Comparative Experiential Learning of Mechanical Engineering Concepts through the Usage of Robot as a Kinesthetic Learning Tool

Dr. S. M. Mizanoor Rahman, University of West Florida

Mizanoor Rahman received Ph.D. and M.Sc. degrees in Systems Engineering and Mechanical Engineering respectively from Mie University at Tsu, Japan. He then worked as a research fellow at the National University of Singapore (NUS) and Nanyang Technological University (NTU), Singapore, a researcher at Vrije University of Brussels (VUB), Belgium, and a postdoctoral associate at Clemson University, SC, USA, and New York University (NYU), NY, USA. During his period at NYU, Dr. Rahman served as the lead robotics instructor for the Center for K-12 STEM education, and led the implementation of a large NSF-funded project entitled “DR K-12: Teaching STEM with Robotics: Design, Development, and Testing of a Research-based Professional Development Program for Teachers”. During that time, Dr. Rahman received license from the New York City Department of Education to conduct robot-based K-12 STEM education research in different public schools across New York City, trained about 100 public school math and science teachers for robot-based K-12 STEM education, and reached more than 1000 K-12 students across New York City. He then worked as an assistant professor of mechanical engineering at Tuskegee University, AL, USA. He is currently working as an assistant professor at the Department of Intelligent Systems and Robotics, Hal Marcus College of Science and Engineering, University of West Florida (UWF), Pensacola, FL, USA. At UWF, Dr. Rahman contributes to the Ph.D. program in Intelligent Systems and Robotics, and directs the Human-friendly and Interactive Robotics Laboratory (HIR Lab). His research and teaching interests include robotics, mechatronics, control systems, electro-mechanical design, human factors/ergonomics, engineering psychology, virtual reality, artificial intelligence, machine learning, CPS, IoT, computer vision, biomimetics and biomechanics with applications to industrial manipulation and manufacturing, healthcare and rehabilitation, social services, unmanned autonomous vehicle (aerial and ground) systems for indoor (e.g., home, factory floors, offices, business and social venues) and outdoor (e.g., fields, public places, space) services, and STEM education.
Comparative Experiential Learning of Mechanical Engineering Concepts through the Usage of Robot as a Kinesthetic Learning Tool

Abstract

Two independent studies of teaching mechanical engineering fundamentals are designed. In one study, a few selected mechanical engineering students are taught a few selected mechanical engineering concepts through the usage of illustrations created with a robot. The selected mechanical engineering concepts are believed to be abstract in nature and hard to comprehend. This study provides experiential kinesthetic learning opportunities to the students. In another study, the same concepts are taught to another group of students of similar grade and major by the same instructor. However, the instructor does not use any robot as a pedagogical tool to teach the students. Instead, the instructor uses the regular (ordinary) classroom facilities and traditional instruction approach. The outcomes of the two studies are assessed using appropriately developed rubrics, and are compared. The results show the efficacy of the robot-based teaching over the traditional (ordinary) teaching. The results can guide the educators and education decision makers to adopt appropriate technologies especially robotics as pedagogical tools to enhance the teaching and learning outcomes and effectiveness. The limitations and future directions of the research are also discussed.

