].

Table 1. The mean test score percentage (%) for each question (standard deviation in parenthesis) between the two learner groups.

Question number	Test score % for the traditional instruction	Test score % for the 7E model instruction	Difference between scores (%)
1	83.74 (2.12)	93.31 (3.22)	+9.57
2	86.23 (3.17)	94.74 (2.66)	+8.51
3	84.56 (2.91)	92.32 (4.01)	+7.76
4	81.69 (1.77)	90.16 (3.65)	+8.47
5	88.13 (3.04)	95.84 (4.59)	+7.71
6	80.26 (2.43)	91.34 (3.18)	+11.08

The results in Table 2 (based on responses to questionnaires set in Appendix B) show the mean assessment scores of engagement and enthusiasm rated by the evaluator team members for the two learner groups. The results showed that engagement and enthusiasm significantly improved due to the 7E instruction method. On average, assessment scores for engagement and enthusiasm for the 7E model were 24.52% better than that for the traditional instructional approach, based on Table 2. The paired *t*-test results showed that the assessment scores between the two learner groups were statistically significant ($p<0.05$). It is assumed that the systematic instruction on 7 types of sequentially executed instruction activities drew attention of the learners and attuned them with the dynamics of the instruction, which might enhanced engagement of the learners in the topic to be learned [7]. Similarly, the 7E model presented the contents of the topic more rigorously and enhanced their interest in the topic, which might enhance their enthusiasm in learning and mastering the topic [24].

Table 2. The mean engagement and enthusiasm assessment scores (standard deviations in the parentheses) between the two learner groups.

Assessment Criteria	Mean scores for the traditional instruction	Mean scores for the 7E model instruction	Difference between the scores
Engagement	5.39 (0.23)	6.67 (0.16)	+1.28
Enthusiasm	5.18 (0.17)	6.49 (0.11)	+1.31

5. Discussion

There are challenges that instructors may face while designing and instructing topics aligning with the 7E model. For example, it may be difficult to develop the framework of the 7E instruction illustrated in Fig.1. It seems to be challenging to determine appropriate activities in each sequential stage of the 7E model for a specific topic [1]. Selection of wrong or irrelevant activities may jeopardize the mission of applying the 7E model in instructions. Wrong or irrelevant activities may also create misconceptions in learners about the topic to be instructed. The allocation of time duration to each stage is also challenging because the activities planned for each stage need to be completed within the specific time durations. The idle time between stages also needs to be minimized to zero. Stages of 7E model should be sequential, the activities should be well-connected so that they can educate the learners in a sequential and coherent manner [1]-[2].

Instruction designers need to make all facilities and resources available for each stage of the 7E model during the instruction period. The instructor may identify limitations in instructing a topic following the 7E model and develop an action plan containing corrective actions for continual improvement (CI) of the instruction. The design-based research method can be used as the CI tool to ensure continual improvement of the instructional quality [25]-[27].

The performance of the 7E model was compared to that of the traditional instructional approach based on instructional qualities, test scores and changes in socioemotional attitudes of learners (students). In addition to that the impact of the 7E model could be assessed based on some summative and formative assessment efforts. Such additional assessments could include assessment of students' final grades and project reports, and qualitative assessments such as short interviews with students on their perceived clarity, relevance, and preparedness for the topic taught. The limitations of the study presented herein are that small number of students and evaluators were involved in the study, and the study was conducted for only one topic in mechatronics. However, the impact of the 7E model can be assessed if such model is implemented for all topics of the same course and topics of similar STEM courses [4], [13]-[14].

The 7E model is an expanded version of the 5E model. As a result, it is logical that the impact of the 7E model should be more intense than that of the 5E model. However, it needs to be investigated how much efforts instructors need to invest to design and implement the 7E model compared to the 5E model [3]. Therefore, the expansion of the 7E model from the 5E model should be judged considering the benefit-cost ratio. On the other hand, it needs to be investigated how the 7E model correlates with other STEM pedagogical frameworks such as problem-based and project-based learning [15], [17].

6. Conclusions and Future Research Directions

A topic in mechatronics (force sensor) was taught to two different groups of learners following two different pedagogical approaches: 7E model-based instruction and traditional instruction. An independent evaluation team observed both instructions, and the team members independently evaluated the instructional quality and instructional outcomes for both instructional (pedagogical) approaches. The results showed that the 7E model-based instructional approach significantly enhanced the instructional quality and instructional outcomes. Then, the challenges and burdens in designing and implementing the 7E model were discussed. The results proved the prospects of the 7E instructional method in instructing mechatronics topics, which can urge relevant instructors, education researchers and policymakers to apply this method for instructing mechatronics and similar STEM courses.

In the future, further research will be conducted to determine the time duration for each 7E stage more accurately. The time duration will be systematically varied, and the activities carried out in each stage and the resources and facilities needed in each stage will be adjusted to optimize the instructional outcomes. The results will be verified using larger number of learners, instructors and evaluators for various STEM topics and courses to ensure the generality of the results. More summative and formative assessments including student perceptions of the 7E model will also be conducted to investigate the impact of the 7E model over the traditional instructional model more rigorously.

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Appendix A: Test questions

1. What was the objective of using the force sensor?
2. What were the main components that were used to develop the force sensor?
3. What was the working principle of the force sensor?
4. How was the gain of the force sensor determined?
5. How were the hardware components interfaced with the programming (coding) environment?
6. How can you improve the sensor design to use it in a robot?

Appendix B: Learners' socioemotional attitudes

1. The learners were found engaged in lesson activities during the instruction. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

2. The learners demonstrated significant interest and enthusiasm in the topic and related areas. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

Appendix C: Instructional qualities

1. The instructor was able to elicit the learners' interest in the topic taught. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

2. The instructor was able to engage the learners in lesson activities. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

3. The instructor was able to encourage the learners to explore information and skills around the topic. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

4. The instructor was able to explain the information that the learners gathered on the topic. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

5. The instructor was able to elaborate on the topic and related concepts. (circle one)

1 (least) 2 3 4 5 6 7 (most)

6. The instructor was able to evaluate the level of understanding of the students on the topic. (circle one)

   1 (least) 2 3 4 5 6 7 (most)

7. The instructor was able to state the future extension of the topic. (circle one)

   1 (least) 2 3 4 5 6 7 (most)