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# Exploring Engineering Students Use of Resources through Study Paths in an Introductory Calculus Course

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## Abstract

In response to high failure rates of engineering students in introductory math courses, such as calculus, a wide variety of interventions have been implemented. Several of these interventions aim to provide students with resources to help them better learn concepts and get continual support as they complete assignments and other coursework. Despite these initiatives, pass rates continue to remain low. We posit that merely the availability of resources is not enough for student success in mathematics courses. Students who lack knowledge of how to use these resources effectively may not necessarily see significant improvement in their math skills and performance. Often, we are unaware of how students use different resources. To address this gap, we explore how engineering and engineering technology students incorporate resources into their study habits for their introductory calculus course. To this end, we longitudinally collected interview data from 14 engineering and engineering technology students enrolled in an introductory calculus course at an R2 institution in the mid-Atlantic region of the USA. These data were analyzed through a combination of thematic and process coding using the analytical framework of Actual Student Study Paths. We found that students broadly followed a learning strategy of three stages: doing problems, checking their answers, then seeking help with these problems. However, students used different resources at different stages. The findings suggest that students place solving course problems at the focus of their study habits, which points to a need for carefully designing course problems in a way that helps students deeply engage with the course content.


## 1 Introduction

Math competency is a vital component of engineering education. All engineering curricula require students to complete introductory college-level mathematics courses such as calculus. These courses serve as the foundation for many higher-level engineering courses. Despite these courses being extremely important, several students struggle to obtain even a passing grade in these course [1]. In explorations of the high failure rates in these courses, several factors have been previously identified. These factors can be grouped into the broad categories of curriculum, pedagogy, and the learners themselves [2]. Examples of these issues respectively are a lack of connection between discipline and curriculum [3], the interaction between student learning styles and teaching styles [4], and student study habits [5].

In response to the issue of high failure rates across multiple generations of engineering students, several interventions have been implemented. These interventions often aim to modify curriculum [3] and pedagogy [6]. These interventions include making changes as to when calculus is taken for specific degrees [7]. Changes have also been made to the structure of how calculus is taught via practice-based learning approaches. In one example, a curriculum was designed around students achieving micro-credentials via projects to demonstrate their understanding of calculus concepts [8]. Other interventions seek to provide additional resources to students to aid their success and learning. These resources include online resources, tutoring, and more [9], [10].

However, prior work suggests that a variety of resources being available to students does not guarantee an improvement in learning [11]. Studies exploring the use of resources in mathematics classrooms show that students struggle to use the resources available to them effectively [12]. These issues can stem from students struggling to determine which resources are relevant to how these resources fit in their study plans [13].

Since students do not always know how to make the best use of resources, they employ trial-and-error techniques. For example, a recent study suggests that students changed how they use resources over the course of the semester [14]. Students generally began by trying to solve problems alone, then drew on more resources depending on their progress. Students also tended to set performance goals for their courses as opposed to learning goals, which is to say, students aimed for exam and assignment grades, which may or may not be the goals set by resource providers for students.

There are various factors that contribute to how students select resources. In one study, Anastasakis et al. [15] investigated what resources students use when they need to solve "real-life" problems in project-based learning. They found that students often preferred to access social resources such as their peers or mentors first. Other related works have also studied how students select between the resources available to them. These works have found that students select resources based on the availability of resource (i.e., what resources are provided by the institution), the nature of course and pedagogical practices (e.g., online, game-based, technology-enhanced, challenge-based), the institutional framework (i.e., the roles and expectations of instructors and students), as well as the goals of the student (i.e., whether the student is trying to gain a mastery of the content or obtain high test scores) [16].

Research has also been conducted into how students use specific resources such as textbooks. These studies have found that students tend to use examples to build up their mathematical understanding as opposed to expository text, and tend to use textbooks more effectively when they are instructed to do so [17]. More recent works have also reported declines in the use of traditional textbooks and textbooks in general [18], [19].

