Can Students Step Up Their Mathematical Learning through Movement?
A Course Evaluation for Move Your Math

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Abstract

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While mathematics is an important subject and mathematical learning is inevitable for all students, developing effective, practical, and fun instructional strategies is urgent and essential. Inspired by the *Mathematics through Movement* program at Emory, the author collaborated with another researcher to further investigate pedagogical approaches in mathematical teaching. The present work assesses the impact of movements on students' attitudes and understanding of mathematical concepts. Through methods of field observation in the directed-study course, distribution of adopted and designed questionnaires, and interview conduction, the author collected quantitative and qualitative data to investigate changes in students' perceptions of math when experiencing instructional movement activities. Results indicate that the embodied tools can create a positive learning experience for the participants, impacting their mathematical attitudes understanding of concepts, whiled enhancing creativity.

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Chapter 1. Introduction

"When I can apply what I learn in math class to solve a real-world problem or when I can solve a three-page problem, I gain a sense of accomplishment, feeling like I just fell in love with math. But the process of grasping the ideas and understanding the concepts is just way too painful…."

It is common to hear students' different attitudes toward math in the building of the Mathematics and Science Center at Emory University. There are always heated mathematical discussions about the efficiency of math models or a partial-differential-equation problem, but there also are students complaining about the complexity and the abstractness of mathematical concepts. Accordingly, it comes naturally to wonder if some pedagogical strategies can make mathematical learning fun and less arduous. Encountering a professor who devoted herself to establishing connections between subjects, the author learned about the *Mathematics through Movement* program at Emory, in the Fall of 2019. This program has been devoted to using Laban Movement theory [1] and somatic movement improvisations to provide students with opportunities to embody mathematical learning experiences. Such an idea is so novel and intriguing that the author decided to conduct this study investigating the impact of this interdisciplinary approach on students' attitudes toward mathematics.

Hence, collaborating with another student researcher, this study was carried out in the Fall of 2022. Implemented through a directed-study course, the aim of the study determineed if movement could help students change their mathematical attitudes and provide an easier approach to mathematical understanding.

Chapter 2. Literature Review

Mathematics has been a core subject in education systems all around the world. This core subject has been listed as a "must" such that students have no choice but to study it to obtain a graduation certificate from different levels of schooling. Despite its significance, throughout the research and the authors' experience in interactions with other math major students, indicate or reveal that many students experience difficulties finding interest in studying math, learning and comprehending mathematical concepts, and persisting in problem-solving. Accordingly, this literature review chapter focuses on the concepts of mathematical attitudes, individuals' positive or negative feelings, beliefs, and emotions toward mathematics [2]. It also explores interventions done by researchers to combat the students' challenges to improve their performance.

Firstly, much literature on mathematics education has recognized the challenge of engaging students in learning and fostering positive attitudes toward the subject. Specifically, as Hembree identified in his research in 1990 [3], abstractness and complexity in math problems cause math anxiety, setting a high hurdle for general students to cross. Walking into a math class, students sense or express frustration, fear, and negativity toward mathematics [4]. In addition, traditional approaches in math instruction, especially at the early levels, often rely on abstract concepts lecturing, routine memorization, repetitive problem solving, or less engaging manner such that students find the material disconnected from everyday life [5]. These two significant challenges combined create an impression and barrier in students' mindsets that math is less relevant, hard to grasp, and painful to learn. What do you mean my less relevant?

Secondly, to address these challenges, researchers and educators have attempted to dive deeper into the pedagogical strategies to improve students' positive feelings during the learning process and change students' attitudes toward mathematics. In particular, some researchers have highlighted the benefits of incorporating movement and physical activities into math instruction. In *A Case Study on Math Dance* [6], Evagelopoulou presented a evidance on the impact of movements on math learning. The study has shown that when incorporating kinesthetic activities in math teaching and learning, students experienced "enhancing better understanding of mathematical concepts and memorizing, increased motivation and encouraged creativity and partnership." Accordingly, physical activity has demonstrated its potential in preschool environments to facilitate math learning and teaching. Perhaps state that this is for elememtary students earlier in the paragraph.

