Abstract

Discussion activities provide an opportunity for improving student learning, both in students' potential cognitive gains as well as emphasizing critical thinking, communication, and problem-solving skills that align with ERAU's strategic goals. However, there is a gap in the literature concerning the development of meaningful discussion activities for students learning mathematics in an asynchronous format. The overriding goal of this study is to develop resources to improve all aspects of asynchronous mathematics discussions.

We have adapted a prominent theoretical framework for analyzing how students develop knowledge collectively in discussions to asynchronous mathematics discussions specifically. Our framework analyzes mathematics discussions along three dimensions: epistemic, argumentation, and participation. We have also developed an epistemic codebook that categorizes the mathematical concepts and representations of said concepts that a student may bring to bear in a number of mathematics discussions.

To validate our theoretical framework and epistemic codebook, we plan to analyze two group discussion activities assigned to fully asynchronous Calculus I sections at ERAU-W in the January 2023 term. For each activity, we will collect three types of data: reflective survey, textual group discussions, and post-activity interviews. The textual group discussions will be analyzed along our theoretical framework based on empirically tested codebooks while the reflective surveys and post-activity interviews will be used to justify trends in the textual analysis.

We anticipate numerous benefits to completing the project at both the theoretical and practical levels. Validating our theoretical framework would address the gap in the literature on how students collectively construct knowledge in asynchronous discussions. The products we plan to create based on results from our analysis will address the practical hurdles to constructing and facilitating mathematical discussions.

Future work on this project will focus on the practical obstacles of applying results of this study to asynchronous discussions. Partnering with a research group at another university will further test the generalizability of the framework, codebook, and resources created from results of the study. Future dissemination products will include:

- Student resources (videos, activities) to improve scientific argumentation skills.
- Instructor resources (videos, workshops) to improve asynchronous discussion activity design.
- A framework for grading discussions beyond correct/incorrect and frequency of responses.

Introduction

Classroom discourse can provide a powerful opportunity for students to gain mathematical knowledge (Erath et al., 2021). Researchers agree that among other beneficial active learning pedagogies, interactive in-class discussions provide opportunities for students to develop robust and productive ways of understanding and reasoning in mathematics (Howe et al., 2019). In fact, numerous learning trajectories relying on group discussions have been developed and shown to be beneficial for students (Borji & Martinez-Planell, 2019). We recognize the opportunity that discussion activities provide for improving student learning, both in students' potential cognitive gains as well as emphasizing critical thinking, communication, and problem-solving skills that align with ERAU's strategic goals. However, there is a gap in the literature concerning the development of meaningful discussion activities for students learning mathematics in an asynchronous format.

Little is known about the ways that students make mathematical meaning in online mathematics courses (Trenholm, Perschke, & Chinnappan, 2019). From what has been explored thus far, some have considered mathematics courses among the more difficult to teach in an online format (Engelbrecht & Harding, 2005). While discussion activities are common in face-to-face mathematics courses, discussions are not widely used in asynchronous formats. For instance, in a survey targeting the format and content of asynchronous courses, 39% of instructors surveyed used at least 1 discussion (Trenholm et al., 2019). Note these numbers are pre-COVID19 and have likely increased.

Research on asynchronous discussion activities has largely focused on Weinberger and Fischer's (2006) Argumentative Knowledge Construction (AKC) framework. Thus far, studies drawing from the AKC framework have examined face-to-face mathematics learning (Williams, Lopez Torres, & Keene, 2019) and asynchronous learning in nonmathematical courses (Schrire, 2006; Clark & Sampson, 2008; Dubovi & Tabak, 2020). Our research team has only recently begun to explore the dimensions of students' learning in asynchronous calculus discussions (Chamberlain Jr., Reed, & Keene, 2023). We have specifically done preliminary work altering the AKC framework to better capture the learning that occurs in mathematics-specific discussions, and now intend to operationalize our altered AKC framework on a large scale to analyze the mathematical learning taking place in asynchronous calculus discussions. The target discussion activities have been specifically designed to promote collaboration, mathematical inquiry, and the development of students' problem-solving skills. We intend the findings of our analysis to hold implications for the design of discussion activities, the design of student-centered support resources for productively engaging in mathematical discussions, and the design of professional development opportunities for VITAL faculty who run online discussions.

Research Questions

Though many students learn mathematics asynchronously, the kinds of learning taking place in asynchronous formats remains severely underexamined. We are motivated to explore in more detail the learning within asynchronous discussions; specifically, we study discussion activities as we contend they are a primary point of contact in asynchronous formats among students, their peers, and their instructor. We seek to answer the following research questions:

1. How do students construct argumentative knowledge and epistemic knowledge collectively?
2. How does the instructor impact students' co-construction of knowledge?
3. How do argumentative, epistemic, and participation dimensions of knowledge construction interact?
4. How can instructors qualify and quantify student interaction?

