Student motivation in virtual laboratories in bioengineering courses

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***Abstract*—This research work-in-progress paper displays research work in the area of online laboratories. This study examined the use of a desktop-based virtual environment that emulates an instructional laboratory experiences in the field of bioengineering, more precisely in the area of tissue engineering. This virtual laboratory was used as a homework activity in an undergraduate engineering course at [university] with in total 43 students. The major goal of this research work was to investigate the impact of this virtual lab activity on the students' overall motivation. Both quantitative and qualitative research methods were applied during the study in form of a post-intervention survey and additional post-intervention interviews with selected students. The interview results are the focus for this particular paper. The interview protocol was informed by Jone's MUSIC model motivation. The interviews revealed significant insights into the students' motivation in context with virtual laboratory work and also offered a general understanding of the students' perspective on virtual, instructional laboratories. Preliminary qualitative analysis discovered that students found the simulation to be very useful to repeat lab procedures. Using the MUSIC model of motivation framework, the qualitative analysis shows that the students appreciate the online simulation in terms of a method to improve understanding but do not find this as a full replacement for hands-on, traditional labs.**

Keywords—virtual laboratory, motivation, online learning

I. Introduction

One challenge for biological engineering educators is that bioengineering is a relatively new and broad discipline that integrates a diverse array of knowledge from the basic sciences and engineering sciences towards application in the biological and medicinal fields. Due to a variety of possible career outcomes and limited department resources, it is particularly challenging to create a single undergraduate curriculum that covers all of the technical skills spanning the entire biological engineering field in hands-on laboratory course settings. Hence, it is imperative that university engineering departments seek alternative methods to deliver real-life applications of classroom concepts [1, 2]. In addition to that, bioengineering educators at many institutions face a variety of logistical challenges in implementing hands-on bioengineering labs, such as limited campus space and expensive equipment that are not shared with other engineering disciplines (cell culturing hoods, incubators, etc.) [3]. Therefore, it is believed that the implementation of alternative laboratories could fill this educational gap.

Due to the previously stated challenges, the biological engineering education community could benefit greatly from the implementation of virtual labs. As such, interest in the development and usage of simulated, virtual lab sections has risen, even before remote instruction mandates in reaction to COVID 19. While these lab experiences offer economic benefits to educational institutions and are more convenient for students to access [4], the exact educational outcome and value of simulated labs, especially when compared to traditional hands-on labs, are still unclear and depend heavily on how they are imbedded in the overall pedagogical course design.

This project seeks to answer the broad question, "How do virtual, simulated lab sections impact student motivation in a bioengineering lab section?". Therefore, this work aims to provide a case study on how the implementation of a commercially available simulated lab alters the motivation of students in a bioengineering course. We collected both quantitative and qualitative data to answer three research questions: 1) How well does the virtual lab intervention work for students in terms of the simulated lab experience?, 2) How do bioengineering students experience disciplinary-specific virtual labs?, and 3) How do those experiences inform us on the student motivation?

The quantitative data has been discussed in [5]. By utilizing the MUSIC Model of Academic Motivation [6, 7] as a theoretical framework, we aim to pin down the social realities surrounding simulated bioengineering labs, clarify the unique motivations of bioengineering students, and provide vital information for the national discourse of proper bioengineering curricula development. The theoretical framework of the MUSIC model informed both the development of our research tools and the interpretation of the gained data set.

II. Prior work

A. Research on virtual online laboratories

Online laboratories have the potential to overcome drawbacks of classical hands-on and in-person labs [4, 8]. In particular, for the area of bio and chemical engineering, in which lab courses are both vital for the student's practice-related skills development and highly resource-intensive when it comes to larger class sizes, online laboratories can offer benefits for the curriculum development. Benefits also include cost-efficiency for laboratory work, flexibility in varying the experience, multiple user access, damage resistance, user safety, and accessibility of experimental setups; all highly relevant for bio and chemical engineering lab instruction [9-13]. However, disadvantages include the complex development process for high-quality online laboratory infrastructure, a potential cognitive disconnect between the real-world and virtual experience in terms of the user's seriousness, and a resulting lack of carefulness among the learner [4, 14, 15]. Studies demonstrate that online labs can have equal or even better impacts on learning outcomes than traditional hands-on labs [4, 15-19]. Additional studies show that online laboratories can be efficient tools for engaging engineering students with lab-based learning experiences and practical tools, stimulating autonomous learning and offering practical problem-solving experiences and improving student motivation [20, 21]. The latter is the focus of the presented study. It also needs to be mentioned that beyond the above-mentioned potential advantages and disadvantages of instructional online laboratories, the empirical underpinning of the effectiveness and efficiency of online laboratory-based learning can still be seen as somewhat weak.

