An Exploration of Human Factors That Influence the Acceptance of Technology in Calculus Students

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Studies on the use of technology in calculus courses have focused on the use of different types of technology as learning tools for visualization, representations, and understanding. However, research on students' perspectives about the use of technology in calculus classrooms needs to be expanded. In this article, we interviewed eight calculus students in a US research institution to understand their perspectives about the use of technology. To analyze the data set, we used thematic analysis informed by the technology acceptance model focused on external variables related to human factors. As a result, students identified human factors that may influence their perspectives about using technology in calculus classes such as: their attitude and skills, selection of mathematical problems, feedback, classroom environment, and resources. These findings inform calculus instructors and coordinators about possible considerations before implementing the use of technology in their classrooms.

Keywords: calculus education, students' perspectives, technology to teach

In the last decades, many researchers have explored the use of technology to enhance students' learning experiences in calculus courses (e.g., Ellis Jr et al., 2000; Ferrara et al., 2006; Heid, 1988; Thompson et al., 2013). The use of technology is one of many approaches to target the retention problem of science, technology, engineering, and mathematics (STEM) programs in US institutions, which has been shown to rely on the effective teaching of calculus courses (Rasmussen & Ellis, 2013).

The effective use of technology can promote understanding of calculus concepts by facilitating visualization of structures, representations, and exploration of concepts such as limits, derivatives, and integrals (e.g. Bressoud et al., 2016; Ferrara et al., 2006). Tall (2002) explains that technology facilitates the understanding of fundamental ideas of calculus such as the approximation process and infinitesimals. For example, using numerical and graphical approaches to explore the concept of limits. In addition, the use of technology may build a stronger calculus conceptual understanding by allowing students to explore different ways of reasoning while solving problems (Ferrara et al., 2006).

Many studies have mainly focused on technologies that are used to do mathematics such as graphing or geometric software. While these technologies facilitate the learning of calculus concepts, it is imperative to understand that technology by itself will not ensure an effective learning experience. For example, Takači et al. (2015) found that students' learning about functions and graphs is better when using Geogebra while working in collaborative groups.

In our study, we explore external variables to the technology itself. Specifically we investigate students' perspectives about social aspects that may be controllable by humans when using technology. The research question that guided our study is: *How do students describe the social aspects controlled by humans that may influence their acceptance of the use of technology in calculus classes?* The understanding of these external variables complements research about how specific types of technology can enhance the learning of calculus concepts by providing possible considerations before implementing technology in the calculus classes as a coordinated effort in an R2 institution.

Theoretical Perspective

The Technology Acceptance Model (TAM) provides guidance on how students accept or reject the use of technology in calculus classes (Davis, 1989; Venkatesh and Davis, 2000)

According to this model, understanding a person's acceptance to use technology depends on two key variables: perceived ease of use and perceived usefulness. These determine if a person will accept the use of technology (Davis, 1989). Specifically, if someone thinks a technology is both easy to use and useful, then that person would like to use that technology tool. Conversely, if a person perceives it is not easy or not useful, then will not like to use the technology.

Since 1989, several researchers (e.g., Venkatesh and Davis, 2000) have proposed extensions to these two variables for understanding the complexities of using technology. For example, if a person intends to use the technology and if the person is using the technology, which are commonly known as behavioral intention and actual use. In addition, Venkatesh and Davis (2000) consider external variables that can influence the relationship between the perceived ease of use, perceived usefulness, behavioral intention, and actual use. These variables include social norms, availability of resources, and personal skills.

When considering the teaching and learning of calculus, we consider that these external variables are controllable by either students, instructors, coordinators, or administrators. Thus, they are also considered as human factors. Alomari et. al. (2020) categorize human factors into three main indicators: technological, psychological, and student-instructor interaction characteristics. However, their research identifies positive human factors attributes like attitude, enjoyment, experience, self-efficacy, and promptness that significantly impact user satisfaction and subsequently contribute to the success of learning using technology. Understanding these external variables provide a clearer picture to explore technology acceptance by an individual.

The TAM informs our study as we aim to understand the complexity of students' perspectives toward using technology for calculus classes. Considering the human factors of using technology will facilitate an informed decision-making process for instructors and coordinators to provide students with an effective introduction to new technologies while learning calculus. Specifically, this may help students embrace these technologies as important tools for their calculus learning experience by helping them see these technologies as both useful and easy to use.