1. Introduction

Based on years of teaching experiences of undergraduate mechanical engineering courses, it is realized that there are many mechanical engineering concepts that are fully or partly abstract in nature. For example, torque, moment, pneumatics, hydraulics, etc. It is experienced that students usually feel difficulty to comprehend such concepts when they are taught such concepts in traditional classroom settings. The difficulty level becomes higher when lower grade engineering students such as freshman and sophomore start to learn these concepts. It is believed that providing kinesthetic experiential learning opportunity to students through demonstrating these mechanical engineering concepts using relevant illustrations created with tangible robotic platforms can help the students learn these concepts easily and effectively [1]-[2]. The fundamental mechanical engineering concepts that students can learn in this way may include manufacturing processes and systems, additive manufacturing (e.g., 3D printing), hydraulics, pneumatics, drawing and drafting, engraving, system dynamics, control of mechanical system, vibration, machine intelligence, mechanical logic, theory of machines, measurement and instrumentation, machine kinematics, gripper design, production line simulation, materials selection, jigs and fixtures design, human-machine interface (HMI), mechanical design, etc. Recent advancements in robotics-aided STEM education have raised the possibility of such robot-based experiential learning concepts [1]-[13]. The advantage with the robotic platform for this purpose is that it is tangible and it is also adjustable so that one platform can be used to illustrate multiple concepts to the learners [3]-[6].
However, most of the state-of-the-art robotic platforms are standalone that may help learn the robotic technology itself, but they may not help learn the specific mechanical engineering concepts through robot-based illustrations [14]. For example, there are vast applications of robots for “demonstrations” or “labs” [21]-[22]. These are mainly for illustrating robotic applications or the robotics-related technologies/concepts such as robot control, automation, robot mechanisms, path planning, motion generation, etc. rather than illustrating any specific subject matter such as the mechanical engineering concepts [21]-[22]. Lesson design and created illustrations involving robots are also not so appropriate. Again, the state-of-the-art robot-based STEM education mainly focuses on K-12 education [1]-[6]. It is realized that such robot-based education for college or higher level especially for undergraduate mechanical engineering courses is still not prioritized [13]. Thus, it is to argue that a special type robotic platform (e.g., all-in-one and user-friendly for STEM solution) can be used to teach the fundamental abstract mechanical engineering concepts so that students can use the robotic platform as an experimental learning tool to learn and review various mechanical engineering concepts through relevant illustrations created with appropriate robotic functions [2]-[4]. However, investigation on integration of such all-in-one and user-friendly robotic STEM solution in teaching mechanical engineering concepts in actual classroom-like environment is yet to be reported.

Thus, the objective of this paper is to use an all-in-one and user-friendly robotic STEM solution in teaching mechanical engineering concepts in actual classroom-like environment, and to investigate its impacts on student outcomes and learning effectiveness. Though the current focus is with mechanical engineering concepts, the approaches and results are expected to be applicable to all STEM subjects directly or indirectly especially engineering majors such as electrical and electronics engineering, computer science and engineering, aerospace engineering, physics, chemical engineering, civil engineering, intelligent systems and robotics, etc.

In this paper, an appropriate multi-DOF robotic system is integrated as an instructional tool to teach some selected representative and fundamental undergraduate mechanical engineering concepts separately. For each representative concept, the instructor uses the robotic platform as a teaching tool to teach the concept to the selected students through appropriate robot-based illustration. The students observe robotic activities, interact with the robot, listen the instructor’s instructions, and thus learn the selected mechanical engineering concepts kinesthetically in teams using the robot under the instructions of the instructor. Appropriate assessment methods/rubrics are developed to assess the outcomes and effectiveness of the robot-based learning [2]-[3]. Then, the outcomes are compared with that when another group of students of similar grade and major are taught the same mechanical engineering concepts by the same instructor without using the robotic platform (the instructor follows traditional/regular/ordinary approach where the instructor verbally explains the mechanical engineering concepts based on figures and diagrams drawn on whiteboard and relevant reading materials provided to the students) [3]. This comparison is performed to understand the impacts of the robot-based teaching and learning over non robot-based teaching and learning. Two research questions are addressed, as follows:

(i) Whether or not the robot-based teaching and learning can positively impact the teaching and learning outcomes.

(ii) Whether or not the learning outcomes learned by the same learner group using the same robotic platform and instructed by the same instructor are significantly different among different mechanical engineering concepts.
The results show that the robot-based learning increases the learning outcomes and effectiveness significantly [3]-[4]. For the robot-based learning, the learning outcomes among the mechanical engineering concepts are also compared with each other, which helps understand the comparative impacts of using the robot as a learning tool on learning different mechanical engineering concepts.

The rest of the paper is organized as follows. Section 2 presents the literature review/related work. Section 3 presents the development of the research setting, and section 4 presents the research design. Section 5 presents the detailed research methods and procedures, and section 6 presents the research results and analyses. Section 7 provides a general discussion. Section 8 draws the conclusions, and focuses on the future extensions of the research.