These studies on students' resource use suggest that simply making resources available to students is not enough. Students need to adopt effective strategies to adequately utilize resources in a way that supports their learning. In literature, this is called charting an academic path with the available resources [13]. However, prior work on resource utilization in calculus courses has generally not explored how students actually incorporate different resources in their studies. This study seeks to address this gap by addressing the following question:

> *How do engineering and engineering technology students incorporate resources into their learning strategy?*

## 2 Analytical Framework

To address this research question, we employ the analytical framework of Actual Student Study Path (ASSP). Pepin and Kock [10], [13] coined the phrase Actual Student Study Path to describe how students used and orchestrated resources for learning mathematics. The ASSP provides a method to visualize resources that students access from their perspectives. In the research conducted by Pepin and Kock, students drew out, explained, and walked through their actual study habits and flow of resources to explore how the resources fit into their study strategies. The existence of the ASSP then allows researchers to follow relationship between the study strategies and the learning trajectory of a student, i.e., the increase in competence from the initial lack of understanding to final understanding of the topics at hand.

The use of the ASSP assumes that students take ownership of their learning as they follow their learning trajectory. In one example illustrating this point, van den Beemt et al. [20] developed a framework for Challenge-Based Learning highlighting how the use of learning trajectories required students to manage their learning tasks. It should be noted that the ASSP is not static and shifts, or may shift, over time. The implication of this is that the ASSPs created at a particular time simply capture a student's learning trajectory at that specific moment in time.

The Actual Student Study Path provides a basis for visualizing students' learning strategies and how students incorporate optional resources into their learning strategies. At the same time, the ASSP framework also helps study how the learning strategies (including resource use) evolve over time. This can be achieved by noting how students modify their use of resources. Thus, this approach serves as an appropriate tool for exploring how engineering and engineering technology students incorporate resources into their learning.

## 3 Methods

To address our research question, data were collected and analyzed from students enrolled in one introductory math course. In this section, we describe the research context and methods used for data collection and analysis.

### 3.1 Research Site and Context

The study took place at a private university in the mid-Atlantic region of the USA. The university is classified as R2 (High Research Activity) based on Carnegie Classification of Institutions of Higher Education [21]. First-Year Students at the research site complete a mathematics placement test prior to the start of the semester to determine their math level. Students who perform well on the placement test are placed on a two-course calculus track (henceforth referred to as 2-track calculus), whereas students who do not perform as well on the placement are placed in a three-course calculus track (henceforth referred to as 3-track calculus). Both tracks cover the same introductory calculus material (limits, derivatives, integrals, optimization, series expansion, etc.) over different timelines and credit hours (8 credits for 2-track calculus and 9 credits for 3-track calculus). The study was approved by the Institutional Review Board (IRB) at the research site.

### 3.2 Data Collection

Participants were recruited from the first course of the 3-track calculus sequence. In the semester that data was collected, 621 students enrolled in this course. A systematic sample [22] of 19 students were selected from 102 interested responses of which 14 students completed all three interviews. Henceforth, we will be using the terms participant and student interchangeably to refer to these 14 participants. A summary of the demographic information of the participants can be seen in Table 1. As can be seen from the table, the participation pool represents variation in terms of demographic indicators, academic majors, and self-reported performance in the course. It should be noted that students who reported “Passed” for their calculus performance did not share their final course grade. All 14 participants were assigned pseudonyms appropriate for their self-reported gender and race, which are used to refer to them in the paper.

**Table 1: Demographic Information Summary for the student participants**

| Demographic Category | Frequency (n = 14) |
|---|---|
| Race | 10 White, 2 Black, 1 White/Black, 1 Asian |
| Self-reported Gender | 10 Male, 4 Female |
| Nationality | 12 American, 2 Dual Citizens (including US Citizenship) |
| Academic Year | 13 First Year, 1 Second Year |
| Major | 6 Mechanical Engineering Technology, 3 Computer Engineering Technology, 2 Computer Engineering, 1 Civil Engineering Technology, 1 Biomedical Engineering, 1 Mechatronics Engineering Technology |
| Self-reported calculus performance | 3 A-range, 4 B-range, 4 C-range, 2 Passed, 1 Failed |

Data collection occurred longitudinally over a semester-long period as shown in Figure 1. Data collection involved 3 interviews with recruited participants. The interviews gave students an opportunity to reflect on their use of resources, which resources they used, and why they chose to use those resources. The interviews also went over resources students stopped using and their self-described study habits. These interviews guided the creation of the Actual Student Study Paths (ASSP).