Even though literature now includes many case studies in this field, most of these studies still focus on the presentation of the technical development of respective instructional labs or an evaluation-based assessment instead of theory-driven educational research, primarily using student feedback or perception as the only data source. Hence, the work-in progress study presented here, tries to approach instructional online laboratories from a theoretical perspective and uses the MUSIC model of motivation in learning as a theoretical lens.

B. The MUSIC Model of Academic Motivation

Jones' MUSIC Model of Academic Motivation is utilized as a theoretical framework for the presented study. This model is backed by a variety of resources to ensure proper implementation and is made to assess specific elements of a course or activity [6, 7]. The MUSIC Model of Academic Motivation derives from separate motivation theories used to create it. This model brings those motivation theories together and combines them into one single very practice-related framework. In this context, MUSIC is an acronym for the five key principles that instructors need to consider when designing instruction: 1) Student e"M"powerment, 2) activity "U"sefulness, 3) "S"uccess in the course, 4) student "I"nterest towards the content, and 5) belief that the academic structure "C"ares for student well-being. By combining separate motivational theories and focusing on the five presented key aspects, the MUSIC Model of Academic Motivation can pinpoint what aspects of motivation can best be improved in the investigated online laboratories. The work presented here builds on another manuscript presented at an earlier ASEE conference, in which the quantitative data was presented. In the following, we will briefly summarize the results presented in that other manuscript [5].

C. Prior work at the University of Georgia (UGA) in particular relevant to this study

This study expands previously published work for which we introduced an entirely virtual tissue engineering lab simulation (see III for details) to a senior-level undergrad course at the College of Engineering at UGA. The study's intervention was placed within a tissue engineering course that did not have any type of lab section before the start of the study. A senior-level class was chosen to eliminate any conceptual gaps that students may have with the covered material. Out of the 45 students (male and female) enrolled in the course, 43 participated in the study by completing the virtual lab activity. The lab was completed outside of the classroom as a homework activity for which the students had one week to finish it whenever they wanted. On average, the students needed 32 minutes to complete the full activity. Students had no immediate help from the instructors while going through this intervention, but could reach out to the instructor with questions whenever necessary via mail or during hoffice hours. None of the students reached out to the instructor or teaching assistant with any issues or additional questions during the lab activity.

The described previous study used a quantitative survey after the intervention to understand the students' experience in terms of the lab activity and their motivation [5]. The post-intervention surveys utilized Jones' MUSIC Inventory, which was also developed by Jones to measure the extent to which college students perceive the presence of each of the MUSIC model components during the learning activity [22]. The survey compromises 26 quantitative Likert scale questions (1 lowest possible score, six highest possible score) and six short answer questions. The short answer questions were added in order to get a more in-depth understanding of the numerical data. The students were directed to fill out the MUSIC Inventory, which was administered through an online survey tool directly after completion of the intervention activity.

The results of the numerical portion of the survey showed a positive effect on the students, as the average score for all five factors was 4.38 (empowerment) or above. We hypothesized that the empowerment category would score the lowest, as the laboratory simulation is heavily pre-structured and would not allow a lot of "free experimentation". However, the additional data revealed in the qualitative short answers that students had multiple options throughout every step of the experiment, including wrong answers that would derail the experiment. This sense of choice and the need to critically think, rather than just simply clicking through an animation, resonated with students' sense of empowerment in particular.

However, while giving a good feel for what was happening during the intervention in terms of student motivation, the quantitative data only allowed a surface-level understanding of the students' experience. To gain deeper insights into the students' experiences, we performed semi-structured interviews with selected students. The work presented in the following builds on that additional qualitative research data in the form of transcribed student interviews.