2. Related Work

A plenty of research activities are reported in the literature that show great interests with research on robot-based STEM teaching and learning. In [1], Rahman et al. illustrated the use of periodic program evaluation and feedback to measure and optimize the design and implementation performance of a professional development (PD) program for in-service school teachers on teaching K-12 STEM using robotics. In [2], prerequisites (the expected aptitude and attitude) of middle school students to participate in robotics-based STEM lessons and to obtain the optimum level of benefits from the robot-based lessons are determined. The ability of computational thinking of students was considered as a great requirement before attending a robot-based STEM lesson. In return, there was a great chance that the computational thinking ability of the students would also increase through participating in robot-based lessons. In [3], a teaching framework called the TPACK (technological-pedagogical content knowledge) was proposed in conjunction with robot-based middle school lessons, and the variations in the TPACK framework for teaching robotics-aided STEM lessons of varying difficulty were examined. The impacts of robot-based learning over traditional learning were also investigated briefly. Earlier in [4], the dynamic nature of the TPACK framework in teaching STEM using robotics in middle school classrooms was thoroughly explored. In [5], a systems approach to analyzing design-based research in robotics-focused middle school STEM lessons through cognitive apprenticeship was proposed, investigated and analyzed. In [6], the factors determining the trust of students and teachers on robots for robotics-based middle school STEM lessons were determined. The impacts of students’ trust in robots on learning outcomes for robot-based STEM learning were also investigated. As reported in [7], robots were used for enhancing elementary school students’ learning of English language. In [8], a framework using LEGO robotics was proposed to teach problem solving that also enhanced engagement of students while in classroom. In [9], LEGO robots were used to create interest in high school students to improve the effectiveness of K-12 STEM education.

The review results in [10] state that social robots can be used in education as tutors or peer learners. The social robots have been proven effective at improving cognitive and affective outcomes. Their outcomes were found similar to those of human tutoring on some restricted tasks. This may happen because of their embodiment, physical presence, which traditional teaching/learning technologies cannot provide. In [11], a review study was conducted on the use of robots in education especially for the young children. In [12], a systematic survey was conducted to explore the educational
potential of robotics in schools. In [13], the authors explored the application of robotics in higher education, and investigated the student creativity through the robotics-based education.

However, all these studies focused mainly on robot-based K-12 STEM education, and the robots used for the lessons were mainly the simple LEGO robots. Thus, there is still room to investigate the impacts of the robot-based teaching from different perspectives and dimensions. In particular, applications of robotics in college level engineering education is still not so prioritized. However, it is believed that there is huge potential as well as necessity of robot-based college level STEM education [13]. This paper aims to contribute to this direction, and bridge the gaps in the state-of-the-art knowledge and practices of robot-based STEM education.

3. Development of Research Setting

3.1 The all-in-one and user-friendly robotic platform to be used as a teaching/learning tool

A Dobot Magician Robotic Arm V3 (advanced educational version) was developed to use as the teaching tool. One complete robotic system includes: one DOBOT Magician Robotic Arm V3, one vacuum pump kit, one gripper, one writing and drawing kit, one 3D printing kit, one laser engraving kit, one Bluetooth and WiFi modules, one joystick control kit, etc. Additional sensors and accessories can be included with this system to teach more engineering concepts. This is a low-cost robotic platform suitable to be used as the teaching tool. This robot can be used to demonstrate various operations such as automated writing, laser engraving, 3D printing, pneumatic gripper-based object manipulation, etc. This robot has flexibility in its operations. Thus, this robot can be used to teach many mechanical engineering concepts directly and indirectly using and adjusting the available operations. These are the motivating factors behind the selection of this robotic platform for the proposed study. Figure 1 shows the selected Dobot robot.

![Figure 1. The selected Dobot robot (Magician Robotic Arm V3).](image-url)
3.2 The participating students (learners)

Twenty (20) sophomore mechanical engineering students were selected randomly. The students were divided into two groups (group 1 and group 2) each consisting of 10 students. The main objective of the grouping was that one group could participate in the lessons that would be taught using the robotic platform, and another group could participate in other lessons that would be taught without using the robotic platform by the same instructor.

3.3 The selected mechanical engineering concepts

Three mechanical engineering concepts were selected randomly: (i) pneumatics, (ii) additive manufacturing (e.g., 3D printing), and (iii) laser engraving. These were selected because (i) in the instructor’s opinion, these topics are very abstract in nature unless illustrated properly, and (ii) the selected robotic platform was suitable to be used to teach these concepts.

4. Research Design

Two separate research studies were designed. In study 1, the instructor taught the selected mechanical engineering concepts to group 1 students in classroom environment using the robotic illustrations. In study 2, the instructor taught the selected mechanical engineering concepts to group 2 students in classroom environment without using robotic illustrations (the instructor explained the concepts verbally, distributed lecture notes, drew diagrams on whiteboard and explained, and showed relevant videos as appropriate). The independent variable was the use of robot in teaching and learning. The dependent variables were teaching and learning outcomes and quality of interactions between the students and the robotic platform (or teaching technologies/ facilities). The rubrics as given in Appendix A were used to assess the teaching/learning outcomes and students’ interactions for learning the selected concepts.