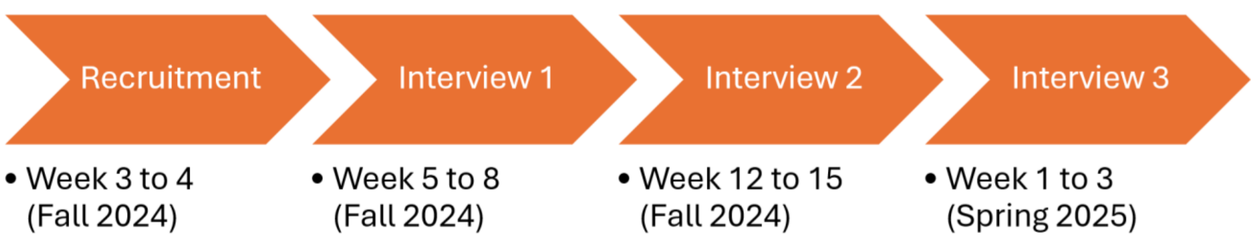


**Figure 1: Data Collection Timeline**

### 3.3 Data Analysis

The interview data were analyzed using a concurrent two-step coding process. In the first step, we thematically coded the data to identify the resources students used outside of the classroom. Any mention of the use of a resource for calculus was highlighted and coded as the use of the specific resource. In the second step we conducted a process coding to identify how each student used different resources in their study path [23].

The coding occurred iteratively with several iterations of the codebook. The codes were merged or split with each iteration to best represent the data. Coding was initially done by the first author. After each iteration, the codebook and excerpts coded under each category were reviewed by the second author to establish trustworthiness. Any discrepancies and disagreements in assigning codes to excerpts and categorizing codes were discussed resulting in revisions to the codebook and the coding process. Once the coding was completed, the codes for each participant were used to create individual ASSPs. The ASSPs included the resources students used, how they used the resource, as well as the resources they stopped using during the semester.

## 4 Findings

The results of our data analysis suggest that students use different resources in their studies. In this section, we describe these resources and how the study participants incorporated them into their studies. We first describe the different resources that the study participants used. Next, we discuss the general strategy that they adopted to incorporate these resources into their studies. Finally, we highlight some notable exceptions from the strategies generally used by the participants. Example quotes from interview are provided to support the findings.

### 4.1 Resources used by students

The thematic analysis of the interviews suggests that students used three types of resources. These resources could be categorized into three groups: 1) resources that involved no interaction, 2) resources that involved the student interacting with others in a one-to-one or small-group setting, 3) resources that were made available to all students and were offered in a large-group setting. The various codes describing the resources used by participants are present in Table 2. Students were recommended recitations and office hours by instructors and teaching assistants in the course. Students chose to use different resources for various reasons though this is outside the scope of this paper.

**Table 2: Resource Use Codes**

| Resource Use Code | Code Description | No. of participants (n=14) |
|---|---|---|
| **No Social Interaction** | | |
| Use of course-provided practice problems | Student use of course provided practice problems as study aid | 12 |
| Use of AI | Student use of AI tools as study aid | 7 |
| Use of videos | Student use of online videos as study aid | 9 |
| Use of websites | Student use of websites not affiliated with the university as study aid | 4 |
| **Small-Group Social Interaction** | | |
| Use of Office Hours | Student use of Professor's Office Hours | 5 |
| Use of Tutoring | Student use of university-affiliated tutoring | 1 |
| Engagement with peers | Student engagement with peers as study aid (asking peers for help, teaching peers, etc. including group study) | 8 |
| **Large-Group Social Interaction** | | |
| Use of recitations | Student use of optional recitations headed by 4 Teaching Assistants | 11 |
| Use of Math Study Center | Student use of Math Study Center (non-course specific classroom setting with faculty and TAs helping students with math on weekends) | 1 |

The codes shaded in orange are university-affiliated resources and codes shaded in blue are external resources not provided by the university. The number of participants refers to the number of unique participants who mentioned using the resource at least once across the three interviews.

