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Instruction Design of a Mechatronics Course Based on Closed-loop 7E Model Refined with DBR Method

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Instruction Design of a Mechatronics Course Based on Closed-loop 7E Model Refined with DBR Method

Abstract

In this paper, a closed-loop novel model of the 7E plan is proposed and implemented for instructing a mechatronics course to mechanical engineering students. The effectiveness of the 7E plan is augmented through associating the DBR (design-based research) with the 7E plan. To do so, a selected topic of the mechatronics course is divided into several (3) lessons. For each lesson, the required activities pertaining to each stage of the 7E plan are carefully determined, and the lesson is instructed to the students following the 7E stages in sequence. Under the DBR method, the classroom environment and intermediate outcomes of the lesson are observed and analyzed, the limitations are identified, and actions are planned to implement in the next lesson (iteration) with an aim of continual refinement of the 7E plan. A comprehensive assessment rubric is developed to evaluate the overall outcomes of the lessons. The evaluation results at the end of the topic (at the end of the 3rd lesson) are then compared with that of instructing a similar topic in mechatronics instructed by the same instructor to the same student population without following the 7E plan and the DBR method. The results show that instruction design of the mechatronics course can be successfully fitted within the framework of the 7E model augmented with the DBR method. The comparison results show that the combination of the 7E and the DBR, which makes the 7E a *closed-loop* model, significantly improves the teaching and learning outcomes and effectiveness, and the instructor's instructing quality. The proposed *closed-loop 7E model* via DBR addition can be a very successful instructional model to instruct mechatronics as well as other similar STEM courses to college-level science and engineering students.

1. Introduction

The 7E plan is a powerful tool and a constructivist approach to teaching and learning [1]-[2]. The 7E plan consists of 7 sequential stages in teaching and learning that are elicit, engage, explore, explain, elaborate, evaluate, and extend [3]. The 7E model is often used as a conceptual change model. This model seems to be a complete and comprehensive teaching tool that initiates with eliciting the interests of the learners and ends up at the future extension of the concepts, and the stages can also be repeated in cyclic order. Within its levels, instructors can work from eliciting dissatisfaction at the beginning to having students extend their new understanding to ensure the misunderstanding has been removed [3]. Due to many potential advantages [1]-[2], the 7E instructional model has recently been appeared to be a common learning cycle used by the educators especially the science teachers. However, the 7E model is still a theoretical model and successful application and evaluation of the model in actual instruction design is still not prioritized.

In particular, no successful instruction model based on the 7E cycle to teach mechatronics course to engineering students especially mechanical engineering students is observed. It is believed that mechatronics course contents can be easily aligned with the stages of the 7E model, and an application model of the 7E plan to teach the mechatronics course can be successfully implemented that may be proven very effective. However, such model is not observed in the literature [31]-[34].

Again, the state-of-the-art 7E model is an open loop model, and there is no proven evaluation scheme to evaluate the effectiveness of the 7E model [1]-[3], [35]-[40]. It means that the outcomes of this model at the end of the stages are not compared with the expected outcomes, which is not helpful towards continual improvement (CI). A method called the design-based research (DBR) can be used as the tool of continual refinement of the 7E model and its outcomes in repeated order [4]. The DBR method can be applied to identify the shortcomings in 7E implementations and outcomes, and appropriate action plans can be developed to modify the 7E plan to be implemented in the next lessons. It is believed that such integration of DBR with 7E can augment the overall teaching outcomes [31]-[34]. However, such approach is yet to be available in the state-of-the-art literature.

Hence, the objective of this paper is to develop an application model of the 7E method for teaching the mechatronics course at college level, implement the model in actual classroom setting, assess the student outcomes and modify the 7E application in cyclic order following the DBR method based on the feedbacks of the outcomes, which is referred in this paper as the *closed-loop 7E model*. The following two research questions are addressed:

(i) Whether it is feasible to design the instruction for the mechatronics course fitting within the framework of the 7E model, and to implement the instruction, and
(ii) Whether the continual refinement of the 7E model and its outcomes through DBR can significantly improve the instruction quality and teaching and learning outcomes and effectiveness.

In this paper, a closed-loop novel model of the 7E plan is implemented to instruct a mechatronics course to mechanical engineering students. A selected topic of the mechatronics course is divided into several lessons. For each lesson, the required activities pertaining to each stage of the 7E plan are carefully determined. Then, the instruction is designed for the lesson based on the 7 stages, and the lesson is instructed to the students sequentially following the 7 stages. The intermediate outcomes of the lesson and the classroom environment are observed and analyzed, and appropriate action plans are developed to modify the 7E-based instructions in the next lessons. A comprehensive assessment rubric is developed to assess the overall teaching and learning outcomes of the topic. The assessment results are then compared with that of instructing a similar topic in mechatronics instructed by the same instructor to the same student population without following the 7E plan and the DBR method. The comparison results show that the instruction design of the mechatronics course can be fitted within the framework of the 7E model, and its continual refinement via the DBR method can significantly improve the teaching and learning outcomes and effectiveness and the instructor's instructing quality. The proposed combined method named here as the *closed-loop 7E model* can be a successful instructional model to instruct mechatronics as well as other relevant college-level science and engineering STEM courses.

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 research methods and procedures, and section 7 presents research results and analyses. A general discussion is placed in section 8, and the conclusions and future works are presented in section 9.