III. Research Design and Plan

A. The Tissue Engineering Lab

The chosen simulated lab intervention was a tissue engineering entirely virtual, desktop-based laboratory simulation developed by the company Labster [23]. In the simulated laboratory, students immerse in a real-world scenario by being prompted to help treat an injured athlete. To accomplish this, students must develop a scaffold to help

Identify applicable funding agency here. If none, delete this text box.

regenerate the athlete's cartilage. Students achieve this by relying on their background in chemistry and material science. In particular, the students perform two crosslinking experiments, ionic and Michael addition methods, to create the hydrogels scaffold. They have to choose the polymers they want to use in the experiment. At the end of each experiment, they watch the chemical or physical reaction between the polymers that take place inside the hardening hydrogels [23]. *Figure 1* shows a screenshot of the laboratory environment into which the students were immersed using their own computers.

Figure 1: Screenshot of the LABSTER tissue engineering laboratory simulation [23]

The Labster tissue engineering activity was a perfect fit for the class and our study as it covers material relevant to both bioengineering and biochemical engineering students, which were the two majors present in the examined course.

B. *Study design and methodology*

To investigate the student perspective in the above-described context and to answer the posed research questions, we added a qualitative approach in the form of semi-structured student interviews to the overall study design. The interview protocol was also informed by the MUSIC model of motivation. The survey questions covered all five presented key factors in context with student motivation.

We performed in total five interviews with students (2 male and 3 female) from the course. We selected the students based on their answers to the open-ended questions of the survey. We particularly chose students who displayed a satisfying level of deeper thinking about the intervention activity itself and who shared those thoughts in their survey answers. Interviews were performed in late Fall semester 2019, just after the tissue engineering course completion, and early Spring semester 2020. The interview length ranged from 32 minutes to 36 minutes.

In order to analyze the interview data, we transcribed and anonymized interview recordings and numbered the transcripts from S-1 to S-5. To develop a deep and thorough understanding of the student perspective, we first applied a topic coding approach [24], in which we identified passages across all five interview transcripts that were linked by a common theme or idea, allowing us to both highlight the student perspective on motivation and the online lab. In a second coding step, we matched the found themes with the MUSIC model categories to highlight our results in that regard and clearly link our research with the existing theory. In the following, we will display the results developed so far by our qualitative approach using the MUSIC model categories as a guiding structure.

IV. Results

A. *Empowerment*

A large amount of data can be connected to the previously mentioned definition of "empowerment" (ranking 2nd in terms of total code count). With the term empowerment referring to how "in-control" a student might feel while performing a specific task, or in this case, the virtual experiment, we can see a noticeable difference in students' attitudes when comparing the virtual experiment to an in-person lab. The virtual lab offered was linear primarily, leaving students in a spot where the lab itself told the student what to do next, not the student figuring it out for themselves. When asked, the student in S-5 preferred a less guided experience. They said:

- *"Having that direct person do it for you can be nice, but I think it gives a better learning if you do it yourself and figure it out. I think I would prefer to do it myself though. I can learn by myself."*

Also, there is a palpable sense of relevance that is missing when doing the virtual lab as opposed to an in-person lab. This can be explained by the fact that their mistakes didn't mean as much, and they could simply redo that portion of the experiment, unlike in a real lab environment. These results create a contrast to the "Success" category, which will be explored further down below.

B. *Usefulness*

The MUSIC model category "usefulness" is represented by the most significant amount of interview excerpts (ranking 1st in terms of total code count). Usefulness is in reference to the material being applied to a student's life outside of the experiment (i.e., future studies, informative learning, preparation for real lab, etc.). The interviewed five students found the simulation to be very beneficial in a learning sense, but note that it would be even more helpful for a student who is not as versed in lab material similar to this as the interviewees were. The student in S-1 commented the following about the benefits of the virtual lab:

- *"I think for other people in the class, it's very useful. Because a lot of people that I'm around, like I said earlier, are in industry and not necessarily research. So, it would be really useful. People that haven't had that research experience would like to figure out what's going on."*

The consensus is that the virtual lab would be an excellent pre-lab learning experience to prepare a student for a real lab experience but could not replace the hands-on, in-person experience offered by a more traditional lab.