### 4.2 Incorporation of resources into ASSP

To understand how students incorporate resources into their learning strategy, we created their individual Actual Student Study Path. This study path provides a flow of how they started using a resource, used a resource, and stopped using a resource. The ASSPs developed for each individual student were also consolidated into a generalized ASSP highlighting the resources used for each stage of the study path.

#### 4.2.1 Generalized ASSP

Although the content and the flow of the ASSPs are unique to each participant, it is possible to observe a broad pattern across the ASSPs. All study paths follow a broad approach of three consecutive stages (henceforth referred to as tasks) as shown in Figure 2. These tasks include doing practice problems, checking their answers, and seeking help regarding the problems. The nuances and differences between the different students' ASSPs come from four main sources: where the practice problems come from, how their solutions to the problems are checked, where help is sought, and which of the three previously noted stages are present. Participants used a range of resources for each of these stages as shown in Figure 2.

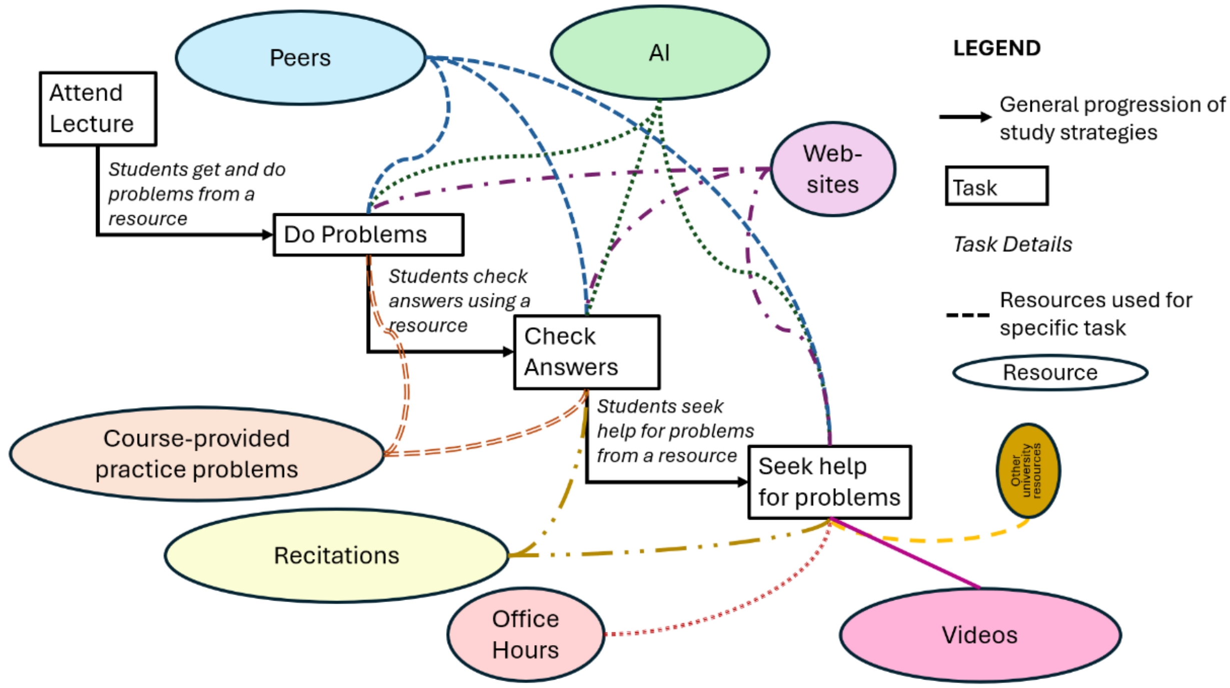


**Figure 2: Generalized Actual Student Study Path (ASSP) for students in the study**
(The width of the resource bubbles corresponds to the number of unique students who used the resource at least once across the three interviews. The 'Other University Resources' bubble refers to use of the 'Math Study Center' and 'Tutoring' as both were only mentioned once across all interviews.)