2. Related Theories and Concepts

2.1 The 7E Model

Detailed explanations of the 7E instructional model, its different stages and its differences from previous 5E model are given in [3]. As it is stated in [3], the 7E plan is a constructivist approach to teaching, which can be a very powerful instructional tool. This teaching approach can allow learners to construct their own learning that is meaningful for their own lives. This plan was first developed by Lawson in 1995 and was narrated by Kanli in 2007. According to [3], addition of two new stages (elicit and extend) to the 5E model has given birth to the new 7E model. The concepts behind each of the 7 stages in the 7E model are explained below being inspired by the insights given in [3].

Elicit

Elicit is the task of drawing out learners' prior knowledge and concepts about a topic or lesson. Elicit can be implemented through statement of learning, quick questions and quizzes, brainstorming, etc. During the elicit phase, the instructor can address any misunderstandings observed in learners, and also discover the interests and expectations of the learners.

Engage

This stage attempts to engage students in the topic that the students have decided to learn. This stage plans and performs something that makes the class interesting, sparks curiosity and captivates the attention of the students on the selected topic/subject. Engagement can be achieved through pointing at big questions, showing startling facts or statistics, using some engaging technologies such as interesting video clips, robot-based demonstrations [31]-[34], etc. The engagement methods used at this stage usually depend on the subject/topic to be instructed, and on the instructor himself/herself.

Explore

Explore focuses on what students can find out in a lesson. This stage can promote a student centered and constructivist approach in learning. In this stage, the instructor may act as the facilitator and the learners may assume a more participatory and moving-forward role in their own learning. To achieve this, the instructor should give opportunities to students to work together through group work or pair work. Peer teaching or tutoring can also be incorporated in this stage.

Explain

In this stage, the instructor takes a more direct role, and the learners are to expect more instructions from the instructor. The instructor needs to provide inputs to learners to formalize the concept. The instructor can explain the concepts, critical definitions, etc. to the students in such a way that the students can understand it in their own words.

Elaborate

In this stage, the instructor should encourage and help the students to ensure a meaningful understanding of the concepts or the topics based on activities. The instructor should encourage students to know how to apply their knowledge, skills, and other learnings in real-world problems/contexts.

Extend

In this stage, the instructor should encourage students to apply or extend the concept in new situations in their daily professional activities. Students should be able to make connections not just in the topic/subject/ideas studied but also beyond it. They should be able to apply the learned ideas, generalize the ideas, transfer the principles to similar topics, etc.

Evaluate

In this stage, the instructor should evaluate the outcomes of the teaching. This is exactly a scale of how much progress the students have made based on the lesson they learned from the instructor. The instructor can use some rubrics to assess this directly. Some formal tests can be administered. Self-reflection and self-evaluation by students can be a significant part of evaluation. Revised and resubmitted statements of learnings of students can also provide some clues towards evaluations of their learning outcomes.

2.2 The DBR Method

As mentioned earlier, the word DBR can be elaborated as the design-based research. It is a general research method to continually improve a design [41], a system [42], a process, a product, etc. It is a continual improvement (CI) tool. It can be also treated as a systems engineering tool [4], [43]. In education, under the DBR method, the design and implementation of a lesson on a particular topic can be divided into several consecutive iterations, the outcomes of each iteration are assessed and analyzed, the outcomes are compared with the desired or targeted outcomes [37], shortcomings are identified, and necessary changes and actions for refinement and improvements in the design are determined to implement in the next and/or remaining iterations [4].

2.3 Mechatronics

According to [5], mechatronics, which is sometimes called as mechatronic engineering, is a truly multidisciplinary branch of engineering that mainly focuses on the engineering of both mechanical and electrical systems. It may also integrate electronics, system engineering and system science, computer science and engineering, telecommunications, controls, robotics, product engineering, etc. The aim of mechatronics is to provide a design solution that properly combines each of these subfields and solves a given problem. Mechatronics can be expressed in the following ways:

Mechatronics = Mechanics + Electronics

Mechatronics = Mechanical + Electronics

The word "mecha" came from *mechanics* or *mechanical*, and "tronics" came from *electronics*. In fact, mechatronics is the electronic controls/operations of mechanical devices/systems. The word *mechatronics* was first proposed by Tetsuro Mori, an engineer at Yaskawa Electric Corporation, Japan. The French standard NF E 01-010 uses the definition of mechatronics as follows: "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". Many researchers and engineers treat *mechatronics* as a synonym of robotics and electromechanical engineering. A popular diagram showing intersections between mechatronics and its subfields as well as domains of applications of mechatronics is given in Figure 1.

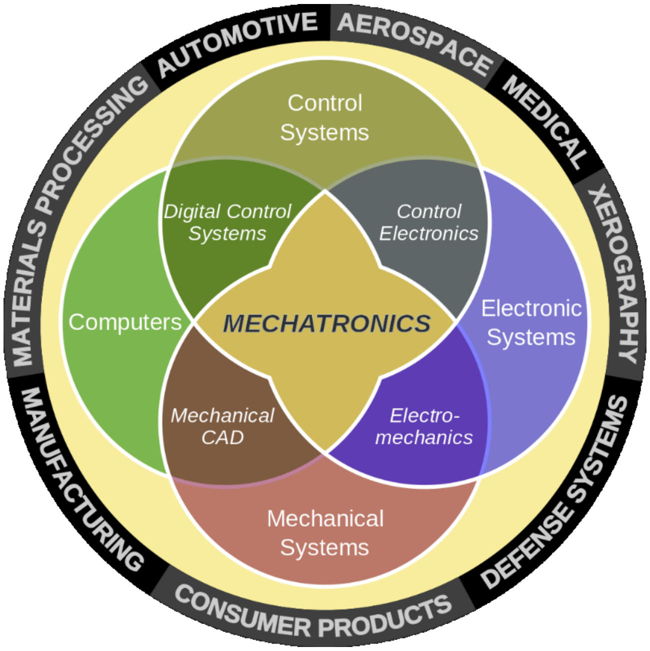

Figure 1. Intersections between mechatronics and its subfields as well as domains of applications of mechatronics [5].

