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Virtual Reality For Robot Control and Programming in Undergraduate Engineering Courses

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Abstract
This paper describes a pilot study to explore how introduction to robot programming influences the motivation of new engineering students. Robots have been a significant factor in the growth of several industries, and they play a vital role in advancing critical sectors like defense, manufacturing, medicine, and exploration. Accordingly, it is essential to introduce realistic robots to all engineering students, not only those majoring in robotic-centric programs so that they are well prepared for the modern workplace. When students learn about robots with scaled-down models or without models, they risk not adequately appreciating the physical scale, abilities, and dangers associated with real-world robots. That said, industrial-scale robots are expensive to acquire and maintain and access to them may be restricted: requiring elevated privileges or requiring time-sharing between students. Therefore, it is vital to develop a cheaper and more accessible educational alternative that offers all the benefits of a real industrial robot. This paper describes the implementation of an industrial robot in Augmented Reality (AR) head-mounted displays (HMDs) and how its use affects the motivation of first-year and second-year engineering students in introductory courses. This system allows students to work on a pick-and-place task using a UR10 industrial robot as often as they want and at their convenience outside of the classroom.

This paper describes the system and the tasks used to test its effectiveness as a motivational factor in engineering education. Specifically, incoming first-and-second-year students in introductory engineering courses were asked to perform a block stacking task in a virtual world with a 3D model and simulation of a robotic arm. The students were split into two groups. In the first part of the study, both groups of students were presented with a desktop interface of the robot and asked to stack blocks in a specific way to mimic everyday pick-and-place tasks that industrial robots typically perform. In the second part of the study, one group observed the demonstration in-person on an industrial-scale robot. In contrast, the second group watched it in an AR environment with a life-size robot model. Additionally, the second group was notified of the existence of the robot arm and its location on campus.

The learning objective for this study was for the students to appreciate the tools that professionals use to program a robot for an industrial pick and place task. Additionally, since we were interested in student motivation, we conducted a 25-minute post-study interview with the participants. We asked questions on the motivational components in the MUSIC (eMpowerement, Usefulness, Success, Interest, Caring) model for academic motivation. We analyzed the interview data using a mix of a priori and open coding methods.

The paper presents a qualitative study that investigated the differences in motivation between students who observed a physical robot and those who observed an AR robot. The study (N=8) found that the interface design of the desktop tool used in the study was highly rated in the interest component of the MUSIC model. On the other hand, the nature of application of the desktop tool scored highly in the success portion. The students found the physical robot useful, while the AR robot scored highly in the interest portion of the MUSIC model.

This study highlights the potential of AR and VR technology to motivate students in the field of robotics. The implementation studied was an effective proof of concept, and future iterations will include a fully immersive programming interface within a virtual environment to allow collaboration over shared tasks and resources, even when geographically separated. Future iterations will also incorporate accessibility and inclusivity to a greater degree by leveraging Universal Design for Learning (UDL) principles to integrate the tool effectively into the curriculum of an undergraduate engineering course.

Keywords: Virtual Reality, robotics, Engineering Education, UR10

1 Introduction

Robotics is considered to be one of the most engaging and tangible subjects in Engineering (Van Dyne and Fjermestad, 2012; Passos et al., 2022). However, certain kinds of robotics, such as small mobile robots, are more often featured in practical engineering coursework due to safety and cost constraints (McLurkin et al., 2013). As a result, engineering students may never get direct practice working with certain types of robotic equipment, such as robotic arms, despite that equipment being vital to modern industry (Gomes and Bogosyan, 2009). In these cases, some instructors have turned to simulations and virtual reality (VR) to provide exposure (Rukangu et al., 2021; Cassola et al., 2021). However, simulations rarely emulate a physical robot perfectly, especially its interaction with the environment (Jin et al., 2022). In addition, the *experience* of being around a moving, potentially dangerous, robotic arm may be difficult to achieve, even with modern virtual and augmented reality headsets (Tsamis et al., 2021). As a result, using VR robots in curriculum may be didactically useful, but they may pale in comparison to the incorporation of physical robots from a student perspective.

