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Work in Progress: Integrating Hands-on Exploration into an Undergraduate Robotics and Automation Class

Ms. Juliana Danesi Ruiz, The University of Iowa

Juliana Danesi Ruiz is currently on her fourth semester as a Ph.D. student at The University of Iowa. She graduated Fall 2020 at the University of Iowa with a BS in mechanical engineering degree, computer science, and mathematics minor. Her work has been focused on Engineering Education and Robotics, researching how to improve students experience in robotics class. She is advised by Professor Rachel Vitali and Professor Phillip Deierling.

Prof. Rachel Vitali, The University of Iowa

Dr. Rachel Vitali is an Assistant Professor in the Mechanical Engineering Department at the University of Iowa. Prior to her appointment, she was a NASA-funded TRISH postdoctoral fellow in the Industrial & Operations Engineering Department at the University of Michigan, where she also received her B.S.E. in 2015, M.S.E in 2017, and Ph.D. in 2019 from the Mechanical Engineering Department. As director of the Human Instrumentation and Robotics (HIR) lab, she leads multiple lines of research in engineering dynamics with applications to wearable technology for analysis of human motion in a variety of contexts ranging from warfighters to astronauts. In addition to her engineering work, she also has an interest in engineering education research. As a doctoral student, she led a project aimed at improving the undergraduate educational experience by systematically incorporating sensor technology into the curriculum as an engaged learning activity, for which she was awarded an ASME Graduate Teacher Fellowship.

Prof. Phillip Deierling

Dr. Deierling is an Associate Professor of Instruction at the University of Iowa. He holds BS, MS, and Ph.D degrees all from the University of Iowa. Prior to joining the faculty, he was a postdoctoral research associate with the Air Force Research Laboratory through the National Research Council and a design and analysis engineer in the commercial vehicle industry. His research and teaching interests are in advanced manufacturing, industry 4.0, machine learning & vision, and autonomous robotics.

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Introduction

For many students to have a positive educational experience in science, technology, engineering, and mathematics (STEM) classes, it is frequently important to have students engage meaningfully with theoretical, often abstract concepts through active learning-based hands-on experiences [1]. This hybrid pedagogical technique in which abstract concepts learned in class are paired with hands-on experiences in laboratories has been described by [2] as "labture." In that study conducted in 2000, this "labture" class format was implemented in a range of undergraduate mechanical engineering classes (e.g., statics, dynamics, and engineering design methodology). The vast majority of respondents reported that the active learning laboratory portion of the class reinforced concepts covered in lecture as well as expressing continuing interest in course content. As one student reported, "*I enjoyed the hands-on activities with products. It brought the theory to life*" [2]. Furthermore, students exhibit deeper conceptual understanding and greater retention of course material with a hands-on laboratory component integrated into the class structure [3]. During the laboratories, students have the opportunity to revise their understanding of the material learned in lecture and interact with robots, observing the real-world application of the abstract concepts covered in the homework assignment. Students are actively reviewing the same topic, which can increase their performance in the class [1]. Additionally, based on the taxonomy introduced in [4], the hands-on laboratories can actively engage students who are physically handling the robots and reflecting on the concepts learned in lecture. In other words, lecture is generally regarded as a passive learning activity whereas the "labture" format can be regarded as active, constructive, or interactive, depending on the activities designed by the instructors. Thus, the hands-on laboratories provide an experience-based learning opportunity.

In the Mechanical Engineering Department at the University of Iowa, the robotics classes are designed to teach students the basics of robotics and robotic kinematics. Robotics is a very large interdisciplinary field with multiple job opportunities ranging from programming to manufacturing [5]. Given the overwhelming breadth of potential material, the class of interest in this study primarily focuses on teaching students the basics of robotics with respect to an industrial setting. The topics covered include three-dimensional (often nonlinear) concepts like rotation matrices and forward kinematics. Since the class consists exclusively of lectures (i.e., this course does not have a dedicated laboratory), it can be difficult for students to visualize these dynamic concepts when the lecture is delivered via static slides – especially when the three-dimensional concepts are presented in two-dimensional slides [6]. However, it is important for students to understand these topics in real-world scenarios as robotics is a prevailing topic in multiple subdisciplines of engineering including mechanical engineering and electrical engineering. In addition, student learning can improve when afforded the opportunity to construct meaning for the topics learned in class by manipulating hardware [7].