3. Related Research Work

3.1 7E Plan Implementation

7E instructional plan is an active area of research. Literature shows a plethora of research work on 7E plans. In [1], the authors provided a representation of improvement of students' cognitive abilities on the concept of static fluid as a result of application of learning cycle 7E with Technology Based Constructivist Teaching (TBCT). In [2], determination of increment in the understanding of achievement in senior high school students was investigated through the Learning Cycle 7E with technology based constructivist teaching approach. In [6], the effectiveness of 7E learning cycle model was determined on students' achievement and attitude to chemistry. It was opined that the 7E plans can help students perform better in chemistry and also positively enhance the attitudes of many more students to the subject. In [7], the authors investigated the impact of the course materials developed in accordance with the 7E model in the unit of electromagnetism in high school physics class on students' conceptual success. They found the 7E plan to be effective on conceptual development and eliminating existing misconceptions of students about the subject of electromagnetism. In [8], the authors described the influence of the model LC 7E on geographic achievement at high school students of the school multi-ethnicity. The results of the study of geography was not affected by ethnicity of students, but was influenced by the model and teaching methods. It was found that the 7E model can help achieve learning objectives. In [9], the authors introduced the design stages of the activities based on the 7E learning model, and developed in the virtual laboratory environment for the "Electric Current" subject included in the "Electricity and Magnetism" unit of the secondary education Physics course, and evaluated them taking into consideration the opinions of the specialists and teachers in the field of physics education. They concluded that the materials developed within the framework of the study taking into consideration the opinions of the specialists in physics education and of the teachers in the secondary education are effective. In [10], the 7E learning model-based computer-assisted teaching materials were developed and applied on precipitation titrations. In [11], the learning environment in physics lesson was investigated using 7E model teaching activities, and so forth.

3.2 Mechatronics Course and Instruction Design

Efforts towards the development of mechatronics courses for engineering students are ongoing 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 discipline. In [23], the authors investigated the application 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, and importantly, preserving a good measure of creativity, and so forth.

3.3 DBR Applications

Research on DBR with applications to STEM education is also an area of growing interest. A plethora of recent literature signify the importance of the DBR method. In [4], the authors discussed the definition and scope of DBR, and applied the DBR to increase teaching effectiveness in robotics-focused middle school STEM lessons. In [25], optimization of a teacher professional development program for teaching STEM with robotics in middle school classrooms was performed using the DBR method. In [26], Brown investigated the theoretical and methodological challenges in creating complex interventions in classroom settings for design-based experiments and researches. In [27], the emergence and prospects of DBR are discussed. In [28], Fishman et al. explained the model of relationship of research and practice under DBR method. Challenges of experiment design and methodological perspectives of DBR are highlighted in [29] and [30] respectively, and so forth.

However, instruction design of a mechatronics course integrating the 7E plans and continual improvement through the DBR method in the form of a closed-loop refinery path for a college-level engineering course is not reported in literature. It is expected that the 7E and the DBR can be complementary to each other, and thus can create great impacts on teaching outcomes. Furthermore, the mechatronics course also seems to be a good choice for such experimentation because of its interdisciplinary nature and demand. This paper exactly presents the same herein.

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 for presentation, a screen, a large 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 for the 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 also demonstrated various pre-built mechatronic systems 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 study.

5. Research Design

Two independent topics from the course syllabus were selected: actuator and sensor. Three separate lessons were developed for each topic. Class duration was 50 minutes for each lesson. For the actuator, three lessons were taught in three classes in three days in a week. The same for the sensor, three lessons on sensor were taught in three classes in three days in another week.

For the actuator lessons, the instructor planned to teach the lessons following ordinary traditional manner, i.e. the instructor used all the classroom facilities, provided lecture materials to the students, instructed through PowerPoint presentation, and also wrote on the whiteboard when and where it was necessary. Students also did some hands-on activities where relevant as administered by the instructor. The students had opportunity to ask questions to the instructor, and the instructor also asked questions to the students where relevant and logical. However, the instructor did not organize the instruction in 7 stages of the 7E model. On the other hand, for each sensor lesson, in addition to the traditional manner as above, the instructor organized the instruction in 7 stages of the 7E approach though this was not disclosed to the students, and then instructed accordingly. In addition, as part of the DBR method, at the end of each class (lesson) on each day, the instructor based on his/her observation and experience, qualitatively evaluated the overall performance of the class, his/her instructional performance and the overall classroom management, and compared the same with the expected/targeted performance. Then, the instructor developed action plans to modify the instruction and classroom management in the next class (lesson) through implementing the planned corrective actions. Here, each class/lesson was considered as an iteration of the DBR method [4]. The combination of the 7E and the DBR is called here as the *closed loop 7E method*. The proposed closed-loop framework of integrating DBR with 7E plans for instruction design and implementation is explained in Figure 2.

Hence, it is seen that there were two conditions: (i) instructing the actuator lessons following traditional instruction methods (called "*traditional instruction method*"), and (ii) instructing the sensor lessons following the 7E plans enriched with the DBR method (called "*7E+DBR instruction method*). The research was to implement the above two conditions separately, 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 7E+DBR), and the dependent variables were the overall teaching and learning outcomes.