In this paper, we demonstrate how first- and second-year engineering students can use a two-dimensional (2D) desktop interface to learn robot programming, and subsequently reinforce these concepts by observing a life-size robot arm, programmed by an expert, in operation. The apparent advantages of this set-up are that the student can spend as much time as they need to absorb the underlying concepts of robot programming on a low-cost platform (the 2D interface) with minimal instructor intervention before advancing to the more expensive industrial-scale version of the robot. The industrial experience can be broken into two tiers: first, we have the more expensive physical robot arm, which is the gold standard and is what experts use in industry: in an ideal world, every student would have access to one of these. Second, we include a relatively affordable AR version of the robot, with the main cost being the hardware cost for the headset and the time spent developing the software for it. To demonstrate the usefulness of the system as an effective engineering education tool, it is only natural that we measure what impact the tools have on the students' learning outcomes.

To this end, we formulated two main research questions which are underpinned by student motivation:

1. What aspects of the active learning programming activities (desktop robot) would the students find motivating?
2. What are the differences between the reinforcement tools (AR robot and physical robot) in motivating the students?

2 Background

2.1 Robots and AR/VR in Education

Robots have been used in education to enhance learning experiences and provide students with hands-on opportunities to develop critical skills such as problem-solving, coding, and teamwork (Yuen et al., 2014). In some settings, using robotics projects can foster the inclusion of students with learning disabilities (Daniela and Lytras, 2019; Nanou and Karampatzakis, 2022). In the case of tertiary education, industrial-scale robots are used to prepare students for careers in industry by emphasizing aspects such as hardware, software, and human-machine interfaces (Nagai, 2001; Brell-Çokcan and Braumann, 2013). However, industrial-scale robots are expensive to purchase. In addition, there is usually some oversight over their usage due to time-sharing and to prevent damage, which prevents "free-play" by students. Some solutions to this include the use of miniature robots and the use of online labs (Mallik and Kapila, 2020; Stein and Lédeczi, 2021). Though these reduce the cost of the setups and allow for more practice time by students, there is a risk that students may not appreciate the true scale of industrial robots and the risks associated with working in close proximity to such robots. AR and VR technologies can be used in conjunction with hardware labs to provide immersive and interactive experiences for students, allowing them to visualize and manipulate complex concepts and equipment in a safe and controlled environment while making it possible to partake in frequent and experiential learning activities (Rukangu et al., 2021; Cassola et al., 2021). The advances in the hardware sector have made AR/VR headsets available to consumers, and researchers are exploring their suitability in tertiary education. A growing body of work shows that AR/VR might be sufficient in replacing tangible experiments (Franzluebbers et al., 2021; Knierim et al., 2020). In contrast, other works do not point to that success (Peeters et al., 2023). This mixed outlook brings out the need to further explore the suitability of AR/VR in education, particularly for labs with substantial moving mechanical components, such as industrial robotics. Furthermore, applying intervention strategies during the earlier years of engineering school has been shown to increase student retention (Krause et al., 2015) and student success (Peuker and Schauss, 2015). In this work, we aim to introduce early-year students to a complex topic - robot programming - to motivate them while studying the suitability of AR/VR technology for advanced laboratories.

2.2 Conceptual Framework: The MUSIC® Model of Motivation

In order to maximize the number of factors related to student motivation that our study captured, we selected the MUSIC Model of Motivation. The MUSIC Model asserts that student motivation to learn—i.e., to engage with learning activities—can be explained through five empirically investigable variables, each derived from other theories of motivation in educational psychology literature, described in Table 1. For readers interested in a more comprehensive

Table 1. MUSIC Model components and their theoretical roots

MUSIC Component	Definition	Theoretical Roots
E(M)powerment	The extent to which students believe they have meaningful control over their learning.	Self-determination theory (Deci and Ryan, 2000), particularly the importance of autonomy to intrinsic motivation (Reeve and Jang, 2006).
(U)sefulness	The extent to which students believe the material will be useful to them.	Future time perspective theory (Simons et al., 2004) and the utility value construct of expectancy-value theory (Wigfield and Eccles, 2000).
(S)uccess	The extent to which students believe that they can be successful if they put effort into a learning activity.	Ability beliefs, including self-efficacy and competence perceptions (Schunk and Pajares, 2005), and the expectancy for success component of expectancy-value theory (Wigfield and Eccles, 2000).
(I)nterest	The extent to which students find learning activities interesting and enjoyable, both in terms of short-term attention (situational interest) and long-term intrinsic engagement (individual interest).	The four-phase model of situational and individual interest developed by (Hidi and Renninger, 2006).
(C)aring	The extent to which students believe the instructor cares about their success and well-being.	A variety of literature on the role of connectedness in motivation, including the "relatedness" component of self-determination theory (Deci and Ryan, 2000) and research on belongingness and caring (Noddings, 1992; Baumeister and Leary, 1995).