Theoretical Framework – Argumentative Knowledge Construction

We apply an adaptation of Weinberger and Fischer's (2006) *Argumentative Knowledge Construction* framework to capture and explain the salient aspects of students' engagement in asynchronous discussion activities (Chamberlain Jr. et al., 2023). Specifically, we consider computer-supported collaborative learning across three dimensions: *epistemic, argumentation*, and *participation*.

The *epistemic dimension* attends to the mathematical concepts that can be identified in a student's response. The focus is on the presence or absence of necessary concepts and not on if the student adequately used these concepts to answer the question at hand. Moreover, each concept is coded for the different ways it may be represented. For example, a student can think of quadratic functions as:

- A geometric object (*quadratic functions look like a smile or frown*)
- Symbols to be manipulated (*quadratic functions look like* $ax^2 + bx + c$)
- An input-output rule (*quadratic functions take in a number, square it, then add/subtract)*
- Quantitatively (*as the x-value increases, the y-value increases quadratically*)

The epistemic dimension codebook lists all mathematical concepts and their potential representations associated to each discussion question based on the research team's expertise and relevant literature. The codebook was then tested and refined with preliminary data.

The *argumentation dimension* attends to the claim, evidence, and connections between the claim and evidence at both the sentence-by-sentence level (*micro-argumentative dimension*) and the whole argument level (*macro-argumentative dimension*). The focus at the micro-level is examining statements for unsubstantiated and substantiated claims while downplaying the content of the individual statements. The focus at the macro-level is the role the statement plays in the broader chain, such as if the student is positing a claim, countering someone else's argument, or trying to integrate one or more students' arguments into a new claim. The micro- and macro-argumentative codes are adapted from prominent literature on argumentation (Toulmin, 1964).

The *participation dimension* examines the quantity and heterogeneity of students' contributions to the discussion board for each discussion activity. This dimension tracks quantitative statistics such as how many times did a student post, how many times did a student respond to another student, how long were the student's posts on average, and how many different students responded in each discussion chain. These statistics are commonly assessed in quantitative analysis of student online participation.

Students' collaborative learning can then be assessed by analyzing posts across these dimensions. For example, we can consider how the injection of a new concept into a discussion (say, by the instructor) is picked up and modified throughout the rest of the discussion. By honing-in on a particular concept in the epistemic dimension, we can analyze the types of arguments that facilitated propagation as well as the quantity of posts containing the concept and/or the number of different students who comment on the concept. This multi-dimensional analysis provides a robust, reproducible way to consider how knowledge is constructed in an asynchronous discussion.

Methodology

This study plans to analyze two group discussion activities assigned to fully asynchronous Calculus I sections at ERAU-W in the January 2023 term. We anticipate up to 3 sections of Calculus I to run in January 2023 and thus the potential total population size is 90 undergraduate ERAU students.

For each activity, three types of data will be collected: *reflective survey*, *textual group discussions*, and *post-activity interviews*. The *reflective survey* will be a short survey asking students to reflect on their process for answering the activity and the types of interactions they made with their peers during the group discussion. The *textual group discussions* will be pdf records of each group's discussion. The *post-activity interview* will be a 1-hour interview where students are asked about the specific comments they made, how they read other students' comments, and their general perceptions of each activity. The research team will secure IRB approval before collecting and deidentifying data.

Analysis Plan

The textual group discussions will be analyzed along our theoretical framework based on empirically tested codebooks. This coding will initially be done individually by at least two researchers, then discussed and negotiated. More specifically, the entire discussion will be broken up into individual sentences and tagged with the speaker's pseudonym and its relative place in the discussion (e.g., 1st chain, 2nd post, 4th sentence of post). A Python script has already been developed to automate this task. Individual sentences will then be coded along the epistemic dimension. Individual sentences will then again be coded along the micro-argumentative dimension. Individual sentences will then be considered together as a post and be coded along the macro-argumentative dimension. Quantitative statistics, such as number of posts per student, number of different student posts per chain, and average word length per post, will then be calculated. Finally, coding will be visualized as chat bubbles with arrows between bubbles to visualize interactions. These visualizations will allow the researchers to qualitatively analyze the interaction between the epistemic and argumentative dimensions.