Research Methods

To answer the research question, we collected audio-recording interviews from eight calculus students who volunteered to participate in this research study. Previous to the interview each participant completed demographic information.

Participants

Participants were sophomores, juniors, or seniors enrolled in Calculus I, II, or III in a US research university in the Midwest.

The university serves approximately 16,000 students from diverse backgrounds with more than half of the student population being first generation undergraduate students. About 46% of the population is White, 20% Latinx, 17% Black, and 6% Asian.

While reporting on demographic information, one student self-identified as Asian, one as Black, three as Hispanic or Latinx, and three as White. Regarding gender, there were four cis-men and four cis-women. Five participants reported being first generation students and one a non-traditional student. None of the students reported being a veteran or having a documented

disability. Seven of them were in a STEM program and one of the students was a non-STEM major pursuing a middle school teaching license in STEM.

Instrument and Data Analysis

We conducted one hour interviews during the summer 2023 to students who were enrolled in a calculus section in the Spring 2023 semester. Questions of the interview were semi structured and focused on relevancy of the course, policies, resources, and technology. In this paper, we analyzed students' responses related to the use of technology in calculus classes.

The interviews were audio-recorded and transcribed for analysis. Data was de-identified by assigning pseudonyms to participants.

The three authors are all junior faculty who self-identify as Hispanic or Latinx. One is a mathematics researcher with focus on analysis, one is a computer science researcher, and the other is a mathematics education researcher.

To analyze data, the three authors conducted thematic analysis (Braun et al., 2019). The three authors initially coded four interviews guided by the TAM framework and met to agree on a codebook. After creating a codebook, two of the authors coded the eight interviews and met until consensus was reached.

Results of the Research

The categories of the code for identifying the human factors are the students' attitudes or skills, the selection of mathematical problems online, the learning feedback, the classroom environment, and the resources.

Table 1. Human factors when using technology for calculus classes identified by participants.

Human Factors	
Factor	Participants
Students attitudes or skills	Audrey, Ben, Diego, Elena, Josephine, Juan, Kate
Selection of online mathematical problems	Josephine, Lin
Learning feedback	Josephine, Kate
Classroom environment	Ben, Josephine
Resources	Audrey, Diego

Students' Attitudes or Skills

Students' attitudes or skills capture the ways students liked or disliked technology. For example, the level of difficulty with using technology to learn calculus, their familiarity, experiences, and perspectives against or in favor of using technology.

Seven students reported some of their attitudes and skills related to the use of technology in calculus classes. The most popular attitude was related to the use of online homework in calculus classes. For example, Kate thinks online homework is beneficial for the learning experience.

Interviewer: Do you think using technology is beneficial for your learning experience?

Kate: I feel like it has been useful just because chances are that's where the world's going is with technology being more useful. So having those lessons with it is helpful. Though I do, I still always end up like even if the assignment is online, I'll write it out on a paper before I do it because it's hard for me to do it all on the computer.

Interviewer: Okay, yeah, and what kind of technology would you like to use in the calculus classes? I don't know. It can be anything. It can be like a web page, an app, or software.

Kate: It can be useful if we use like graphing apps and stuff. So we can plug in like the equation and get an idea of what it's supposed to look like. Because when there's all those different things in it, it's really hard to visualize the graph and like do it and because there's so many different parts to the equation, it's really hard to graph by yourself. But and then I also I like being able to look up similar examples online that are like I don't even know like some sort of like especially with like trig stuff that's always the trouble with me, figuring out how people, if there's like a sine over a cosine or whatever how people treat that in certain problems and different things.

Kate, sees the use of technology as beneficial for the learning experience when perceiving technology as part of keeping up with the uses of technology in the world and as a tool for learning mathematics. It is interesting to see how Kate connects the calculus learning experience with a more global perspective on how people are increasing the use of technology "in the world". However, it is interesting how Kate still sees a need to work on math problems using paper and pencil before sharing the answers in online homework systems. In addition to the online homework, Kate thinks that the use of graphing apps is important to visualize graphs and to see different strategies when solving mathematical problems.

Students also reported on their familiarity with different types of technology. For example, Juan mentioned using several types of technologies in both high school and college.