summary of theories that informed the MUSIC model, see (Jones, 2018). We believe this model is appropriate for our study, as we designed our intervention as a learning activity that requires active student engagement, which is consistent with the MUSIC Model's definition of motivation to learn (Jones, 2009, 2018). It has also been used to study student motivation in engineering contexts, including disciplinary engineering courses (Hall et al., 2013; Smith-Orr and Garnett, 2016), engineering student support programs (Hampton and Morelock, 2015 Published; Lee et al., 2013, 2015 Published), informal engineering learning environments (Akalin et al., 2013 Published; Schnittka et al., 2012), and a senior capstone course (Jones et al., 2013).

3 Implementation

The system implementation and description can be split into three logical parts:

1. Desktop programming interface
2. AR reinforcement system
3. Physical robot reinforcement system

We implemented all the parts in the system so as to minimize the differences between the three sub-systems.

3.1 Desktop programming interface

The desktop interface was implemented using Unity 3D engine and C# language. We replaced Unity's in-built physics system with a custom physics engine (AGX Dynamics) to make the simulations more realistic. AGX Dynamics is a high-fidelity modelling suite that allowed us to model and simulate the system with contacts and friction. The user was presented with a log-in screen wherein they entered their participant ID, after which they were led to the tutorial portion of the study. We logged the user ID and stored the user's program in JSON format for persistence across sessions (if, for example, the system crashed during the activity or if the user wanted to review their program after the study). Figure 1 shows the simple tutorial task where the experimenter walked the user through the steps required to program the robot to move a single block to the highlighted position, while Figure 2 shows the more complex task that the user had to complete on their own.

Figure 2 shows the available interfaces and the waypoints. The jogging interface allows the student to move the robot into specific positions, open and close the gripper and pull up the programming interface. This is similar to the controls available when programming a real robot where you can manually move the robot into different positions. The programming interface gives the student the ability to add points and actions to the robot trajectory, edit the trajectory, play back the trajectory and jump between poses of the robot in the trajectory. Finally, the navigation help menu provides an overview of how to navigate in the environment in addition to switching between tasks and resetting the scene and camera views.

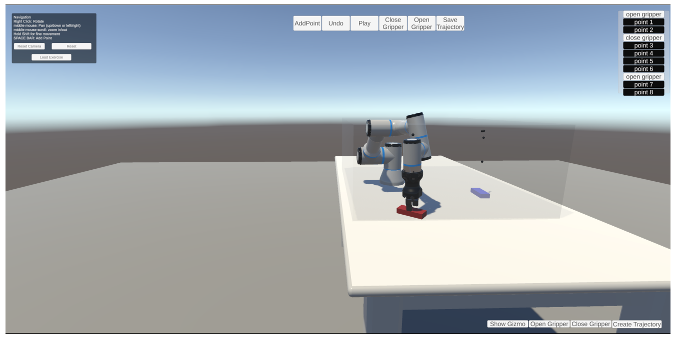

Figure 1. Task1: The student first observed as an instructor completed a 'simple' task of programming the robot to pick a block (red) and place it on the highlighted position (blue), then they completed the simple task themselves