Survey data will be used to identify trends to consider in the qualitative visual analysis. It will also be used as further justification for trends that appear in the textual data analysis. For example, survey data that shows students read all other comments will justify claims that a particular idea was picked up in another chain of comments even though there is no explicit statement saying the student saw the concept in another post. The short surveys will also illuminate students' discussion response habits such as why they post and what they consider when posting.

Interview data will be used to justify results from coding along the epistemic dimension as well as further justify trends that appear in the textual data analysis. Asking a student how they came up with an idea and having them explicitly state they read it in another chain of comments will further justify any trends found the epistemic dimension analysis.

References

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Project Timeline, Expected Outcomes, and Deliverables

Project Timeline

	Month	Activity	Products
Pre-Grant	**Dec 22**	-Draft survey -Draft interview protocol -Submit to IRB	-IRB approval
	Jan 23	-Finalize survey -Finalize interview protocol	-Survey ready to launch -Interview protocol
During Grant	**Feb 23**	-Hire student assistant -Collect discussion 1 data -Collect survey 1 data -Begin interviews for discussion 1	-Hired assistant -Raw Data for 1 discussion -Discussion data deidentified and ready to be coded
	Mar 23	-Conduct interviews -Continue data analysis -Draft data visualization script	-Transcribed interview scripts -Working Python script for data visualization
	Apr 23	-Draft first paper from prelim results -Finalize data visualization script	-Refined Python script for data visualization
	May 23	-Submit first paper from prelim results	-Under review paper on preliminary results
	Jun 23	-Finish data analysis	-Drafts of student resources to improve discussion participation
Post-Grant	**Fall 23**	-Begin NSF Grant writing -Write and submit manuscript -Seek additional universities for joint test of framework/codebook	-Under review paper on finalized results -Github for sharing Python data visualization script
	Spring 24	-Continue NSF Grant writing -Conference presentations (2)	-Presentations for practitioners and researchers -Secure at least 1 external research team for NSF grant partnership
	Fall 24	-NSF Grant submission	-Draft of Professional Development for instructors -Grant submission for external funding

Future Work

Future work on this project will focus on the practical obstacles of applying the results of this study to asynchronous discussions. Partnering with a research group at another university will further test the generalizability of the framework, codebook, and resources created from results of the study. Future dissemination products will include:

- Student resources (videos, activities) to improve scientific argumentation skills.
- Instructor resources (videos, workshops) to improve asynchronous discussion activity design.
- A framework for grading discussions beyond correct/incorrect and frequency of responses.

We recognize that generally, a large portion of asynchronous discussions are graded by adjuncts and graduate students that do not have extensive training in educational practices. A future goal of the NSF grant will be towards the creation of a Center for VITAL (Visiting, Instructors, Temporary, Adjuncts, and Lecturers) Professional Development that provides professional development nationally. While our previous dissemination products aimed to improve discussion development and student interaction, this type of national training will help improve how asynchronous discussions are run.

Expected Results, Outcomes, and Deliverables

Research Question	Expected Results	Outcomes	Deliverables
How do students construct argumentative knowledge collectively?	Students present superficial (claim only) statements. Counterarguments and integrations are largely content agnostic.	Improve the use of evidence and justification when students make claims.	-Videos that assist students with making justified claims. -Framework for grading argumentative claims in discussions.
How do students construct epistemic knowledge collectively?	Students engage in post-and-run tactics that reflect their own thinking. Students rarely incorporate others' thinking into their responses.	Improve metacognitive skills and group efforts to engage with concepts.	-Videos that assist students in reflecting on concepts and integrating other concepts. -Framework for grading epistemic engagement in discussions.
How does the instructor impact students' co-construction of knowledge?	Instructors largely grade on correctness of a response and do not encourage cooperation.	Improve student-instructor interactions and increase student satisfaction.	-Framework for engaging with students beyond accuracy.
How do argumentative and epistemic dimensions of knowledge construction interact?	Counterarguments and integrations drive the development of concepts.	Improve overall quality of discussion activity prompts as well as the ways students interact with the prompt.	-Framework for rigorously analyzing links between epistemic and argumentative dimensions.
How can instructors qualify and quantify student interaction?	Instructors can count number of counterarguments and integrations. Instructor can check that student engaged with all expected concepts in some way (whether right or wrong).	Improve the grading of discussions as reflecting student engagement with a prompt without focusing on correctness.	-Framework for quantifying quality interaction (argumentative and epistemic) within the discussion.