5. Research Methods and Procedures

For study 1, the instructor turned the robot on, and the instructor and the students stood (and/or sat) in front of the robot. The instructor at first taught the pneumatic concept using the robotic platform as an illustrative teaching tool. The instructor operated the robot to perform a manipulation task, which was such that the robot picked an object from the table surface and placed it on another location on the table surface within the workspace of the robot. The robotic manipulation was actuated by pneumatic actuation mechanism. For that mechanism, a cylinder was connected with a tube and some mechanism. The tube could supply air to the cylinder. A piston resided inside the cylinder, and the robot gripper was connected with the piston. The piston showed linear motion due to the flow of air. As the piston was connected with the gripper that gripped the object, the linear movement of the piston also controlled the opening and closing of the gripper.

The instructor explained the above concept regarding pneumatics verbally to the students while the robot was in operation. Based on that exemplary operation, the instructor taught the definition and possible applications of pneumatics. Students observed the operations and listened to the
instructor, and tried to comprehend the fundamental concepts and applications of pneumatics. The students got chance to ask questions to the instructor. The students also had chance as well as necessity to physically interact with the robotic system given that the students were fully aware of the safety requirements. The instructor repeated the operation for maximum 3 times so that the students got enough time to try to comprehend the concepts, observe the operations and ask questions to the instructor for further clarification. The students were encouraged to take short notes based on their observations. It took about 10 minutes to complete the instructions for the selected concept (pneumatics). Figure 2 shows the study environment and the students’ observations of and interactions with the robotic operations related to the pneumatics concept.

Then, the instructor gave a break of about 15 minutes to the students. In that break time, the students were supplied with the evaluation rubrics shown in Appendix A, and asked to respond the questions related to pneumatics. The instructor at that break time also replaced the robot end effector by the appropriate one for the next operation (topic).

![Figure 2. A team of students are observing the robotic operations (pneumatics-powered manipulation) related to the pneumatics concept.](image)

In the same way, the instructor instructed the other two mechanical engineering concepts such as additive manufacturing and laser engraving. As shown in Figure 3, the instructor demonstrated the operation of the robot performing the 3D printing, and followed the similar instruction procedures as used for the pneumatic concept as above. The students responded to the questions related to additive manufacturing/3D printing according to the rubrics in Appendix A.

At last, as shown in Figure 4, the instructor demonstrated the operation of the robot performing the laser engraving, and followed the similar instruction procedures as used for other concepts as above. The students responded to the questions related to laser engraving according to the rubrics
given in Appendix A. At that time, the students also responded to the questions (11-14) related to their interactions with the robot using the rubrics of Appendix A.

Note that the instructor could arrange multiple sessions as above if all students did not show up for the lessons at the same time. The students needed to strictly abide by the safety regulations (e.g., wearing protective goggles during laser engraving) during the study.

In study 2, in another session, the instructor taught the selected mechanical engineering concepts to group 2 students in similar classroom environment without using robotic illustrations. During that study, the instructor explained the concepts verbally, distributed lecture notes, drew diagrams on whiteboard and explained, and showed relevant videos where appropriate. At the end of the instruction of each concept, the students needed to respond to the rubrics in similar way as used for study 1.

The evaluation sheets for two studies were kept in separate bundles so that they could not mix. The two set answer sheets were coded properly so that the identity of the students and the instruction conditions (robot-based or non robot-based) could not be identified. This was considered to avoid any potential bias during the evaluation of the teaching/learning outcomes and interactions. This also helped ensure the appropriate treatment of the data.

Figure 3. A team of students are observing the operation of the robot performing 3D printing.

Note 1: The questions in the assessment in Appendix A are basic. The instructor had also asked the participants about the selected mechanical engineering concepts before they participated in the studies in order to verify their pre-knowledge about the concepts. However, the participants were
found having very low or no knowledge of the concerned mechanical engineering concepts. Hence, it was assumed that the participants had no pre-knowledge of the concepts selected to teach them. The participant selection criteria were that the participants would not have pre-knowledge on the selected concepts. If in any case some of them had pre-knowledge, then they could be put in separate groups, and separate questionnaires could be set for them to assess their learning effectiveness. In the presented studies as above, the main objective was to know whether the robot-based instruction might be more effective than the non robot-based instruction. This objective was to be fulfilled because the same basic questions were asked to both the robot-based and the non robot-based study participants. The differences in the assessment results were to be sufficient to understand the effectiveness of the robot-based instruction. However, more critical/depth questions can be set if the proposed approach is adopted in the actual curricula of mechanical engineering programs. It means that the presented studies were just for the proof of the concepts, and those could be scaled up to actual requirements in actual classroom settings.