Interviewer: Okay, so you have experience with scientific calculators. You also have some experience with online homework. Is there something else I'm missing about your experience with technology in math and calculus classes?

Juan: Umm, sometimes in my calc class as a teacher will like pull up a functions calculator or like a plot system to kind of just see things visually. I think those are nice. But for the most part, yeah, that's pretty much accurate. This is my first time ever having online homework for a math class. For my calc 3 class that I'm taking online right now. [...] WebAssign I think it's called Yeah, it's definitely a Cengage Webassign, yes.

Interviewer: You said something about functions and online graphing. Is that also inside WebAssign?

Juan: No, there are some applications in WebAssign where they can use those for certain problems. But I know like the one I'm using right now, because the one prior I can't use it anymore because a lot of my stuff is like in 3D, so I use 3D plot, personally, but that's not like through the instructor. I forget, there's another popular one. That a lot of instructors have used in my calc 1 and calc 2 experience.

Interviewer: So you do use them for your own learning. Is that correct?

Juan: Yes, I do

Interviewer: Okay, is there anything else that you use? Any other technology that you like to use for your own learning outside of class?

Juan: Lecture videos like sometimes if I need extra help on a certain topic. I'll watch a YouTube video. That kind of goes over it again. I use the online homework, which I like. Actually, I never knew if I would like online homework. But, since I've taken a lot of

physics classes that have used, even in my high school, that have used WebAssign Cengage, and since I'm really familiar with it, I do like it now. Umm, let me think and then. It's nice to have a calculator. No, I think that's all the technology.

In this interview excerpt, Juan mentions using scientific calculators, mathematical software programs and online homework. He has a positive attitude toward instructors using visual representations in what he describes as function calculators that "are nice". This may be a graphing software that instructors use to visualize functions while teaching calculus classes. While he does not explicitly mention familiarity with these technologies, he may be familiar with using graphing softwares as he likes using other three dimensional graphing software programs outside of the classroom that helps him learn calculus. Regarding online homework, Juan mentions that he likes it because he is familiar with the technology as he used it in a physics high school class.

When asking students about using augmented reality in calculus classes most students mentioned unfamiliarity with how this may be used in a calculus class. They admitted they did not have enough information to have an opinion on how it may or may not be beneficial. For example, when asking Diego if using augmented reality would be beneficial, he said "I would say no [...] but I also don't have any experience with it, so I feel like my opinion just isn't too great just 'cause I don't have that knowledge." Later in the interview Diego explains having an open mind to maybe use it if someone explains how it would be useful with some specific examples.

Selection of mathematical problems online

Another human factor mentioned by some students was the way instructors or coordinators select the mathematical problems online. For example, Josephine finds mathematical problems in ALEKS as tedious.

Josephine: [...] Oh, I thought my Mathlab was horrible, but there is another like program like software, it's called ALEKS. Have you heard of ALEKS?

Interviewer: Yes.

Josephine: I hate it, absolutely hate it. I think I was using that app in appreciation for My Mathlab after using ALEKS because I took a trig summer class. But the difference between My Mathlab and ALEKS is that ALEKS will have you do like 30 different problems on a math subject lower than your math subject before you could even start practicing on your math subject if that makes some sense. So I feel like using the computer is just a little bit too tedious and just you know cause math is complicated, yes, but I feel like the computer makes it even more complicated than it needs to be. That's just my opinion as far as technology and math, I don't think math should have nothing to do with it. Well, math [inaudible] with technology, but as far as I'm learning it, I don't think it's necessary. Technology is not necessary for it though. Yeah.

In her interview, Josephine expresses a dislike of using a specific online homework system, however, the reason is related to the problems selected by the instructor. Specifically, she thought it was tedious to work on problems that were (1) not addressing the concept that was discussed and (2) too many. This presents two factors that can be controlled by an instructor: the alignment with the curriculum and the quantity of problems selected. What Josephine is experiencing with the online homework system may be reflecting the drill and train practice about mathematical procedures.

The lack of alignment when selecting mathematical problems online, was also mentioned by Lin when we asked about ideal technologies for calculus classrooms. Lin said not to use online

homework because, in his experience, online homework "wasn't exactly tailored to what they learned for that day. It was more generic for the topic."