In previous years' offerings, the robotics class at the center of this work consisted entirely of lectures until a month prior to the end of the semester. At that point, students engaged in a combination of robotics laboratories in addition to lectures for the last four weeks of the term, in which they had the opportunity to have hands-on experience by jogging and programming industrial robots. Based on students' feedback offered in previous semesters, the class was restructured to accommodate bi-weekly laboratories. Specifically, we identified the need to offer certain laboratories closer in time with the lectures that teach similar topics so they could frequently and strategically revisit class material. In other words, they have the opportunity to engage with hands-on exploratory laboratories while learning theoretical background alongside traditional lectures.

To investigate the effectiveness of this instructional approach, this work-in-progress study aims to address research questions focused on the students' understanding of the material, the students' intrinsic motivation [8] to learn the material, and the students' performance in the course through their self-reported homework percentage grade. By gathering students' grades, their perceived understanding can be analyzed alongside their actual understanding of the material, providing us with valuable insight into any discrepancies or similarities between self-reported grades and survey responses [9]. Laboratories have shown to be crucial in engineering and other STEM disciplines [10-11], but this work focuses on specifically evaluating the "labture" format for an upper level robotics class. It is hypothesized that students' conceptual understanding and intrinsic motivation can be positively influenced by the hands-on laboratory experiences. Thus, the following research questions will be answered in this study: (1) Does having hands-on experience bi-weekly positively influence students' motivation? (motivation) (2) How much does hands-on experience improve students' conceptual understanding of class topics? (conceptual understanding) (3) How does their perceived understanding compare with their understanding before lab? (conceptual understanding). The remainder of this paper describes the setting and participants engaged in the study, the data collection and analysis, and an example of a hands-on laboratory. Then, the paper will discuss progress thus far as well as conclusions and future work.

Methods

Study Setting and Participants

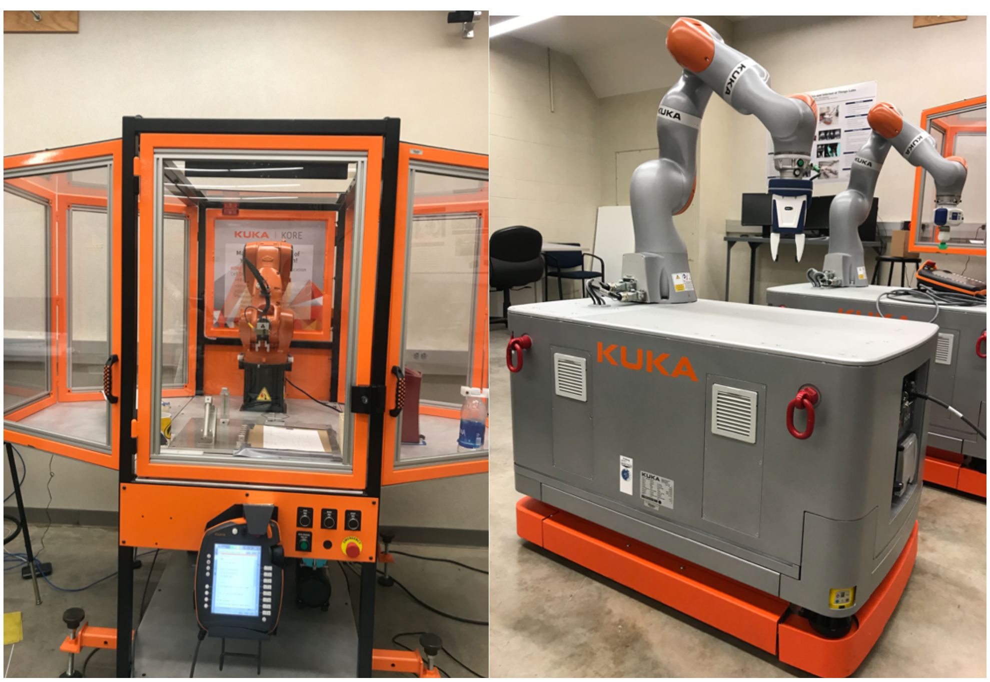
This study focuses on a technical elective robotics class that is largely populated by mechanical engineering students in their third or fourth year in the program. The only prerequisite for the course is an introductory dynamics course that covers particle dynamics and planar (i.e., two-dimensional) rigid body dynamics. Enrollment in this robotics class is typically around 60 students each Spring semester. For this study, the entire class was eligible to participate. However, students that drop the class during the semester will not be included in completing the surveys.