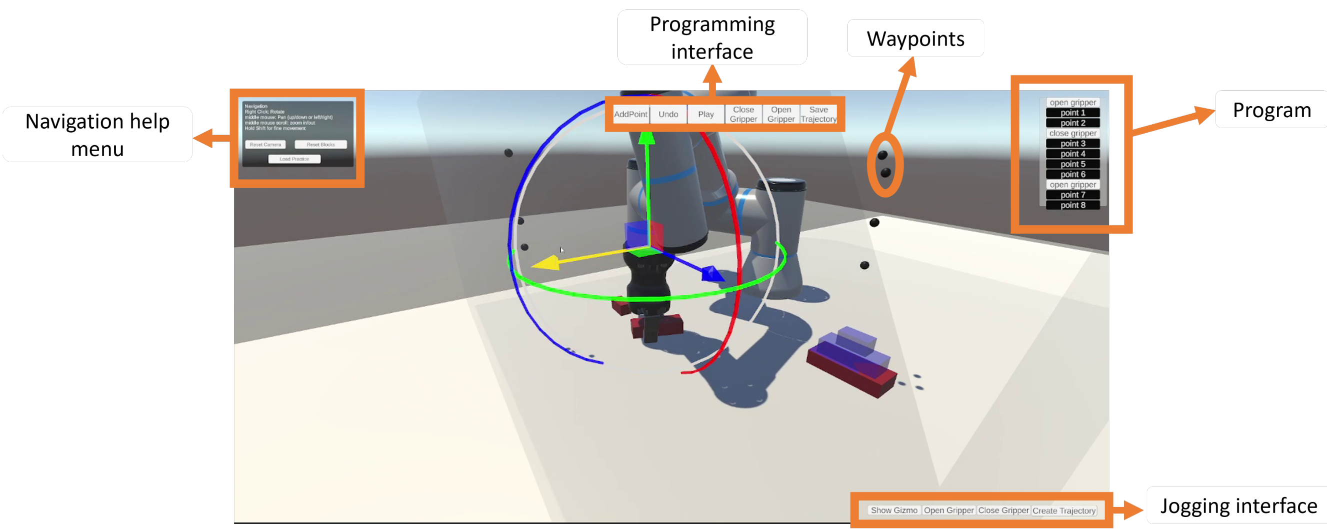

Figure 2. Task 2: The student then performed a 'complex' task on their own. This task required more maneuvering than task1, and the three blocks (red) were initially placed in a variety of positions.

3.2 AR reinforcement system

The AR reinforcement system was implemented on a wired Varjo X3 headset, which offers 70 pixels per degree (PPD) - more than the 60 PPD required for a comfortable experience (Kress, 2019). The programs created in the desktop interface could be run on a computer connected to the headset and viewed in a AR setting, bringing the robot into the real world with the student. Thus, to ensure consistency, the experimenter created one program that was used by all participants in the AR group, although we should note that it would have been possible to observe the AR robot execute the students' custom programs. In addition, the program flowed in a top-down fashion which is similar to how the program that ran on the real UR10 robot looked. Furthermore, the programming interface was designed to reflect how an expert would program the real robot by adding waypoints and actions in between the waypoints.

3.3 Physical robot reinforcement system

The researcher programmed a 6 degree of freedom (dof) UR10 industrial robot arm to demonstrate a pick and place task with three aluminum blocks. The UR10 robot uses a scripting language known as URscript which is very similar to Python programming language. The researchers created the program using the teach pendant shown in Figure 4a.