6. Research Methods and Procedures

In a week, the instructor instructed three lessons on actuator topic separately in three days following traditional instruction method as explained earlier. Each lesson/class was 50 minutes long. The instructor developed three lessons on actuator as follows: (i) in the first lesson, the instructor discussed the definitions and types of different actuators, (ii) in the second lesson, the instructor explained the working principles of different types of actuators, and (iii) in the third lesson, the instructor asked the students to develop and use a selected type of actuator using provided hardware and software resources. The instructor also helped the students in such development. Figure 3, as an example, shows the prototype of an electric actuator that a team of students built during the third lesson under the cognitive apprenticeship of the instructor [4]. At the end of the third day (third lesson), the instructor evaluated the overall teaching and learning outcomes. The evaluation was based on (i) the instructor asked the students to respond a rubric as given in Appendix A, and (ii) the instructor administered a formal test of the students on the entire topic (actuator).

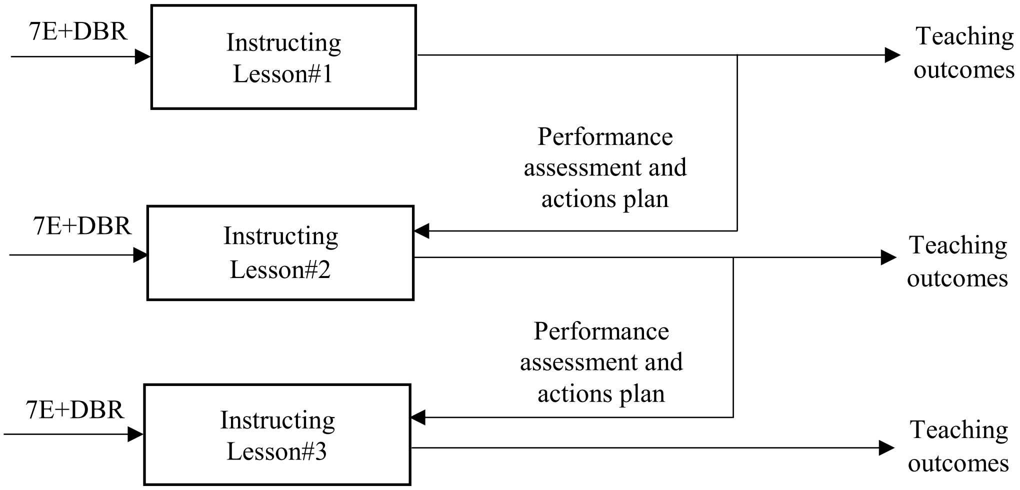

Figure 2. The proposed closed-loop framework of integrating DBR with 7E plans for instruction design and implementation.

For the sensor topic, in another week, the instructor instructed three lessons on sensor, each 50 minutes long, in three different days following the *closed-loop 7E method* as explained earlier. For the sensor topic, the instructor developed three lessons as follows: (i) in the first lesson, the instructor discussed the definitions and types of different sensors with areas of applications, (ii) in the second lesson, the instructor explained the working principles of different types of sensors in details, and (iii) in the third lesson, the instructor asked the students to develop and use a selected type of sensor system using provided hardware and software resources. The instructor also helped the students in such development. Figure 4, as an example, shows the prototype of a sensor that a team of students built during the third lesson under the cognitive apprenticeship of the instructor [4]. For each lesson, the instructor designed the instruction according to the 7E format. The instruction design according to the 7E method for the first lesson on the sensor topic is illustrated in Table 1. The instructor also qualitatively evaluated the overall performance of the class, identified the problems, developed action plans, and modified the instruction and classroom management in the next class/lesson (iteration) through implementing the planned corrective actions under the DBR method [4]. Table 2, as an example, shows what problems the instructor identified for the first lesson on the sensor topic, and what corrective actions the instructor took to improve the lesson on the sensor topic on the second day (second lesson or iteration).

For the sensor topic, at the end of the third day (third lesson), the instructor evaluated the overall teaching and learning outcomes. The evaluation was based on (i) the instructor asked the students to respond a rubric as given in Appendix B, and (ii) the instructor administered a formal test of the students on the entire topic (sensor).