Students are invited to voluntarily participate in the study by completing surveys at the beginning and end of each laboratory. To keep track of the students that (anonymously) consent to participate in the study, the first page of the survey contains the consent letter and a question regarding whether they consent to participate. If students elect not to participate during the post-lab survey, the students will be redirected to the end of the survey. This study has been reviewed and approved by the Institutional Review Board (IRB).

Data collection & Analysis

The bi-weekly laboratories cover multiple essential topics in robotics and, more specifically, robotic kinematics such as three-dimensional orientation representations (e.g., rotation matrices and axis-angle representations) and forward kinematics. Since the laboratories are bi-weekly, each meeting covers the topics learned in the previous two weeks in lecture. The robotics laboratory contains three KUKA robots: two KUKA LBR iiwa (Fig. 1(b)) robots and one KUKA KORE robot (Fig. 1(a)). The KUKA robots are utilized in all of the laboratories. These hands-on exploration experiences are designed to aid students in visualizing the topics learned in class and applying those concepts in a real-world scenario.

To collect data on how these hands-on experiences are affecting students' conceptual understanding and intrinsic motivation, pre- and post-lab surveys are conducted for three laboratories. Since the bi-weekly laboratories occur on Fridays, the students are provided with the pre-lab survey at the end of lecture on Wednesdays. In the case that students do not attend class, an anonymous link is also available through announcements on the course site. At the end of the laboratory, the students are provided with the post-lab surveys, which they are able to access through a QR code. The surveys are administered using the online survey tool Qualtrics, and the responses are collected anonymously to protect students' identities. The post-lab surveys are available to the students at the end of laboratories on Friday until the end of the day.



(a) (b)

Figure 1: *The three KUKA robots used for the laboratories. (a) One KUKA KORE educational robot. (b) Two KUKA LBR iiwa robots with different grippers.*

Additionally, the surveys ask students more general questions about their knowledge and experience upon enrolling in the course. For example, they are asked about their previous programming and laboratory experiences. These questions provide some insight into students' programming knowledge and whether their previous experiences in laboratory-based courses could influence their perception on these laboratories and therefore their responses to the survey. To keep track of each student's data with an anonymous survey, a survey identifier will be used to keep track of student's data throughout the semester. The survey identifier is a name of the student's choice that they will enter for all surveys. This identifier is used to evaluate how a specific student's conceptual understanding and intrinsic motivation changes between pre- and post-lab surveys as well as how it changes over the course of the entire semester. Lastly, the survey will be used to compare students' perceived conceptual understanding with their self-reported homework grade. The pre- and post-lab surveys throughout the semester have similar questions and format, but each set of surveys will be updated to reflect the topics currently being taught in lecture. The survey items are presented in a Likert-scale type format ranging from 5 (strongly agree) to 1 (strongly disagree). The survey items regarding intrinsic motivation were modified from [12], and the survey items regarding perceived conceptual understanding were modified from [13].

Example Laboratory

The aforementioned laboratories are designed to incentivize students to review and deeply learn the lecture material. For example, the third homework assignment for the course includes questions regarding frames of reference and transformation matrices. Students are given different relevant scenarios and use the equations learned in class to solve the problems by using the axis-angle representation for orientation to answer questions about rigid body rotations. Thus, during a 30-minute laboratory, students have the opportunity to visualize how those topics are used in practice. Specifically, they are tasked to find how the different frame of reference (World and Tool frame) are positioned in the KUKA KORE and KUKA LBR iiwa, by jogging the robot using the right-hand rule. Then, they determine the transformation matrix between the World and Tool frame using the formulas learned in class. The laboratory instructor explains the similarities between the homework and the KUKA robots, assists students computing the result for the transformation matrix, and verifies the correct values. During this first laboratory, the teaching assistants anecdotally observed an increase in the number of questions from students regarding the material than in previous years' offerings of the course. By scheduling the laboratories temporally close to the relevant homework assignments, the students ideally should be able to recall the material more easily.