Meanwhile, some cognitive scientists have adopted a different approach to the same topic. While the body and the environment play a significant role in cognitive processes, there can be embodied tools to improve learning. In particular, "embodied learning could allow learners to extend body-based representations, familiar and easily understandable in sensorimotor terms, to map onto more abstract (or less embodied) concepts." [7] That is, through building the embodied analogies, students can map the unfamiliar terms and concepts to what they are familiar with, helping them make the connections, thus helping them understand the concepts in mathematics.

Additionally, while instructors and scholars have been focusing on discovering innovative strategies to teach, it is also significant to notice the differences existing in students' learning habits. As Hawk and Shah suggested in their research, each student accepts and gives out information in unique ways. To be specific, the VARK Model categorizes students' instructional preferences into four categories, which are also what VARK stands for Visual (V), Aural (A), Read/Write (R), and Kinesthetic (K) [8]. When students experience their preferred instructional method, they learn in the most effective manner. Hence, while a kinesthetic learner prefers hands-on approaches and use of their senses in learning, students with this learning style should make the best out of the embodied tools, especially when such a tool is their body and the setting [9].

Therefore, because of these theories and the potential effect of physical activities in improving learning, two professors from the department of The Mathematics and Dance and Movement Studies program at Emory started a program called *Mathematics through Movement* to teach an interdisciplinary course called *Dancing Dynamical Systems. I*n 2019, this course initiated an embodied teaching practice for higher education and test its effectiveness. As the program continued to grow with more involvement from a a variety of students, the course design evolved through reflection, repetition, and invention of new approaches. on previous experiments and repetitive brainstorming. The project adopted a mainstream form of assessments to evaluate the impact of the course--Mathematics Attitudes and Perception Survey (MAPS, see [2]), However, there has not been a systematic and detailed tracking system to fully evaluate the course design and students' participation from a holistic perspective. The current study seeks to contribute to this part of the program, examining the impact of the embodiment of movement and physical activities on students' attitudes toward mathematics by utilizing qualitative and quantitative data collection tools.

Chapter 3. Aims and Objectives

This project aims to study the impact of students' usage of body movements to understand mathematical concepts. Many variables helped us illustrate the relationship between math and movement. Specifically, the main independent variables are the course instructor, the environment or location, the exact time of the course during the day, specific designed activities, selected mathematical concepts, and class structure. Additionally, since each person is unique, and so is their learning style, personal factors, such as educational background and learning habits, are also considered as independent variables. The dependent variables are students' self-reported mathematical perceptions and concepts comprehension. By utilizing surveys, field observation, and other methods described in this work, it is possible to investigate the relationship between these two major sets of variables. Based on the literature review, this work is emerges from the hypothesis that body movement impacts students' attitudes toward mathematics positively and facilitates students' mathematical learning.

Chapter 4. Method/Experimental Design

This chapter describes the experimental method, including the field observation within the directed study course, the design and distribution of surveys, and the plan and arrangement of interviews. Collecting qualitative and quantitative data through each method helps this project achieve its overall goal to measure, analyze, and comprehend the movement's effectiveness in facilitating the students' understanding of mathematical concepts. Tools utilized include Canvas, Google Forms, and mobile devices.

4.1 Directed Study Course: Move Your Math

Most of this research is done through field observation in the directed study *Move Your Math* course. Below is a brief description of the history of the program at Emory. In spring 2022, the author decided to work closely with another student who was interested in the pedagogical side of mathematical instruction through embodiment by developing activities able to help students digest mathematical concepts in a stress-free and non-traditional mathematical environment. On the one hand, this partnership allowed for collaboration toward the goal of diving deeper into the connections between mathematical concepts and movements. On the other hand, the collaboration gave both researchers opportunities to approach each session from different perspectives and senses, assess students' response to designed content with unique lenses, and extract various outputs through instructing, participating, and observing to perform analysis. Although the roles were therefore inevitably different throughout the course, both researchers had to do work to prepare for, participate in, summarize, and report on each of the sessions, including its activities and students' immediate feedback. Accordingly, the two researchers led their experiment within a course called *Move Your Math* in the Fall semester of 2022. From now on, the researcher who focused on the pedagogy would be referred to as the "instructor," and the author who focused on the assessment would be the "evaluator."