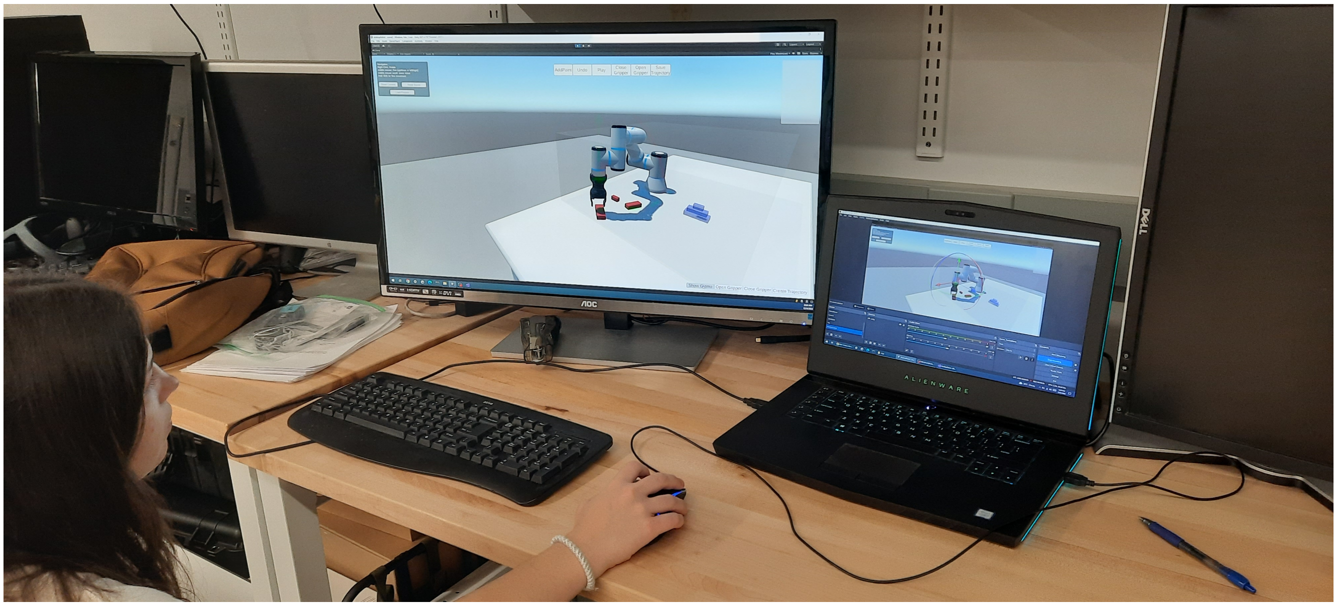

Figure 3. A student programming on the desktop robot interface

(a) The physical UR10 industrial robot arm with one of the three aluminum blocks (far-right) already placed at the drop off location

(b) A student observing the Augmented Reality version of the robot perform the pick and place task on a Varjo XR3 headset.

4 Methods and Context

To answer our research questions, we used a qualitative research design consisting of a screening survey, a series of lab-based activities, and individual interviews following the activities. All procedures were approved by the institutional review board (IRB) at the researchers' institution.

4.1 Sampling

In line with qualitative research best practices, we used a screening survey to purposely sample participants for our study (Krathwohl, 1998). The goal of our sampling process was to recruit eight first- and second-year students with minimal prior robotics experience, with at least 40% of participants being women or non-binary in order to balance the gender representation in the sample. However, given the small sample size of genders within each group, it would not be appropriate to discuss gender differences across the groups. The survey asked students for information such as their identified gender, academic year, level and description of prior robotics experience, and, for safety reasons, any known susceptibility to vertigo or epileptic seizures. The survey was sent to all students enrolled in the introduction to engineering courses in the researchers' College of Engineering. In total, we received 24 responses and selected eight participants to enroll in the study. Half of the participants conducted the desktop activity (described below) followed by observing the real-life robot arm perform an action, and the other half conducted the desktop activity followed by observing the AR robot arm perform the same action. Table 2 shows relevant information about the participants in each treatment group.

Participant ID	Treatment Group	Gender	Year in College
101	Real Robot	Male	1st
102	Real Robot	Non-binary	2nd
103	Real Robot	Female	1st
104	Real Robot	Male	1st
201	AR Robot	Male	1st
202	AR Robot	Male	1st
203	AR Robot	Female	1st
204	AR Robot	Male	2nd

Table 2. Participant Information

4.2 Research Activities

Each student spent approximately 90 minutes engaging with study activities. Table 3 provides an overview of the activity schedule across both groups. First, the researcher gave the students a standardized tutorial regarding how to use the desktop robot app, and answered any questions the students had. Second, participants used the app to conduct what we called the "simple task", which required them to pick up a block with the robot, rotate it to a specific orientation, and place it back down in a specific spot (Figure 3). The purpose of the simple task was to give students a chance to get used to the controls with a relatively easy goal in mind. Students then conducted what we called the "complex task." This task involved picking up and rotating three blocks (one large, medium, and small) that were scattered around in different orientations, and stacking them as a pyramid in a specific location and orientation. The purpose of the complex task was to challenge students to apply their knowledge of the system to a task that is more involved and builds upon itself.

Once students finished the desktop app programming tasks, the researcher then demonstrated the complex task being completed by a life-sized robot arm. The nature of the robot arm (a physical arm (Figure 4a) vs. a virtual arm (Figure 4b) in an AR environment) depended on the student's treatment group. The goal of this activity was to observe motivational differences in engaging with a real robot arm versus a life-sized AR recreation of a real robot arm. Finally, after a short break, the researcher collected data via an individual interview with each student.

Study Activity	Duration (minutes)
Researcher gives tutorial on how to use desktop app	15
Student works through simple task	15
Student works through complex task	20
Researcher demonstrates complex task with real/AR robot	10
Short break	5
Researcher conducts individual interview	25

Table 3. Schedule of activities for both treatment groups

4.3 Data Collection

We collected data via individual interviews using a semi-structured interview protocol based on an existing MUSIC Model protocol from Brett Jones' MUSIC assessment guide (Jones, 2022) and refined with guidance from (Patton, 2002). The full interview protocol is available in Appendix A. The purpose of the interview protocol was to identify what aspects of the research activities students found motivating and why. Interviews lasted approximately 25 minutes and were audio-recorded for transcription. Recordings were transcribed by the parrot.ai artificial intelligence service; researchers retained the original audio files to allow them to verify the accuracy of transcription during analysis.