Note 2: The same explanation as the above can be considered for the short duration (10 minutes) of the instruction. In fact, the instruction was provided just to understand the differences in the learning effectiveness between robot-based and non robot-based instructions. The objective was to be fulfilled because the same (short) time durations were used for both the robot-based and the non robot-based studies, and the differences in the assessment results were to be sufficient to understand the effectiveness of the robot-based instruction. However, the robot-based instruction can be conducted for standard class duration (e.g., 50 minutes or more) if the proposed approach is adopted in the actual curricula of mechanical engineering programs.
Note 3: The students needed to write the responses to the questions set in the Appendix A (1-10). The responses could be open-ended. However, the instructor instructed the mechanical engineering concepts in such a way that the appropriate answers to the questions were properly spelled out. The instructor was to look for those correct answers when evaluating the responses of the students. All the students were instructed in the similar ways by the same instructor, and their responses were also evaluated by the same instructor. Thus, it is assumed that the evaluation was unbiased that was to be sufficient to understand the differences in learning effectiveness between robot-based and non robot-based instructions. However, appropriate evaluation guides may need to be developed if multiple evaluators evaluate the responses. For example, the scoring guide may specify what type of answer can receive a score of 10 out of 10 versus what type of answer can receive a score of 5. Such guides will be essential if the proposed approach is adopted in the actual curricula of mechanical engineering programs, and multiple instructors instruct the courses.

Note 4: The first 10 questions in Appendix A were set to assess the mechanical subject knowledge learned by the students based on the instructions of the instructor. The instructor during the instruction showed how the robot functioned for the selected mechanical engineering concepts, and the students also interacted with the robot to have more kinesthetic experience. For example, the students touched the filament materials, the robot end-effector and the printed product (after cooling) for the instruction of the 3D printing with the help of the robot. Similarly, the students touched the engraved product (after cooling) for the laser engraving to examine the quality of the product and to understand the concept deeply. This is why, the last 4 questions were asked to assess the quality of interactions between the robotic device and their users (students), which might be helpful to understand the suitability of the robot and its acceptance by the students as a physical learning tool. Again, the instructor had briefly explained all the questions set in Appendix A to all the responding students in similar ways using similar words before they started to respond the questionnaires. Thus, they could comprehend the meaning of the questions properly. For example, the instructor clearly explained what “least cognitive workload is the best” in question 14 meant.

6. Research Results and Analyses

Figure 5 shows the mean (n=10) evaluation points or scores for different evaluation criteria of teaching and learning outcomes (see Appendix A) for teaching and learning the mechanical engineering concepts with and without using the robot. The results show that the evaluation scores for learning the concepts using the robot are significantly higher than that for learning without using the robot. The analyses of variances (ANOVAs) conducted on the evaluation scores between learning with and without using the robot also show that the differences in scores between these two conditions are statistically significant (p<0.05). The results thus prove the efficacy of teaching and learning using the robot over teaching and learning without using the robot. The results thus successfully address the first research question adopted for this paper. The differences in scores between the learners (students) for each evaluation criterion are not statistically significant (p>0.05), which indicates that the results can be considered as the general results even though only a small size participants participated in the studies.
The results also show that there are statistically significant differences ($p<0.05$) in evaluation scores between the learning concepts. For example, the evaluation scores for the definition of laser engraving were significantly higher than that for the pneumatics though both concepts were taught using the robot. It is believed that the pneumatics concept is more abstract than the laser engraving concept, and thus the learners comprehended the laser engraving concept more thoroughly than the pneumatics concept. It might also be possible that the operation and illustration created using the robot for the pneumatics were less appropriate than that for the laser engraving. The results thus successfully address the second research question adopted for this paper.

It is believed that the robot as a teaching and learning tool provided kinesthetic experiential learning opportunities to the students [15] that increased student engagement [16], improved cognition, helped conceptualize through visual observations, removed misconceptions, unmasked confusions, enhanced critical thinking, improved imagination, and motivated them intrinsically and extrinsically [17]. All those contributed to raise the effectiveness and outcomes of the robot-based instruction and learning over the traditional instruction and learning.