Thhe following specifies course details contextualize the goals. The class meeting time was from 18:00 to 19:15 every Tuesday in the dance studio of the Rich Building[1]. The Rich dance studio is designed for classes or personal rehearsals, and it has a Marley floor allowing course students to move safely. The directed-study course had a total of eight sessions organized as follows:

Session Number	Content
1	Introductory Session
2 - 7	Sessions with Selected Mathematical Topics with two in-class sessions per topic
8	Students' Final Presentation: *Design "your" Move Your Math*

Table 1 Directed-Study Course Plans

In addition to the interactive in-class time, there were preview and review assignments and week-long projects asking students to reflect and expand the conversations in class with their comprehension of course materials and creativity. To keep the evaluation as objective as possible, the evaluator did not get to decide the topics and specific activities before attending the sessions.

The course recruited students by putting up flyers around campus and emailing all college students. Since participating in the study would give students one credit as compensation, students still needed to consider their tight schedule and the additional workload they were responsible for. Seven students enrolled in the course. To collect data on the demographics and prior knowledge in dance and mathematics, a pre-course survey was generated and distributed. According to the survey, all students were female with no formal experience with dance and some experience with two-hundred-level math classes. There were no freshmen enrolled, and all students had already

[1] Rich Building at Emory University at 1602 Fishburne Dr, Atlanta, GA 30322

declared a major in math or science. (See *Table 2*) When the survey asked them to rate their preference and experience with mathematical concepts on a scale from 1 to 5 with 1 being "least preferred" and 5 being "most preferred," they demonstrated an above-average

A score of 3.2 out of 5.

Participants	Gender	Year	Major	Learning Styles	Experience with Dance
A	F	Junior	Applied Mathematics and Physics (BA)	Kinesthetic	N
B	F	Senior	Applied Mathematics and Statistics	Kinesthetic	N
C	F	Junior	Applied Mathematics	Kinesthetic	N
D	F	Junior	Applied Mathematics and Integrated Visual Arts	Kinesthetic	N
E	F	Senior	Computer Science	Visual	N
F	F	Senior	Quantitative Science with Biology Track	Visual	N
G	F	Senior	Mathematics (BA) and Quantitative Sciences	Kinesthetic	N

Note: when asked these students if they have any prior experience with dance, the questionnaire mainly focuses on formal education in dance such as participation in professional dance trainings

Table 2 Participants' Basic Information Collected through Introductory Survey

Field observation and activity participation were the most crucial means to achieve the project's goal. Specifically, each session was filmed with mobile devices and was recorded on a pre-designed observational log. This in-class observation log was designed according to the logic model suggested by Coldwell and Maxwell [10] to track the session through class input, intervention, output, and general notes (Use Table 3 as Reference):

1. *Input*: This section recorded the preparations made by both instructors and the students before each class. For students, examples of "preview" assignments and materials that wererequired to bring to class, whereas the examples for the instructors were slides and movement activities, and any possible guest lecturers.
2. *Intervention*: This section was designed to log the instructor-student interactions in each session, including activities, in-class handouts, screenings, and so on.
3. *Output*: This section was divided into the immediate outputs and after-session output. Immediate outputs included completed work resulting from in-class activities such as

students' finished worksheets or drawings. The after-session assignments were what the instructor assigned as homework for students to finish in their spare time after class.

4. *General Note*: This section allows the evaluator to record immediate sensations, and document comments, and notes during and after each of the sessions.

Observation Log				
Input	Student		Instructor	
	Prework Before Class	Studying Materials Requried to Bring to Class	Instructional Tool (PPT?/etc)	Any outside resource (Speakers)
Interventions	Activities Done in Class		Comment Class Atmosphere/Side Notes	
	Name of the Activity	Comments on the Interaction between Students/Students vs. Instructor	Did the students enjoy this activity?	
Output	Immediate Output		Aasignment after this Session	
	Is there any product produced in class?	Comments on the purpose of the product	Name/Kinds	Requirements for the Students
General Note				

Table 3 Observation Log Template

4.2 Survey

In order to further investigate participants' responses to the directed study course, various kinds of surveys were adopted and designed to ask for participants' demographic information, educational and social backgrounds, feedback regarding each session, and mathematical attitudes and topic comprehension. In this section, the evaluator provides the rationale behind the surveys by categorizing the used surveys based on the level of information they were collecting: the Macro-level survey and the Micro-level survey.