4.4 Data Analysis

Data analysis was conducted in the MAXQDA qualitative data analysis software, using processes established by (Miles et al., 2014). Particularly, we coded the interview transcripts using a mix of open and a priori codes. As we approached the study with no presumptions about what students would and would not find motivating, we used open codes to identify what aspects of the study experience they described as being motivating. We then used a priori codes consisting of the five MUSIC Model components to classify which aspect of motivation the participant described the activity as affecting.

Once each interview was coded, we used MAXQDA's visual analysis tools—particularly the Code Matrix Browser and Code Relations Browser—to looks for patterns in how each motivating aspect of the study appearance related to each component of the MUSIC Model, as well as to look for differences in motivation-related experiences between the two treatment groups. Doing so allowed us to answer both of our research questions.

4.5 Limitations & Appropriate Interpretations

The primary limitation of this work is the sample size associated with the study. Qualitative research intentionally uses small, purposefully selected samples in order to allow researchers to explore each participant's experiences in-depth (Miles et al., 2014), and there is no generally applicable rule about appropriate qualitative research sample sizes. Rather, qualitative research often proceeds in waves of iterative data collection and analysis until the researchers achieve "saturation": the point at which introducing new data does not change the study's results Green et al. (2007); Strauss and Corbin (1998). However, achieving saturation is a time-intensive process, and like all studies, the design of our research was bounded by the resources available to us (McGrath et al., 1982). Particularly, this study was conducted as the main component of a semester-long, self-contained educational research training experience for this paper's first author. We scoped the study's design and intended impacts based on the time constraints of this arrangement.

Accordingly, we encourage readers to interpret the results of this study as a preliminary window into what factors mattered to motivate students to engage with this novel introduction to robotics programming. We acknowledge that our findings are not generalizable to larger populations of students, but we also believe the patterns we saw within our sample have salient implications for the use of this type of intervention for early post-secondary robotics education. In keeping with qualitative research best practices, we include a detailed description of our intervention and many direct quotes from our participants so that readers can decide whether or not our results could transfer to their own robotics education contexts (Borrego, 2007; Leydens et al., 2004).

5 Results

To answer the two research questions introduced in section 1, we focused on trends in motivation across both the AR and physical robot arm groups, as well as differences between the two. Based on the interviews, we found three overall themes in what affected students' motivation: (1) the design of the desktop programming interface; (2) the structure of activities around the desktop programming interface; and (3) the nature of the reinforcement system (AR vs. physical robot).

5.1 Design of the desktop programming interface

Participants across both groups expressed admiration toward the interface's design. For some, it was because the manner of interaction mirrored some commercial software they had previously used. For others, it was because the interface gave them comfort and mobility in the environment as they carried out the block-stacking tasks. These observations can be attributed to the interface's functionality. However, some users mentioned that they appreciated how closely the interaction in the exercise scene matched real-world physics and how it did not feel scripted or pre-programmed. Also, some liked the interface's design (describing it with words such as "awesome" and "cool"), or described feeling like they were playing a game. These observations can be linked to the aesthetics of the interface, the realistic physics engine used to simulate motion, and the game-like design of the scenarios. As one participant said:

> I would say [I was] motivated, I mean I wasn't bored or anything like that. It was presented in a game format [...] I was just moving the little blocks around, so that was fun. (202)

Overall, the comments about the interface's design strongly corresponded with the interest component of the MUSIC model.

5.2 Structure of activities around the desktop programming interface

All participants reported feeling very motivated after completing the block-stacking assignment effectively by aligning the end position of their blocks with the exercise pyramid. The participants appreciated having enough time to do the task multiple times until they were satisfied that their program could appropriately stack the blocks. In addition, other participants appreciated being able to play with the tool and receive a tutorial from the experimenter before having to program the robot independently. Finally, some participants mentioned that the independent programming exercise at the end motivated them because it allowed them to practice and showcase the skills they had learned. Below are some excerpts from students appreciating being able to get it right:

> [...] And so then when I got [the solution] wrong, you asked me if I wanted to retry it, [and] I wanted to get it right. Like I just, I wanted it to be perfect. So that was exciting. (103)

> What really made me feel successful was playing back the waypoints that I set up in here and out there and seeing it all come together and work, that was really gratifying. (201)

Overall, the application of the tool corresponded primarily to the success component of the MUSIC model, and secondarily to its empowerment component.