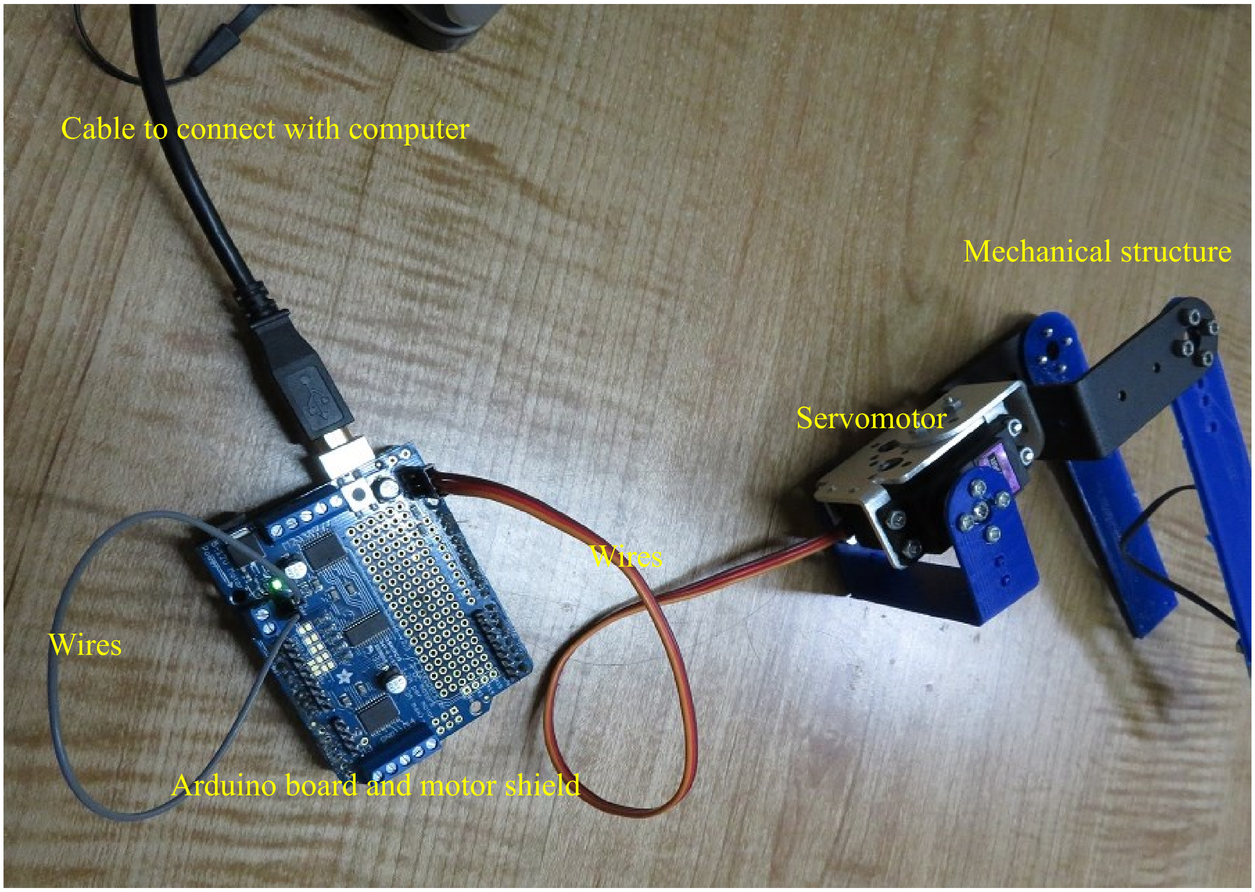

Figure 3. Prototype of an electric actuator that a team of students built during the third lesson on actuator topic under the cognitive apprenticeship of the instructor.

In addition to above evaluations of lesson outcomes through responses to rubrics and formal tests, the instructor based on his/her experience in the classroom made some qualitative observations on the overall class performance and classroom 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

Figure 5 shows the comparison of mean ($n = 22$) evaluation scores on the quality of the instructions in the 7E terms assessed by the participating students at the end of the 3rd (the last as well) lesson between the topics sensor (7E+DBR instruction model) and the actuator (traditional instruction model) based on the rubrics in Appendices A and B. Analyses of variances (ANOVAs) conducted