As can be seen from Figure 2, before students started using resources in the course, they attended the lectures. These lectures introduced students to calculus topics. Students then used out-of-class time studying by doing practice problems. Participants noted that these problems were usually from course-provided materials such as in-class workshops, homework, or exam review sheets. Some students also mentioned using their peers, AI or websites as sources for questions. These problems helped students better prepare for upcoming exams or quizzes. For example:

> *I mean the homeworks that aren't graded, definitely those are like ones I actually like, super duper do… because I know… they model them similar to the quiz… I feel like the homeworks give you… another level of practice.* (Maeve, Interview 1)

As Maeve notes in this comment, given the similarity between the questions on homework and weekly quizzes, she found them to be a valuable resource to prepare for the quizzes.

Once students attempted to solve these problems, the next step involved verifying their solutions. The approaches taken by students to verify their solutions varied. Students used a variety of resources at this stage including the homework solutions posted by the course instructors, online calculators such as Desmos, AI tools, recitations or engagement with their peers.

> *There's... calculators… that… give you the step by step solution, and that helps, because just knowing the answer is not [enough]… and you need to show your work… So seeing a step by step and understanding that this is where you start… all the way to the final step helps.* (Murphy, Interview 1)

It is important to note here that students often used optional resources to check their problem-solving process, not just the final answer. Students generally received only the final answers to some problems through the course materials posted on the Learning Management System, and at times, these did not contain answers for all problems. As a result, students (e.g., Murphy) used resources to verify not only their solutions but also the process of how they got to their answers.

Finally, students sought help to rectify their mistakes or understanding of the problem. Students utilized Office Hours, recitation sessions, AI tools, websites, engaging with peers, or use of videos to get help at this stage. For example:

> *I've been using ChatGPT just to walk me through the process [of solving a problem], or to check certain things if I'm doing it right… if it's wrong, then I'll try it again. Or ask for a hint, I guess. But like, I feel like, when you're in that situation with AI, you're a lot less likely to feel stupid for asking questions… If something just doesn't make sense to you, it'll explain it. And then if you don't understand that, and if it just never works, then I'd say, go to recitation and stuff.* (Marcus, Interview 2)

Students usually made a distinction between checking their answers and seeking help regarding their answers. The reason for this distinction is likely because the resources being used to check for final answers did not necessarily explain the process. However, in some cases such as Marcus', checking their answers and seeking help for a problem became the same step. It is interesting to note that Marcus showcased a preference for AI due to his belief that he was less likely to feel stupid in asking questions from AI.

Students also discussed preferences for which resources they used. The reasoning for these preferences varied from feelings of effectiveness to feeling more comfortable with the setting in which the resource was provided. For example:

> *[I prefer] the one-on-one connection between a student to another student, instead of a professor… for me, I'd go from student to student, because it's what I'm more familiar with.* (Mario, Interview 1)

In this quote, Mario highlights his preference for tutoring over going to office hours due to being more familiar with the student-student interaction. Other students discussed preferring to go to a professor due to feeling one-on-one time with the professors to be more effective.

One of the unique uses of a resource was with regards to recitations. The course offered reworks for the weekly quizzes allowing students to make up for lost points by redoing quizzes they got poor grades on earlier in the week. These reworks were offered during recitations. Multiple students discussed using recitations for these quiz reworks. Many of these students also used the recitations for help with problems, but some only used the recitations for quiz reworks. An example of this is Martin, who chose to use recitations purely for quiz reworks.