C. *Success*

"Success" attempts to measure the level of achievement the student felt while performing the virtual lab and ranks 4th among the MUSIC model categories in terms of representation by the number of codes. Although the amount of codes under success is a smaller number, this does not reflect the amount of success the students felt while completing the virtual lab. Students felt that being guided through the experiment with small quizzes to check up on their progress was a good boost to morale and showed that they are comprehending the content. The interviewee in S-4 mentioned the following in this context:

- *"I think that that made me feel successful because I realized that if I had done that in real life and I followed everything correctly, it should work. So, I think that was helpful instead of just saying, okay now do this. It gave you like a congratulations notice that you did it right."*

While students felt like they might have learned something informative, it was clear they did not feel like they were bettering themselves for an in-person lab environment where their benchtop skills could be developed. This could be explained by the fact that the interviewed students were versed in in-person lab work even before this virtual lab experience (see the following category).

D. Interest

"Interest" pertains to a student's desire to learn or do more with the experiment or a prior interest in the material and/or lab (ranking 3rd among the categories). In the case of the five students interviewed, they were all very involved with other research and already intrigued with the contents of the lab, so a virtual simulation had their interest from the start. A quote from S-2 support that:

- *"I did this because it was... I had been needing to sort of do this work and research anyway, for my own research. And so, the timing of doing this, and then for me planning my upcoming research and what my next steps were."*

In the case of this particular lab, it went into deep detail around the subject, so the students were able to take notes and learn more for their own personal research. All five of the students never found the lab boring at all. All five expressed their interest in seeing similar labs integrated into other courses in the future.

E. Caring

The category "Caring" is in reference to the impact a professor/TA (or lack thereof) has on the student while performing the lab experiment. "Caring" by far has the least amount of qualitative data associated with it, which makes sense considering there is no professor/TA present during the virtual lab. When asked if the lack of a professor/TA was noticeable, the interviewee in S-3 stated the following:

- *"I think I was able to pretty much, it was really straightforward about what needed to be done in the simulation and all the material was pretty clear. So, I don't think there was any point where I would need an instructor, like their assistance right away."*

Students noted that the lack of a professor/TA was only noticeable when they would get stuck, but a robot was placed inside the simulation to help guide the student. It is worth noting that the students found the robot somewhat annoying and nowhere near the value of a professor/TA, though.

F. Further minor sub-categories

There are other takeaways from the qualitative data aside from the MUSIC model of motivation. These categories are still to be explored more in detail to develop a thorough understanding of the categories meaning themselves and their impact on student motivation. Listed below are those minor subcategories detected in the interview transcripts, including a brief description:

- A Replacement for In-Person Lab: All five students found that the online/virtual lab would be very useful as a pre-lab or a way to improve the understanding of a student who is inexperienced in the given subject, but it cannot replace an in-person lab hoping to obtain the same benefits.
- Convenience: It was widely appreciated that the students were not tied down to a specific lab time and location. The flexibility of accessing and doing the experiment whenever and wherever they want was a nice plus.
- Improving Understanding: Often connected with the "Usefulness" category, students felt the experiment was beneficial in helping them improve their understanding of the lab content. One interviewee actually mentioned that they used the lab as a helpful recap of the overall lab procedure and made notes throughout the lab experience, even though this was not a requested part of the activity.

V. Discussion

By taking our qualitative data and relating it to the MUSIC model, we were able to see different aspects of motivation on display and how the virtual labs affected that. From our data, it is clear that the main factors playing into motivation through this specific type of online labs are usefulness, empowerment, and interest. Students found the lab useful in a learning sense but did not think this was a suitable replacement for a hands-on, in-person lab. The five students selected were also involved in extracurricular lab activities, which can potentially lead to a higher rate of interest in the subject matter. This higher overall interest may have led to a higher reported interest in the virtual lab. The students seemed relatively pleased with the virtual lab and are interested to see how more of them could be implemented in a variety of different courses. The students found the lab to be useful in a learning sense where they could improve their theoretical understanding.

Looking critically at our chosen approach and methodology, we can observe that we were able to understand the student perspective to a good extent. The MUSIC model also proved to be a very helpful theoretical lens to develop the research instrument and understand the qualitative data. Future work will focus on engaging even more in detail with the student interviews. To expand our database, we conducted three more interviews in the late Fall semester 2021 and plan on applying our qualitative analysis approach to them, too. This would allow us to expand on the current data we have, along with finding new data to further understand motivation in virtual labs, specifically now with two years of online teaching. The students' general experiences may have impacted their sense of motivation in context with such virtual laboratories, too. This may also lead to insights we have not been able to obtain with the interviews examined so far.

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