4.2.1 Macro-Level Survey

As the study's interest was in finding the impact of movement activities in the directed-study course, it was necessary to measure participants' attitudes toward mathematics before and after their experiences.

In the introductory survey, participants were asked to answer a set of questions about their basic demographic information and former experience in dance and math before the directed-study course. Questions in this survey are in four big categories (See APPENDIX I for the Full Questionaire):

1. Personal demographic and educational information questions consider gender, graduation year, major/minors, type of secondary school they went to, and years they have spent at Emory to provide the participants' basic information.
2. Learning styles investigates the students' learning and studying styles when they approach new knowledge or review for exams.
3. Prior experience with Mathematics aims to study students' prior mathematical background. Questions ask the students to rate and explain their past experiences in mathematical learning and level of enjoyment in studying. In particular, the mathematical courses offered at Emory and the major foundation topics in mathematics are addressed in the survey for the participants to select and illustrate their interest as well as understanding.
4. Prior experience with dance or movements questions participants previous learning or general experience with movement and body language use.

In the post-course survey, in addition to the four categories above, there was an additional one to inquire about the participants' experience regarding the final presentation and the entire directed-study experience. The added section questions how their attitudes and perceptions changed when they were forced to switch roles from being “students” to “course designers.” Moreover, participants’ overall experience and suggestions regarding the directed-study course were asked at the end of the post-course survey.

To measure the sets of dependent variables, or students’ attitudes toward mathematical learning, the evaluator adopted the Mathematics Attitudes and Perception Survey (MAPS, see [2] and APPENDIX III) which helps uncover students’ attitudes in the mathematics learning process. Based on empirical evidence, it was structured to contain questions assessing seven factors in mathematical learning:

1. Personal perceived confidence in mathematics
2. Persistence in problem-solving
3. Growth mindset in learning mathematics
4. Motivation and interest in studying mathematics,
5. Real-life applications using mathematics.
6. Personal management of mathematical knowledge
7. The nature of answers to mathematical problems

In *The Mathematics Attitudes and Perceptions Survey* article, these categories have been validated through experiments with 3,411 students. Data was analyzed by comparing students’ results with the responses of the experts.

4.2.2 Micro-Level Survey

Despite the macro-level investigation, the detailed design in each of the sessions was also worth noting to understand how it impacted the students. Accordingly, for each mathematical topic chosen, a pre-session survey and an end-session survey were given to the participants. The pre-session survey targeted students' previous knowledge regarding the specific mathematical topics covered in class. Specifically, questions such as related courses taken, their understanding or believed definitions of the specific topic, and their expectations for the class. At the end of each meeting, the post-session survey was sent to the participants to investigate if their comprehension and perspectives had changed based on their in-class experiences. The comparison between the surveys would provide with information about the impact of movement on learning specific topics in math. (See APPENDIX IV for Sample Micro-Level Questionnaire)

4.3 Participant Interviews

At the end of the semester, students were interviewed individually. Personalized questions were based on each participant's responses in the previous surveys and in-class interactions with the instructor to collect qualitative data useful to evaluate the success of the course. (See APPENDIX VI for Full Interview Question Banks)

Chapter 5. Result

In this chapter, qualitative and quantitative data collected before, during, and after the duration of the course are initiated and discussed. Specifically, field observations are provided from both the students and the evaluator's perspectives in Section 5.1. Macro-level and Micro-level survey results are provided in Section 5.2. Finally, the end-of-term interviews are discussed in Section 5.3.

5.1 Field Observation

The opportunity to be both an observer and a participant allowed the evaluator to have a deep understanding of the class dynamics and the learning experience. Providing a description from the participant's perspective, the next section will provide extensive explanations of some of the remarkable in-class activities presented for each mathematical topic.

5.1.1 Participants' Perspective

Below is a summary of the in-class activities for each mathematical topic.