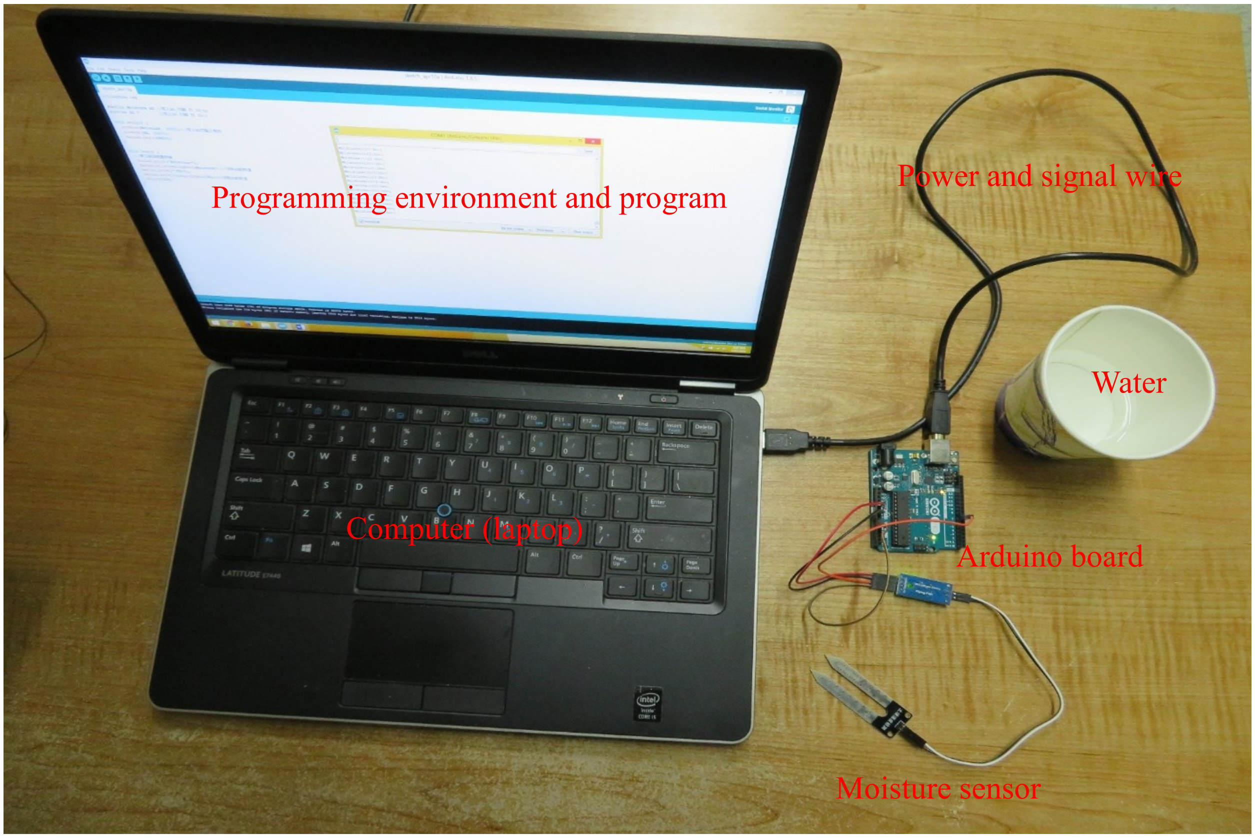

Figure 4. Prototype of a sensor that a team of students built during the third lesson on sensor topic under the cognitive apprenticeship of the instructor.

Table 1. Different stages of 7E model, actions that the instructor planned and implemented in each stage, and time planned to spend in each stage for the first lesson on the sensor topic

Time duration (minutes)	7E stages	Actions planned and implemented by the instructor
0-5	Elicit	The instructor pulled out learners' prior knowledge and concepts about sensor. The instructor randomly selected 3 students out of 22, and asked them to do the following tasks: (i) Tell briefly whether the students knew anything about sensors (ii) If anyone knew the term sensor, the instructor asked the student to tell something more about sensor such as types, real-world applications, etc. Students could answer the question alone or in group through brief brainstorming. (iii) Tell about their level of interest about sensors, etc.
6-15	Engage	The instructor showed PowerPoint slides in the projector that contained almost all about the sensors at a glance: photos of different types of sensors with specific applications, the data they measure,

		tentative costs of different types of sensors, a video link showing the applications of a few types of sensors in some exciting areas, etc.
16-25	Explore	The instructor made 4 groups of the students each comprising of 5/6 students. The instructor asked them to write down their understanding of the definition of sensor based on what the instructor showed in the PowerPoint slides. The instructor also asked each group to select two types of sensors and write down two applications of each type sensor that they observe in their daily life. The instructor also mentioned a specific application and asked the students to propose the most appropriate type of sensor for that particular application.
26-35	Explain	The instructor listened general working definitions of sensor from different student groups, and provided his/her opinions and necessary corrections on each definition. The instructor also listened the answers of the students on selecting two types of sensors with applications that they usually observed in their daily life, and provided his/her comments and inputs. The instructor also listened the most appropriate types of sensors that the students proposed for the particular application, and provided his/her comments and suggestions.
36-40	Elaborate	The instructor asked the students to think briefly about the pros and cons of each type of sensors, their limitations, etc. The instructor asked the students to know the challenges that the students may face and the requirements that the students must fulfill while working with each type of sensors in real-world applications.
41-45	Extend	The instructor asked the class to propose a prospective type of sensor for using in a novel robotic device that the instructor was developing [49]-[50]. The instructor also asked the students to propose a new or alternative type of sensor for that application.
46-50	Evaluate	The instructor did two actions to briefly evaluate the outcomes of the lesson: (i) The instructor randomly selected a student and asked him/her to reflect what he/she learned in the class. (ii) The instructor randomly asked three yes/no questions to three randomly selected students on the contents of the entire lecture/lesson.

Table 2. Problems the instructor identified for the first lesson (first iteration) on the sensor topic, and the corrective actions the instructor took to improve the lesson on the sensor topic on the second day (second lesson/iteration) under the DBR method

Limitations observed	Actions planned to implement in the next class/lesson (iteration)
• Time planned to spend in each stage was little bit insufficient and impractical to complete the actions within time. Hence,	• The instructor planned the activities more realistically so that the activities could be completed within the planned time

the instructor was in hurry to finish activities planned for each stage. • The instructor did not provide the reading materials before the class started. The students' opinions were that it would be better if the reading materials could be provided before the class started. • It appeared that some students were not so excited at the activities the instructor planned for each stage of 7E. • The instructor did not find some resources around him/her when those were necessary during the lesson. The instructor needed to look to and fro to get those resources ready for usage.	duration. The instructor also performed some rehearsal before instructing the actual class in order to fit the activities within the planned time frame. • The instructor decided to prepare and distribute the relevant reading materials to the students before start of the class from the next classes (iterations two and three). • For the next iteration, the instructor was more cautious with planning activities during each stage of the 7E model so that the activities were liked by all or most of the students. To do so, the instructor randomly selected a small group of students from the entire class and shared the planned actions to that representative student group before the next class, took their opinions and reflected their opinions in the activity planning for the classes in the next iterations. • The instructor planned the required resources more realistically, made all the resources available in the classroom several hours before the lesson start time, and kept the classroom under lock so that nobody could hamper the resource organization and allocation.

on the evaluation scores show that variations in the scores between instruction methods (7E+DBR instruction vs traditional instruction) are statistically significant ($p<0.05$). The results thus show that the 7E+DBR instruction model produced better instruction quality in all 7E terms over the traditional instruction model. This is logical because the instructor was aware of the specific 7E terms of evaluation for the 7E+DBR instruction model, and the instruction was also refined repeatedly under the DBR method. However, the instructor was not aware of the 7E terms and the instruction was not planned according to the 7E terms for the traditional instruction model. In addition, continual refinement did not occur for the traditional instruction. Note that the 7E terms can also reflect the overall instructional quality in general. Thus, the results show that the 7E+DBR instruction model produced better instructional quality. The results in Figure 5 also show satisfactory instructional quality for the 7E+DBR instruction model. For the 7E+DBR instruction model, ANOVAs show that the variations in the evaluation scores between the subjects were statistically nonsignificant ($p>0.05$), which indicates that the results can be used as the generic results or general findings. Again, the variations in the scores between the 7E terms are statistically significant ($p<0.05$) for the 7E+DBR instruction model, which indicates that the instructor's achievements of instruction quality in the 7E terms are different for different terms, though the quality is satisfactory in all terms.