5.3 Reinforcement: AR Robot vs Real robot

The groups differed in their motivation-related perceptions of the reinforcement activity. The participants in the physical robot group reported being able to link their efforts in the desktop tool to the actions of the real robot. Some of them were cognizant of the speed and accuracy afforded by the robot arm and were able to associate this with ways in which the robot could be used to solve problems in the real world. One student said:

> My key takeaway is I still think robotics is very fascinating. I think the things that you can do with it are very impressive and the fact that you can take something virtual and make it so efficiently and precisely done in the real world is a very cool concept to me. (204)

Another participant spoke on the applications of the robot in the real word:

> I think it's interesting to see because we all know robots can replace humans, but it's interesting to see how it can be used to cut down time. For example, in research, instead of you doing things manually you can get a robot to do things like pick up some things and do some things [you're] doing in a process. So you don't have to do it like 100 times. So it's just interesting to see that. (203)

Participants in the AR robot group reported the experience as being highly novel to them, as one student puts succinctly:

> It was nice. I've never used VR so it was cool seeing it. It was really interesting like seeing it interact with the blocks like not just on a computer screen. [...] and knowing I programmed it in that sequence was cool, seeing it come to life. (102)

Some participants in the AR robot group had some difficulty tying the experience with real world robots. One student comments on their perception that the AR robot arm was an oversimplified represented on a physical robot:

> Well programming a real [robot arm] would take much more work and be much more difficult. But I think if given enough time, I could learn how to do that. Since everything I learnt was at the beginner level, I'll definitely remember that in the future if I ever do that. (104)

Students reinforced with the physical robot has no such reservations, as one student's comment demonstrated:

> It mainly just showed me that whatever I can do virtually I can do physically too. So when I watched the robot arm do pretty much the same thing I had done in that program, it made me feel confident that if I wanted to do something with the robot arm, if I wanted to seek out a career or something in robotics, then that is the kind of work that I would probably be doing. Not necessarily all the work, just working in the program might obviously be doing programming stuff too, but at least that aspect I have confidence in myself now. (204)

Overall, students in the AR robot arm group reported the interest portion of the MUSIC model as a major driver of their motivation, with novelty being a big driver of this observation. By contrast, students in the physical robot arm group commented more on the Usefulness portion of the MUSIC Model, being able to more easily connect the experience to real-world robotics. We observed similar levels of scoring in the success and empowerment components of the MUSIC model in both reinforcement groups.

6 Discussion

The implementation of a desktop robot programming interface for active learning coupled with observing a programmed life-size robot arm was very encouraging. Results indicated the presence of strong motivating factors that cut across the board from the 2D interface to the 3D environments. In addition, the similarities in motivating factors in both the AR and physical robots activities point towards the possibility using either as the reinforcement tool. We view this outcome as encouraging for the accessibility of robotics education, as a headset through which to experience the AR robot arm is several thousand dollars cheaper than purchasing a real robot arm for educational purposes (and could be adapted to mobile devices for even cheaper.) However, there were interesting differences between the two that warrant further investigation before we get to that stage. In particular, the two modalities of seeing a life-size robot arm in action were motivating in different ways. When the AR robot was used for the observation part, students found it highly **novel**, in fact all the participants in the AR group commented on its novelty, compared to only 1 of 4 in the physical robot group. The students that observed the physical robot for the reinforcement part were able to readily link the experience with **usefulness** and they were able to draw parallels with real world applications. In general, motivation literature suggests that usefulness is a more potent motivational factor compared to novelty-driven situational interest (Jones, 2009; Hidi and Renninger, 2006). Accordingly, if the AR robot arm were to be used to introduce students to a life-size robot arm in action, instructors may wish to introduce other real-life elements of robotics (smaller real-life robots students can tinker with, or examples of what real-life robot programming looks like) to improve student perceptions of the usefulness of the learning experience.

The desktop robot played a foundational role in the study because the students used it for active learning before they observed a life-size robot arm. Overall, students associated the desktop tool with the interest part of motivation in the MUSIC model; particularly, the students found the interactivity and game-like design of the interface to be a major motivating factor. In addition, the students reported feeling the greatest amount of success when they were able to program the desktop robot to perform the stacking tasks. Motivation literature—especially around game-based learning—has highlighted the importance of low-stakes play and early experiences of success in building student motivation and self-efficacy (Jones, 2009; Schunk and Pajares, 2005; Plass et al., 2015), emphasizing the importance not only the design of the desktop app, but also how it is used. In implementing the desktop app into a classroom, it would be vital from a motivation perspective to do so in a way that allows students the time necessary to play, experiment, and successfully complete the tasks assigned to them.