5.1.1.1 Calculus

The first unit of the independent study course was devoted to calculus. Due to the importance of this topic in mathematics courses at the advanced level, the participants seemed to be familiar with the concepts and related terminology. The setting was simple but equipped with all features of a dance studio. It was well-lit and set up with a mirror and a whiteboard. Since no one had worked on a math problem in this setting before, this experience has been novel and unique.

When the course formally started, the class structure was clear. Particularly, after the warm-up body motions, easy concepts were presented. The focus was then shifted to movement activities, the critical component of the class, when more difficult and abstract terminology was introduced. Such intervention required everyone to make the abstractness tangible through movement invention.

The first class began with elementary calculus terminologies such as function, linearity, and variable types. When limits and derivatives slides were shown through the PowerPoint, the instructor asked some questions, such as "what does it truly mean", "how to show," and eventually "how to demonstrate such notions" to encourage visualize the concepts' meaning in mind and act the concepts out. While everyone followed the instruction to ponder how the shape of a graph could be represented, the instructor kept emphasizing that the notion was not only a shape but a definition, repetitively encouraging everyone to re-think and rework the representations. Accordingly, such repetitive processes have allowed everyone to realize the lack of comprehension and memorization of the origin of the concepts and the logistics behind the theory and formula’s establishment. This sequence of the course flow gave the participants opportunities to deconstruct the complete mathematical notion into its components, allowing everyone to reassemble the definition in order to generate a holistic understanding.

In the second session, students were working in pairs for a movement activity designed for derivatives. The groups of twos had grown increasingly accustomed to finding connections between the origins of the mathematical theories and physical actions. When asked to perform derivatives and integrals, instead of showing their shapes separately using the limbs, participants demonstrated how they were the inverse operation of one another. The class had shown improvement in thinking deeper about the definition.

Overall, the structure of the two sessions for Calculus was simple to follow and to be easily engaged in, allowing everyone to quickly adapt to the new environment and become comfortable with drawing links between mathematical definitions and physical motions. Also, the process of making mathematics less abstract and more tangible might assist the class participants in testing their understanding not only of the macrostructure and the concepts' applications but also of the holistic meaning and purpose and origins of such mathematical notions.

5.1.1.2 Linear Algebra

Linear Algebra is an essential mathematical topic setting the foundations in machine learning, deep learning, and higher-level mathematics. Due to its significance, the topic is also selected by the instructor for the participants to enhance their understanding through embodied tools.

For these two linear algebra sessions, the instructor changed her instructional language, attempting to encourage participants to think of in-depth definitions, challenging them to express the definitions through body. Particularly, the instructor prompted the participants to think as they had to "teach" the concepts through collective movements. From the first glance at students' movements, the change in instructional language did not help participants to focus on the definition due to their lack of comprehension. However, when the instructor recalled the eigenvalue problem by inviting students to think about the "action" of a matrix on its eigenvectors, the attitude changed. In the activities, some students were prompted to zoom in on the axis, using the aligned position and connected arms to show the "stretching effect" of the eigenvalues, while others observed the operations in space. It was much simpler to visualize the concept. Via embodiment, the class had a "wow" moment, and many participants claimed that they were reminded of eigenvalue and eigenvectors more applications in mathematics. One of the participants stated that visualizing the problem helped them explain why scholars have been applying eigenvalues and eigenvectors to image identification in machine learning.

While mathematics is typically abstract and exists in planes or three-dimensional graphs, bringing the traces or images into the real world or an actual space can help to identify the concepts' key characteristics and implications, supplying scholars with sufficient information to solve real-world problems more efficiently. So, the linear algebra sessions allowed the participants to dive deeper into the concept definitions and helped students grasp the definitions and applications of the concepts more accurately.

5.1.1.3 Differential Equation

Differential Equation is introduced in this directed-study course because of its significance in applied mathematics. Due to the intricacy of the concepts and the need to make the difficult concepts easily accessible to students, activities were introduced to the participants first and occupied most of the session time.