![Figure 5](image_url)

**Figure 5.** Mean ($n=10$) evaluation points or scores (out of 10) for different evaluation criteria of learning outcomes (see Appendix A) for learning the mechanical engineering concepts with and without using the robot.

Figure 6 shows the mean ($n=10$) evaluation scores (out of 5) for different evaluation criteria for interactions between the students and the robot (or other educational technologies/facilities for the case robot was not used). The results show that the safety in learning and teaching is higher for learning and teaching without using the robot over teaching and learning using the robot. This is very logical because there is almost no danger or risk when the instructor uses the ordinary educational technologies such as marker pen, whiteboard, hand note papers, etc. Nonetheless, the
safety of the robotic system and its operations is still high enough for teaching using the robot, which justifies the appropriateness of the robot as a teaching and learning tool. Engagement of the students while learning enhanced due to the application of the robot as a learning tool. It happened because the robot is an embodied physically existed dynamic device that provided kinesthetic experiential learning opportunity to the learners, and enhanced physical and mental engagement. Students’ trust towards the robot as a learning tool is higher because the students found the robot a good performer helping them learning the concepts easily without any error [6], [18].

The students had lower cognitive workload [19] while comprehending the engineering concepts using the robot over without using the robot. It is assumed that the real-world examples of the concepts illustrated through the applications of the robot made the concepts easily understandable and clearer that imparted lower cognitive workload on the students while comprehending the engineering concepts using the robot. The ANOVAs conducted on the evaluation scores between learning with and without using the robot show that the differences in scores between these two conditions are statistically significant ($p<0.05$) except for the safety. The nonsignificant difference for the safety is also favorable because it indicates that the robot-based teaching and learning is as safe as the ordinary teaching and learning in classroom environment, which argues for the application of robot as a safe teaching and learning tool [20].

![Figure 6](image.png)

**Figure 6.** Mean ($n=10$) evaluation points or scores (out of 5) for different evaluation criteria (see Appendix A) for interactions between the students and the robot (or other educational technologies for teaching and learning without using the robot) for learning the mechanical engineering concepts with and without using the robot. **Note:** Lower cognitive workload is the better.

### 7. Discussion

#### 7.1 Limitations of the Studies

The studies include some limitations. These are discussed below:

1. The selected group 1 and group 2 students did not show up together to attend the classes (lessons). Instead, they showed up in small teams. Hence, the instructor needed to repeat the instructions and demonstrations in several sessions.
The participants gave written consent to participate in the studies, and they were fully aware of their responsibilities. However, some of the participants did not show up timely.

Only small number of students took part in the studies. Larger student population might enhance the reliability of the results [24]. Again, only a few engineering concepts were taught. More concepts need to be taught using the robot to understand the impacts of the robot-based learning more generally and confidently [25].

All the responses were evaluated by only one person (instructor) though it was possible to hide the identity of the responders. However, it could be more reliable if each response sheet could be evaluated by several independent evaluators, and the conclusions could be drawn based on the average results.

The robot could be programmed in better ways to illustrate the engineering concepts in better and more clearly understandable ways [26]. Robots with better capability and scope could be a better choice though such robots are believed not to be readily available [27]-[28].

The results of the robot-based instructions were compared with the ordinary classroom instructions. However, it could be better if the results of the robot-based instructions could be compared with more mechanized non-robotic device-based instructions. For example, the robot-based illustration of 3D printing could be compared with the illustration of 3D printing using a regular 3D printing machine instead of using the ordinary facilities (drawings, whiteboard, lecture notes, etc.) available in the classroom environment to explain the 3D printing process.

The rubrics include only subjective quantitative evaluation criteria though the subjective assessments should be reliable as evidence can be obtained from prior works [29]-[35].

7.2 Alternative Approaches

Several alternative approaches may be investigated to compare the presented results with the potential alternative results, which may lead to more pragmatic decisions regarding employment of robot in STEM education. One approach may be to verify whether the robot is better than other hands on small team approaches. In fact, having a small team is an advantage in classroom management, but it is not a teaching tool, and thus it cannot provide the benefits of employing a robot as a kinesthetic teaching tool. The opposite is also true. If a large number of students are put in one team, and the team is taught using a robotic tool, then the teaching and learning effectiveness may not be appropriate due to the disadvantages of managing a large team. It is to posit that usage of suitable robotic tool to teach a student team of optimum size may jointly provide the optimum teaching and learning outcomes and effectiveness.