The desktop robot was designed as a readily available learning tool that introduces the major concepts of technical industrial robot arm programming, that is, creating a trajectory, evaluating the real-time performance of the robot arm across a variety of metrics (like accuracy and speed), and obstacle avoidance. Although a 2D interface and lacking the depth associated with the real world, the desktop version serves the purpose of introducing students to the concepts listed above as a precursor to interaction with a life-size robot arm in the form of an industrial robot arm in physical form or in AR. The life-size robot arm allows the user to apply 3D visual cues on the robot trajectory in the real world and reinforces the concepts picked up in the 2D robot exercise. In other words, the 2D desktop robot serves to lay a programming foundation for the student while the life-size robot arm (whether AR or physical) reinforces these concepts in a workforce-like setting. Conceptually, it is akin to a flipped classroom model where the learner interacts with the course material on their own time (programming on the desktop version in our case), and filling in their knowledge gaps at their own pace before practicing the concepts with an instructor present. **We are happy to share the desktop app and AR robot arm modules upon request**, and encourage interesting instructors to make use of them as a way to introduce robot programming to engineering students.

7 Conclusion

In conclusion, the desktop robot interface, though lacking in some realism aspects, was found to be a useful tool in motivating students. However, we need to be cognizant of the fact that the design of such a tool and its implementation in a learning setting plays a role in motivating students. The AR and physical robots were found to be motivating in different aspects: the physical robot was stronger than the AR robot in the usefulness category while the AR robot was stronger in the novelty category. Overall, the motivating factors were similar in both life-size robots and they might be used as drop-in replacements for each other, or in conjunction with one another.

A limitation of this work is that it was a proof of concept and was not used to teach students as part of an engineering course, therefore, it lacks ecological validity. Furthermore, given the small sample size of genders within each group, we could not discuss gender differences across the groups. Finally, in order for the tool to be integrated into an engineering course, it is essential to consider accessibility and inclusivity by incorporating Universal Design for Learning (UDL) principles. While the tool was designed to provide greater access to a realistic robot programming learning environment, it could be designed to more equitably reach a wider range of students through features such as the use of hand-held tablets for AR to increase accessibility or the use of haptic, sound and visual effects in the application.

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Appendices

A Interview Protocol

Thank you for taking part in the study and I hope you enjoyed programming the robot. This is the last part of the study, and we will be interviewing for around 25 minutes to get your thoughts on your experience during the robot control activities. You have received a consent form to sign, which indicates your consent to this interview. The interview will be recorded.

1. (Icebreaker question #1) Tell me a little bit about what you'd like to do once you graduate.
2. (Icebreaker question #2) We would be interested in knowing what inspired you to participate in this research. What about it appealed to you?
3. (How motivated) First, how motivated were you to engage with the activities we did today?
4. (Why motivated) Second—and this is the main question—what are some things about the activities we did today that helped motivate (or demotivate) you to stay engaged?
    (a) How did you feel about experiencing the real-world robot arm example (in-person/via virtual reality)? How motivating was that experience in terms of wanting to learn more?

(The following questions are intended as follow-up questions if students do not touch on them when answering Question 4. These questions were adapted from (Jones, 2022).)

5. (Usefulness setup) What were your key takeaways from the activities?
6. (Usefulness) What did you find useful about the activities?
7. (Success) What made you feel successful during the activities?
    (a) How did the activities affect your perception that you could be successful engaging with robotics in the "real world"?
        i. How did seeing the life-size robot arm in action help with this perception?
8. (Interest) What did you find enjoyable or interesting about the activities?
    (a) How did the activity(s) relate to your personal interests?
9. (eMpowerment) What meaningful choices did you have when completing the activities?

(The following questions are wrap-up questions to be asked in the last 5-10 minutes of the interviews.)

10. What could we have added or done differently in these activities to help motivate you more?
11. (Back pocket question) Okay, you have been very helpful. Any other thoughts or feelings you might share with us to help us understand your experience with programming the robot and how it affected you?
12. Do you have any questions for me?