In the first session, the instructor introduced small oscillations and asked the participants to recreate the trajectory of a pendulum clock using body parts. While some students used their arms and others utilized their bodies directly, the activities helped everyone understand that the ultimate result of these movements was identical. The instructor next explained the meaning of "fixed point" and how the preceding practice exemplified it. Via this teaching format, the class was able to engage effortlessly and experience a "wow" moment as the veil was lifted from the true principles. In the following session, the instructor proposed a game with the Yoga mat in the second session. She circled two different-sized areas, allowing two participants to occupy the biggest area and four to occupy the smallest area. Participants were told to "battle" for space within the ringed area, losing if their feet or body parts touched any area outside the circle. In the end, while the participants in the biggest area-maintained harmony, there was only one victor in the smallest region. With students' engagement, the instructor then disclosed that the game illustrated the competing species model, a typical application of differential equations to illustrate population dynamics. Thus, through an immersive and simply engaging activity, participants were captivated by the material and provided a foundation for applying mathematical principles.

These two games sparked a great deal of attention and fierce debate among students. Students from diverse academic backgrounds drew connections between disparate subjects, from physics and visual arts to economic game theory. The majority of these concepts were innovative and cross-disciplinary. Even though the mathematical topics chosen could not be fully covered in two sessions, all participants expressed a desire to go deeper into the concepts if the sessions were longer. So, through these sessions, it was determined that mathematics might be enjoyable and effectively engaging when students could "perform" it or connect it to previously acquired knowledge. In addition, such embodied tools could increase students' curiosity to continue learning complex mathematical subjects.

5.1.2 Evaluator' Perspective

This section illustrates the summarized reflection and notes from the evaluator's observation, and the sample observation log recorded could be found in APPENDIX IV.

There was a pattern of emotional shifts preceding and following each session during the semester. As participants entered the classroom on Tuesday evenings, the facial expressions and body language always suggested exhaustion because the majority of them had just finished their second-to-last class and rushed into the classroom. Hence, the scheduling of the day had an effect on the response of the participants, causing them to appear less engaged at the beginning of the sessions. Moreover, while the lecture sections may give students a sense of a "typical classroom," the movement portions usually sparked their enthusiasm and generated lively dialogues. When assignments were allocated to groups, regardless of the number of individuals in each group, the output, including debates and movement performances, was typically vigorous. Hence, although the timing could have been better, the activity aided the lesson by increasing the participants' energy and participation.

The participants' reactions and replies varied with class structure. Specifically, if the instructor started with lengthy explanations about what the exercises would entail, participants were more likely to remark and establish connections using their understanding of the exact topics - which may be restricted but detailed. In contrast, when the instructor prepared movement activities, i.e., during the differential equations sessions, the participants tended to draw on information outside of mathematics to provide explanations. There were advantages and disadvantages associated with both these strategies. Although the former may be simpler, participants may become disinterested during the lecture portions. The latter one would allow participants to be more engaged, but due to their ingenuity, the themes might be easily distracting. Thus, for this project, the instructor experimented with both class arrangements and found that the second strategy was more likely to be appropriate for this group of participants based on their comments and the subsequent discussion. Therefore, the manner in which the instructor approached each session's content has a significant impact on the participants' approach to assigned tasks.

While class organization might impact student involvement, the manner in which instructors communicate course material also plays a significant role. Specifically, during concept explanation, videos, particularly those with animation and images, engaged participants more than verbal and mathematical explanations alone. Although the instructor's explanation was lively, the presentation was comparable to the usual and formal lectures that participants had been exposed to for the entire day. Thus, the shift in presentation affected the involvement of participants throughout the directed study courses.

5.2 Survey

5.2.1 Macro-Level Survey Results

5.2.1.1 MAPS

The MAPS survey introduced in Section 4.2.1 is analyzed to compare the overall score with the experts' results as illustrated in [2] and also by performing a two-sample t-test. After computing the overall score for each participant, comparing their response to those of the experts shows that five out of seven participants improved their scores after participating in the directed study course. Such a result means that students' attitudes toward mathematics have become more similar to that of the experts. (See *Figure 1*) Additionally, the mean score indicates that the directed study has had a good effect on the respondents' confidence, interest, and openness of mind. (See *Figure 2*)