Previously Collected Survey Data

In the Spring 2022 semester, an end of semester survey was conducted in the offering of the robotics course at the center of this work to gather information about students' overall satisfaction with the course. The last question in the survey was open-ended to allow students to express what they believed would improve the class structure. The consensus was that students believed that it would be a valuable educational experience to have hands-on laboratories around the same time as topics were being taught in class. These educational experiences would provide students with an opportunity to review the (abstract) topics learned in class in hands-on laboratories. As a result, this feedback provided during last year's survey was the catalyst for modifying the Spring 2023 semester's class structure.

While the data from this survey cannot answer the research questions posed by this work-in-progress study, we developed our instructional intervention and experimental design around responding to this consensus. The data collection is currently ongoing, but the results from this study will be useful in investigating the importance of adding 30-minute bi-weekly hands-on laboratories to introduce students to real-world applications of the concepts taught in lecture.

Preliminary Results

This study is conducted in the Spring 2023 semester in a technical elective robotics class. While the data collections are still ongoing, the preliminary results provide evidence relating to the outcome of the set of surveys associated with the first laboratory. As mentioned, the surveys are voluntary and that can affect the number of students' responses. For the first laboratory, the pre-lab survey had a 12% response rate while the post-lab survey had a 70% response rate. To analyze the current data, the mean was calculated for the items regarding students' conceptual understanding and motivation as shown in Table 1.

Table 1: *Preliminary results (Mean and Standard Deviation) of first laboratory set of surveys. Items 1-3 relate to students' conceptual understanding, while items 4-9 relate to students' intrinsic motivation in the class. Items are presented in Likert scale from 5 (Strongly agree) to 1(Strongly disagree).*

Items	Pre-lab Survey (n=7)	Post-lab Survey (n=42)
1. Better understanding of transformation matrices would help me choose better frame of reference	4.14 ± 0.64	4.52 ± 1.71
2. I feel that I understand what transformation matrices are	3.86 ± 1.25	4.07 ± 2.75
3. Overall, I feel I have an understanding how transformation matrices work	3.71 ± 1.16	4.00 ± 2.67
4. I feel able to meet the learning objectives of this course	4.43 ± 0.73	4.31 ± 1.56
5. I have positive experiences in this course	4.29 ± 1.03	3.95 ± 3.11
6. I participate in class discussions to improve my understanding in academic	4.43 ± 0.73	4.21 ± 1.73
7. I take personal responsibility for my academic learning	5.00 ± 0.00	4.67 ± 1.27
8. I seek out the information I need to master course objectives	4.71 ± 0.45	4.40 ± 1.78
9. I feel competent in my learning and master of module objectives	4.29 ± 0.45	4.14 ± 2.04

The mean metric was used to evaluate the central tendency of the data [14]. The results demonstrate a distinct trend for items regarding students' conceptual understanding and students' motivation. The mean of the conceptual understanding items increased from 3.90 to 4.20, while the mean for students' motivation items decreased from 4.52 to 4.28. Additional data collected from the other laboratory surveys are needed to draw definitive conclusions, but there are two possible reasons for low student motivation: 1) fatigue from a demanding school week since laboratories are conducted Friday afternoon, and 2) disengagement due to technical difficulties with using the robots (e.g., troubleshooting firmware bugs). Furthermore, the sample size imbalance between the pre- and post-survey groups for the first laboratory alone is too large to support drawing any meaningful statistical conclusions at this time.

Conclusion and Future Work

The findings of this study will support our investigation into the effectiveness of hands-on laboratories when implemented to a technical elective robotics class in the Mechanical Engineering Department at the University of Iowa. Hands-on experience is extremely important for engineering students to deeply understand three-dimensional, nonlinear concepts as well as understanding how to apply these concepts in specific settings like the industrial robots utilized here. Given the abundant evidence supporting the positive effects of active learning [1], it is hypothesized that by implementing hands-on laboratories students will have increased intrinsic motivation to learn the topics in class, pursue deeper understanding of class material, and generally have a more positive educational experience. While these findings may be transferable to other STEM courses, immediate future work focuses on completing the data collection and statistical analyses. The results for this study will support updating future iterations of the class pedagogy as well as possibly restructuring the course entirely in future offerings. Preliminary results of the first laboratory suggest an increase in student conceptual understanding and a decrease in student intrinsic motivation, but additional statistical analyses will be conducted once the data collections for the Spring 2023 semester have been completed.

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