Another approach may be investigating whether or not the video-based demonstration of the mechanical engineering concepts would be more effective than the robot-based instruction [23]. In this regard, it is assumed that there are two types of video-based instructions: (i) making a video of the operation of a mechanical engineering concept implemented without the usage of a robot (example: a video showing the 3D printing activity using a formal 3D printer) [36], (ii) making a
video of the operation of a mechanical engineering concept implemented through the usage of a robot (example: a video of a robot performing the 3D printing as presented herein). In the first case, the 3D printer may be less motivational and less flexible than the robot, but the printing capacity and quality may be better than that for the robot-based 3D printing. In general, live robot-based instructions may result in better engagement and motivation than video-based instructions due to the physical presence, physical interaction, engagement and tangibility of the live robotic system.

However, formal comparative studies [37]-[39] are required to make concrete decisions regarding the above alternative approaches.

7.3 Scope of Innovation in Robot-based Teaching and Learning

The main objective of the proposed robot-based teaching is to have the hands-on kinesthetic experience that can help the learners learn in more realistic, tangible and flexible ways. Commitment towards investigating novelty is expected in all teaching and learning approaches whether it is robot-based or not. So, it is not guaranteed that the robot-based learning will result in more novelties in the subject matter than the non robot-based learning. However, robotic platform is more flexible for multiple prototyping in a very short time, and it is also a motivational tool to the students. All these in general can result in better novelties and innovations in robot-aided learning, and can motivate the students and faculty to participate in more changing and challenging studies.

8. Conclusions and Future Work

Two independent studies of teaching fundamental mechanical engineering concepts were conducted. In one study, a few selected mechanical engineering concepts were taught to a few selected students using demonstrations created with a robot. In another study, the same concepts were taught to another group of students of similar grade and major using usual (ordinary or traditional) classroom facilities and teaching methods. The student outcomes were assessed for both cases separately using appropriate rubrics. The results are compared between the two cases. The results show that the robot-based teaching and learning produced better outcomes than the ordinary or traditional teaching. The interactions between the students and the robot were also found satisfactory. The results also show that the outcomes are even different between the concepts taught to the students. The results can help educators and education decision makers to incorporate robotics into teaching as kinesthetic pedagogical tools, and produce better student outcomes.

In the near future, it will be necessary to remove or reduce the limitations of the studies listed earlier. Especially, more concepts will need to be taught using robots to have a general model of teaching outcomes using robots. More depth questions will need to be set to assess the learning outcomes [40]. The class duration will need to be similar as the actual class duration (50 minutes or more). Different types of anthropomorphic robots [41] and multiple teaching illustrations based on robots will need to be investigated. The results can also be verified to teach concepts from other domains such as computer science and engineering, electrical engineering, civil engineering,
medical science, mathematics, biology, etc. More qualitative observations on the classrooms will need to be added to the quantitative evaluations for mixed method analyses and triangulation, which can provide better and more in-depth understanding of the teaching and learning outcomes [1]. Some alternative approaches can be implemented to compare the effectiveness of the proposed robot-based approach with that of the alternative approaches. The studies will need to be more organized and systematic.

References


Appendix A

Student’s name code:

Write answers of the following questions (1-10) in the spaces provided. Maximum achievable point/score is 10 for the answer of each question.

1. What is pneumatics?

2. What is the main source of power in pneumatics?

3. What are the factors that determine the performance of a pneumatic system?

4. What is 3D printing?

5. From where does the material used in 3D printing come?

6. Why is 3D printing called additive manufacturing?

7. What are the parameters/factors that determine the quality of 3D printing process and 3D printed products?

8. What is laser engraving?
9. What form of energy is used in engraving and what is the source of this energy?

10. What are the factors/parameters that determine the quality of laser engraving?

Circle appropriate numbers for the following questions (11-14):

11. How safe did you feel when learning with the robotic system? (circle one)
   1 (least) 2 3 4 5 (most)

12. How engaged did you feel when learning with the robotic system? (circle one)
   1 (least) 2 3 4 5 (most)

13. How much trust do you have in the robotic system for learning mechanical engineering concepts with it? (circle one)
   1 (least) 2 3 4 5 (most)

14. What is the level of your cognitive workload while learning mechanical engineering concepts with the robotic system? (note: least cognitive workload is the best) (circle one)
   1 (best) 2 3 4 5 (worst)