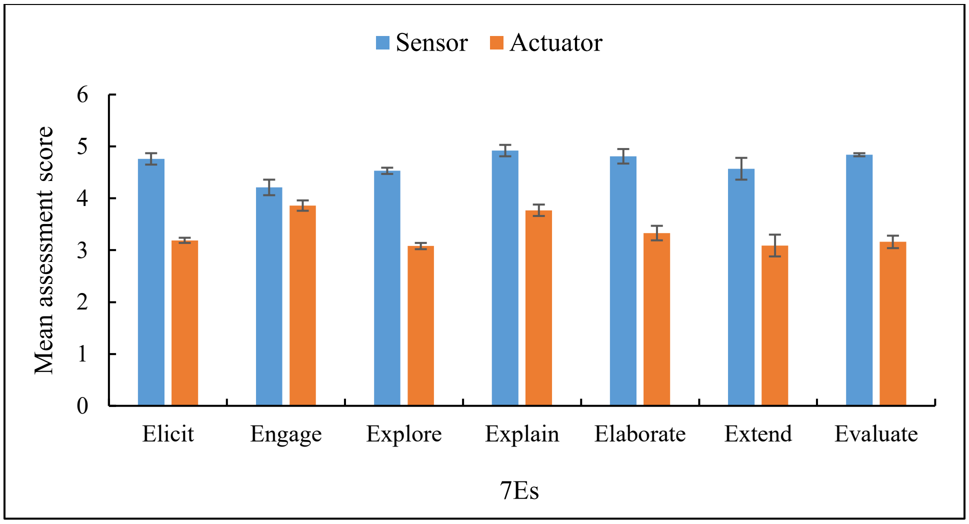

Figure 5. Comparison of mean (*n* = 22) evaluation/assessment scores (out of 5) on the quality of the instructions in the 7E terms assessed by the participating students at the end of the 3rd (the last as well) lessons between the topics sensor (7E+DBR instruction model) and actuator (traditional instruction model).

The results show satisfactory instruction quality achieved through the implementation of the 7E plans with DBR. The results thus signify the application of 7E and DBR combination to the selected mechatronics course, and justify the adoption of the integrated 7E and DBR as a means of quality instruction.

Figure 6 shows the increment (%) in the test scores for the test taken on the sensor topic at the end of the 3rd (the last as well) lesson that was instructed following the 7E plans enriched with the DBR

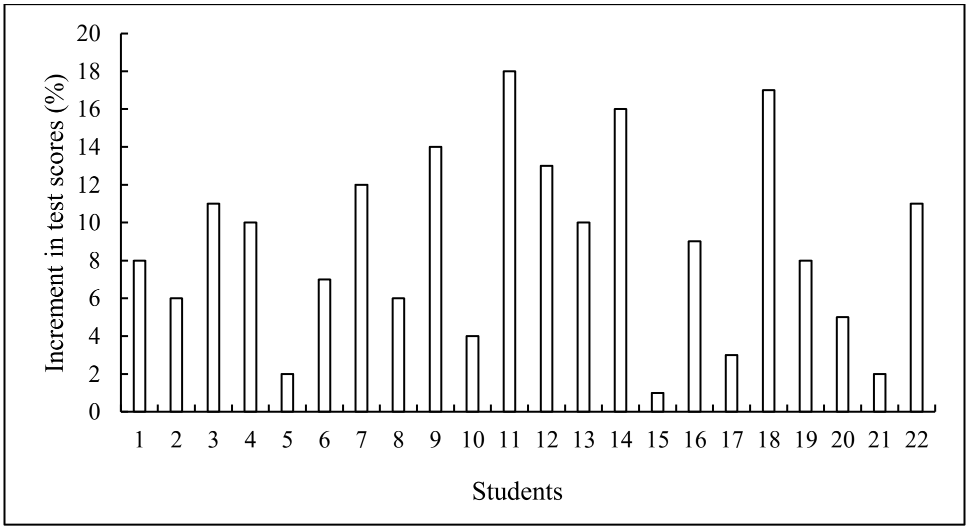

Figure 6. The increment % in test scores for different students for the test taken on the sensor topic at the end of the 3rd (the last as well) lesson in comparison with the test scores for the test taken on the actuator topic at the end of its last lesson.

method in comparison with the test scores taken on the actuator topic at the end of the last (3rd) lesson that was instructed by the same instructor to the same students without following the 7E plans and the DBR method. ANOVAs show that variations in the test scores between the actuator and the sensor topics are statistically significant ($p<0.05$). The results thus show that the application of the 7E plans and the DBR method jointly improved the teaching and learning outcomes in comparison with the traditional instruction method. The results thus again signify the application of the 7E and the DBR combination to the selected mechatronics course, and justify the adoption of the integrated 7E and DBR as a means of quality instruction.