Learning Feedback

Students were also concerned about needing more assessment feedback in their calculus classes. Two students mentioned learning feedback as an issue when using technology.

Specifically, Josephine and Kate explained it was difficult for them to know where exactly they had a mistake. For example, when talking about online homework, Kate noted: "[...] it's hard for me to go through and know what I did wrong when it's such a big problem and there's so many little steps that I could have messed up on." While Kate is receiving immediate online feedback on whether a problem is correct or incorrect, she perceives this is not enough feedback. Here, Kate would expect feedback to point out mistakes in her rationale or computations while solving calculus problems.

Classroom Environment

Students reported on the classroom environment while using technology, for example, using a collaborative learning environment, working in small groups, or mimicking other non-math courses' classroom settings.

A student, Ben, noted that he has had a great experience in the college of engineering with collaborative learning when using technology. When asking about recommendations for types of technology we could use in calculus, Ben referred to this experience.

> Suppose potentially having some kind of like a screen that's more of like a table. I don't know what that would be but something that we could all kind of like look down at and kinda talk about like, like I said before, kind of in like that circle, you all kind of look down and kind of have more forward and open discussions versus the way classrooms kind of are, whether you're just kind of staring at the board which is understandably easier but yeah.

Ben perceives that the technological tools available in this engineering class would potentially be beneficial to include in calculus classes. Here, Ben perceives that technology could be used to foster more open discussions in the classroom by using screens and arranging classrooms in circles around those screens. It is worth mentioning that Ben uses the opportunity not only to introduce this as an option to improve mathematical discussions in the calculus classrooms but also to critique that the current classroom setting is traditional and is limiting discussions.

Resources

Participants mentioned that, when using technology, it is essential to consider the institution's available and needed resources. For example, having a computer at home to complete online homework and having access to computer labs in the institution.

For example, Diego agreed to implement technology in calculus classes and referred to resources available at the institution. He mentioned that the institutional access to the internet was pretty good, especially in computer labs. He explained that the institution had computer labs in case "a student did not have those types of resources [personal computer or laptop]."

Significance and Further Research

This study contributes to understanding students' perspectives about the use of technology in calculus classes, including human (students, instructors, coordinators, and administrators)

factors. Specifically, students' skills and attitudes, selection of mathematical problems, learning feedback, classroom environment, and resources.

Students' skills and attitudes toward the use of technology would identify the human factor of the student as a learner. Skills and attitudes may result from their experiences or lack of experience with using technology in calculus classes. Understanding these factors may provide information about possible students' issues when mixing technology and mathematics, which could offer calculus instructors and coordinators targeting tools to overcome them. For example, a possible need to train students and help them feel more familiar with the technology before implementing it.

The selection of problems, learning feedback, classroom environment, and resources are primarily human factors related to instructors, coordinators, or institutions. These factors were mostly perceived as contributors to negative experiences from the students when using technology. Specifically, (1) students perceived that the selection of problems had alignment issues and became tedious because of the number of problems, (2) students perceived a need for more feedback than the correct (or incorrect) feedback in online homework, (3) students perceived a need for restructuring classroom environments, and (4) students discussed issues of accessibility when using technology. Some of these have been shown to be important for students' learning of calculus, such as considering the classroom environment when using technology (e.g., Takači et al., 2015) and their attitudes toward the use of online homework (e.g., Lampe and White, 2023).

Instructors may control the selection of problems, learning feedback, and classroom environment. Some of these issues may suggest a need to provide instructors with technology professional development activities before officially implementing online homework as a coordinated effort, as well as effective active learning practices and curriculum alignment. We must see these findings about learning feedback with caution as these vary in different online homework systems and it would not be appropriate to conclude that all online homework systems lack the feedback students perceive they need. For example, there are initiatives to use artificial intelligence to give more meaningful feedback to students when working on online homework. Future research may investigate students' perspectives about using artificial intelligence to provide feedback on assignments.

Administrators may also control some of the classroom environment and resources needed for effectively implementing the use of technology. While instructors have control over classroom settings, some of this effort relies on classroom conditions that facilitate active learning. In addition, when applying technology, it is important to consider if the type of technology would be available to all students.

Instructors, coordinators, and administrators must engage in open discussions to ensure equitable access to technology for all students, fostering an inclusive and technologically enhanced learning environment in calculus courses.

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