> *[I used recitations] mainly just for quiz reworks… Most of the time when I go, it's usually a bit crowded, and… I usually understand the concepts better, so I don't really want to take the time away from someone who might happen to not understand it as well. I'm also not a huge fan of a lot of people.* (Martin, Interview 2)

### 4.2.2 Students deviating from the generalized ASSP

It is important to note that there were two participants whose resource-use strategies did not align with the ASSP described above. One such participant is Mason. Mason admitted to not studying for calculus outside of class, stating that he did not feel the need to study for the course or engage with resources outside of class. Mason did not provide any additional reasoning, and when asked about his use of resources, he stated that he never needed or felt a reason to use those resources, as he already knew most of course material from earlier educational experiences.

> *I haven't felt the need to yet. I'm sure once I feel the need to, I probably will, like I have, for other classes like chemistry and things like that, where I haven't taken them in over three years. But as of now, I haven't had to do it for calculus, and I don't see having to do it for a while.* (Mason, Interview 1)

Mason finished the calculus course with a "B", which he noted met his expectation for the final course grade.

Another student whose study path deviated from the generalized ASSP is Murphy. He, in addition to the stages mentioned above, also used YouTube videos from a creator he trusted to follow along with the syllabus of the course.

> *And obviously online resources. There is a YouTube channel that I do watch that helps with calculus, [it's] great. Like, it literally goes across the [course topics], like we are doing now, and it definitely helps a lot*. (Murphy, Interview 1)

While the use of YouTube video can be thought of as a resource that students generally use, we highlighted this as an exception because the use of these videos was noted by only one student in our participant pool.

## 5 Discussion

Our findings provide key insights into how students use out-of-class resources, especially in an introductory calculus course. As can be seen from Table 1 and Figure 1, students incorporate a variety of into their study paths. What is significant to note here is that this resource use is generally centered around solving course problems, which aligns with what Pepin and Kock [10] found as a focus of students' resource use. Often, students get these problems from the course instructors in the form of homework or practice material. This finding points to an important implication for instructors and course designers. If we want to help students deeply engage with course material and disciplinary knowledge, then these problems should be designed with that prompt students toward these goals.

It is also worth exploring in the future how resource providers believe the resources should be used. As discussed earlier, several students used resources to complete practice problems and verify their answers. But is that what is the intended goal of resource providers for students? Data on this aspect could be used to highlight any differences between how students use resources and how resource providers expect their resources to be used. An understanding of these differences could also help resource providers adjust how the resources are presented to students and encourage students to use resources in alignment with their intended purpose.

Another key aspect is that students make choices about the resources that they use. Along similar lines, students choose to stop using resources during the semester. Our data suggest that some resources (e.g. tutoring) were not adequately used by students while some others (e.g. recitations, course-provided practice problems) were more popular among participants. An implication of this finding is that we need to know the factors that students consider while selecting resources so that we can provide resources that match student preferences. Future research can be conducted to explore the factors that affect student choice of resources. Additionally, future studies conducted with a large number of students can provide insights into what resources students generally use so that resource offerings can be accordingly tailored.

An interesting point of discussion here is the declining use of textbooks. Students explicitly discussed not using the textbook as it was optional for the course. This is in alignment with the prior research that suggests a drop in the use of textbooks with the advent of online materials [19] and shifting attitudes toward reading [18].

## 6 Conclusion

This research sought to explore how engineering and engineering technology students selected and used optional resources for their introductory calculus course, as well as how they incorporated these resources into their study strategies. It expands the literature on how students engage with resources by examining how they use the optional resources available to them.

We found that the study habits of students using optional resources generally centered on acquiring and solving course problems outside of class. Students then used resources to verify their answer and seek help with the problems if they had gotten the answer wrong. These findings point to significant implications for resource providers, particularly related to carefully examining and ensuring whether these problems help students attain the course learning outcomes. Another implication is that resource providers must provide resources that align with students' preferences for resource use.

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