The qualitative evaluation results based on the instructor's experience show that the students seemed to be more satisfied, pleased and motivated during the lessons instructed following the 7E and DBR methods over the lessons instructed in traditional method. Figure 5 shows that the students were more engaged with the lessons instructed following the 7E and DBR methods over the lessons instructed in traditional method. The instructor based on his/her experience believed that the well-planned lesson under the 7E model and the continual improvement of instruction via DBR resulted in better motivation, satisfaction and engagement in the learners over the traditional instructions. All those might produce better learning outcomes for the 7E and DBR case as reflected in Figure 6. Likewise, better motivation, satisfaction and learning outcomes of the learners might result in better satisfaction in the instructor as well because the instructor found his/her success in teaching, and thus achieved the desired teaching outcomes. Furthermore, it is realized that there is a good agreement between the qualitative observation results and that presented in Figures 5 and 6 as the quantitative results. Such combination and agreement in results between qualitative and quantitative evaluations justify the effectiveness of mixed method analysis, and help crosscheck the results via triangulation [25].

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

(i) It was feasible to design the instruction for the mechatronics course fitting within the framework of the 7E model, and to implement the instruction, and
(ii) The 7E plans and the continual refinement of the 7E model and its outcomes through the DBR can significantly improve the instruction quality and teaching and learning outcomes and effectiveness.

8. Discussion

The sensor lessons were instructed after the actuator lessons. Hence, it may be apparently thought that the students gained more experiences about the mechatronics subject matter and with the instructional approaches of the instructor, which might help the students achieve better test scores for the sensor lessons over the actuator lessons. It may be true that the experiences of the students in subject matter and familiarity with the instructor's approaches for the third lesson might impact the learning outcomes. However, it is assumed that the impacts of the application of the 7E plan with DBR on the learning outcomes were heavier than that due to the experiences and familiarity. A separate comparative study [44] may be needed to determine the relative contributions of the 7E plan with the DBR and of students' experiences and familiarity about the subject and its instructor.

There were several limitations of the presented studies. For example, the actions planned and implemented by the instructor for each 7E stage as given in Table 1 could be made more appropriate. In fact, it may need further research to select those activities appropriately, and the success of the 7E model largely depends on such selection. Similarly, the problems the instructor identified for the first lesson (first iteration) on the sensor topic and the corrective actions the instructor took to improve the lesson on the sensor topic on the second day (second lesson/iteration) under the DBR method as depicted in Table 2 also need further research. The success of DBR largely depends on such efforts. However, the instructor/author did not get much time and opportunity to conduct such research.

9. Conclusions and Future Work

Two similar topics of a senior-level mechatronics course were instructed to a class of students by the instructor/author. Each topic was divided into 3 lessons that were instructed in 3 different days in a week. Hence, 6 lessons in total were instructed in 6 days in two weeks. The first 3 lessons were on actuator topic. The remaining 3 lessons were on sensor topic. The actuator lessons were instructed following traditional instruction method. The sensor lessons were instructed by the same instructor to the same student population following the 7E plans associated with the DBR method. The instruction quality and the teaching and learning outcomes of the two approaches were assessed and compared. The results showed that the instruction quality and the teaching and learning outcomes for the sensor lessons were far better than that for the actuator lessons. The results thus prove the efficacy of the proposed 7E-plus-DBR instruction method and urge the relevant educators and research communities to follow this method while designing instructions for mechatronics and/or similar courses.

In the future, the activities for each stage of 7E model will be determined after further research. Similarly, the limitations of each lesson implementation will be identified, and action plans to improve the lesson in the next iterations under the DBR method will be performed more scientifically. External evaluators and observers will 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 presented approach will be implemented with more STEM courses such as robotics, control technologies [45]-[48], etc. to understand the generality of the proposed combined 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.

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Appendix A: Actuator

Student’s Name Code:

1. How much did the instructor do to elicit your interests in actuator? (circle one)

   1 (least) 2 3 4 5 (most)

2. How engaged did you feel during the class? (circle one)

   1 (least) 2 3 4 5 (most)

3. How much did the instructor do to explore novel ideas about actuator during the class? (circle one)

   1 (least) 2 3 4 5 (most)

4. How much explanation did the instructor provide on actuator during the class? (circle one)

   1 (least) 2 3 4 5 (most)

5. How elaborately did the instructor instruct on actuator? (circle one)

   1 (least) 2 3 4 5 (most)

6. How competently did the instructor evaluate/assess the level of understanding of the students on actuator? (circle one)

   1 (least) 2 3 4 5 (most)

7. How much did the instructor tell about future extension of lectures and research on actuator? (circle one)

   1 (least) 2 3 4 5 (most)

Appendix B: Sensor

Student's Name Code:

1. How much did the instructor do to elicit your interests in sensor? (circle one)

   1 (least) 2 3 4 5 (most)

2. How engaged did you feel during the class? (circle one)

   1 (least) 2 3 4 5 (most)

3. How much did the instructor do to explore novel ideas about sensor during the class? (circle one)

   1 (least) 2 3 4 5 (most)

4. How much explanation did the instructor provide on sensor during the class? (circle one)

   1 (least) 2 3 4 5 (most)

5. How elaborately did the instructor instruct on sensor? (circle one)

   1 (least) 2 3 4 5 (most)

6. How competently did the instructor evaluate/assess the level of understanding of the students on sensor? (circle one)

   1 (least) 2 3 4 5 (most)

7. How much did the instructor tell about future extension of lectures and research on sensor? (circle one)

   1 (least) 2 3 4 5 (most)