Prior Work (1 page limit)

The current research group (Chamberlain, Reed, Keene) has completed preliminary work on the theoretical framework and codebook used to analyze discussion data. These results have been disseminated through the following venues:

- **Regional Conference Presentation** – Northeastern Conference on Research in Undergraduate Mathematics Education, 2021
- **National Conference Presentation** – Conference on Research in Undergraduate Mathematics Education, 2022
- **National Conference Paper/Presentation** – Conference on Research in Undergraduate Mathematics Education, 2023 (accepted)

The proposed SEED project provides funding to validate the theoretical framework and codebook. The proposed data collection and analysis methods have been completed once by the research group and thus the research group has all the relevant skills and qualifications needed to complete the proposed SEED grant project.

Individual members of the research group are working on separate that focus on how students develop mathematical knowledge. The success of individual members in securing external funding further demonstrates the potential for this proposed SEED grant project to eventually secure external funding and form potential partnerships to test the framework and codebook across multiple universities.

- **Chamberlain**
    - **External Grant, NSF –** Analyzing the social and cognitive statements students make during asynchronous discussions. The project has analyzed weekly group discussions in over 30 sections of physics and mathematics courses. Moreover, Co-PI Chamberlain developed the Python scripts to collect, deidentify, and unitize (by sentence) online discussions as part of this external grant. These scripts will be utilized to begin data analysis of the proposed SEED grant.
    - **Internal Grant, SEED** – Analyzed student scratchwork to determine the mathematical representations students exhibited during exams as well as interviewed students to investigate their mathematical concepts and representations. Cataloged concepts and representations that have been used in the proposed SEED grant epistemic codebook.
- **Zack**
    - **External Grant, NSF** – Co-PI Reed and collaborators explore and build theory around the nature of productive student reasoning about equivalence within and across mathematical domains. Reasoning with equivalence is inherent to the myriad algebraic calculations involved in mathematics problem solving and communication in calculus, and Co-PI Reed has gained valuable insight into subtleties of students' algebraic activities in a calculus setting. These insights directly apply to the development and analysis of tasks at the core of the proposed SEED grant, and Co-PI Reed will be applying these insights throughout the course of the project.

One member of the group (Karen Keene) has published two papers that use the Argumentative Knowledge Construction framework to analyze student group work in synchronous classes. Their published work provided an initial guide for the changes we made to conform the Argumentative Knowledge Construction framework to mathematics discussions.

Budget Justification

$3700 – Student Researcher

- Student researcher at $12.50 an hour for 296 hours.
  Reasoning: *Grant projects a student will work from 2/1/23 to 6/30/23, which is approximately 22 weeks. Estimating 15 hours a week, this totals 296 hours. Based on paid student researchers from other grants, 15 hours a week is an average number of hours to work for our students and is below the 20-hour maximum. The student researcher is expected to only complete qualitative coding for the project. Qualitative coding is a time-intensive process however, thus the student will not run out of work to do before the grant is over. A pay rate of $12.50/hour is budgeted to attract a highly skilled undergraduate student worker as it is beyond the $11/hour minimum wage for student workers. An undergraduate student is sufficient for the project as they are only expected to complete qualitative coding and are not expected to contribute to the data analysis nor the manuscript writing.*

$2300 – Participant Incentives

- Up to 10 participants interviewing twice (once after each activity). $40 per interview. Total of $800.
  Reasoning: *Incentive set at $40 per interview as each interview is expected to take an hour. Previous SEED grant set participant incentive at $25 per 1-hour interview and participant interest was low (1 participant out of 300+ potential student participants).*

- Up to 75 participants completing survey twice (once after each activity). $10 per survey. Total of $1500.
  Reasoning: *Incentive set at $10 per survey as each survey is expected to take at most 15 minutes. This puts the participant incentives for both tasks at an equal $40/hour rate to increase potential participation.*

$0 – Qualitative/Quantitative Analysis Software

- No money is being requested for Qualitative and Quantitative Analysis Software.
  Reasoning: *Open-source (Python) and university-provided (Excel) software will be used to run all data analysis. PI Chamberlain has written Python scripts that convert PDFs of discussions into Excel documents enumerating student posts by line. Excel is sufficient for the project's qualitative analysis needs. PI Chamberlain has written Python scripts that run quantitative data analysis from Excel documents. Therefore, paid qualitative/quantitative analysis software is not necessary for the success of the project.*

Total budget: $6000

2022-2023 WW Faculty Seed Grant Budget

Itemized Expense	Amount Requested
Student Researcher	3700
Participant Incentives	2300
Total	6000

Project Title:

Collective Knowledge Progression and Proliferation in Asynchronous Calculus Discussion Boards

Investigator:

Darryl Chamberlain

Department Chair:

Karen Keene

Investigator Signature:

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