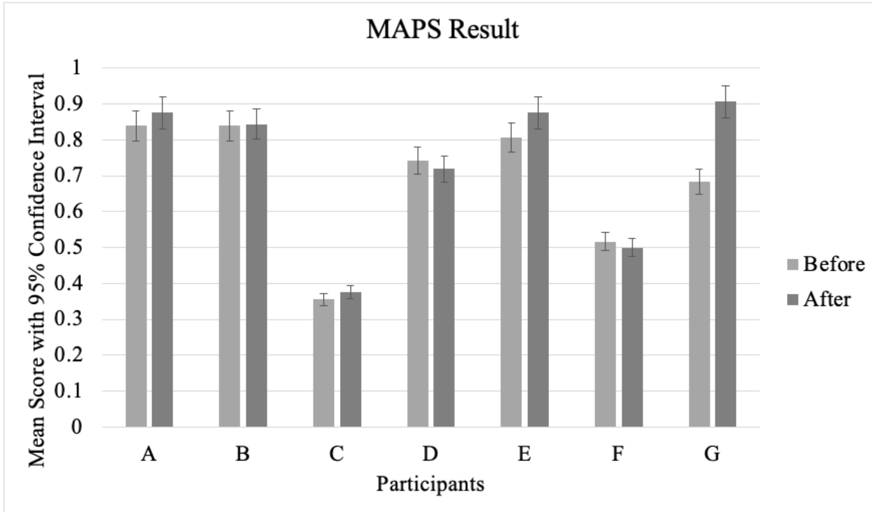

Figure 1 Overall Score for Participants Before and After Directed-Study Course

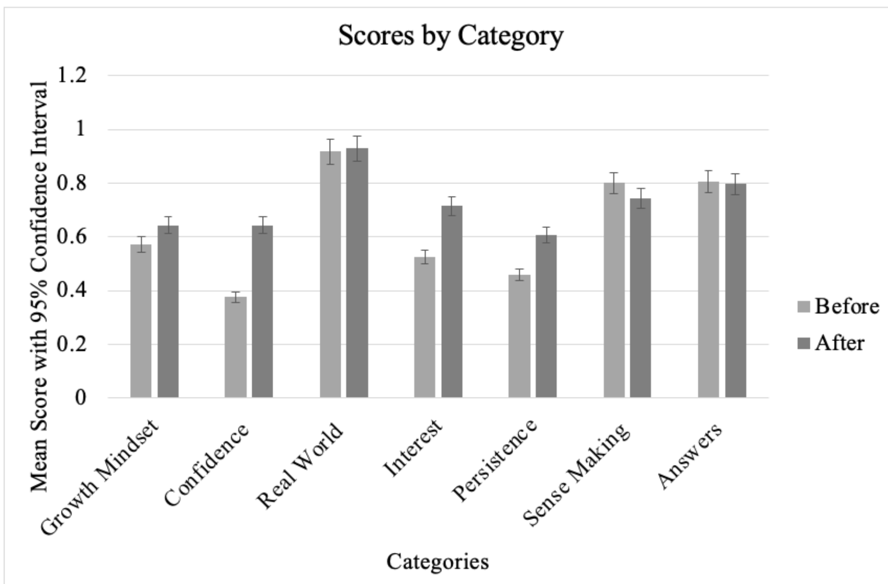

Figure 2 Scores by Measured Factors for Participants Before and After Directed-Study Course

In order to offer another approach to the results, the surveys are quantified by coding the response using the scale presented in table 4 and doing a paired t-test test. This method will be able to uncover if students’ confidence levels changed significantly just based on the eight-session intervention. It is proposed that the null hypothesis that this directed-study course has no effect on students' perceptions of mathematics; the alternative hypothesis was set to the contrary. In this method, the two-sample significance t-test can be performed with the t-score and p-values for each category to determine if adequate evidence exists to demonstrate any progress or change during the guided study.

Response	Code
Strongly Agree	2
Agree	1
Neutral	0
Disagree	-1
Strongly Disagree	-2

Table 4 Coding System for MAPS Analysis

To perform the test, the alpha was set to an arbitrary value of 0.1, and the one-tail p-value is calculated by using a built-in function in excel to expediate the calculation. While most researchers adopt the value of 0.05, due to this experiment's small scale and limited time frame, the larger alpha value could uncover the influence direction of the directed study course. Based on the selected alpha value, the result shows that for the "Persistence" and "Sense-Making" categories, there is sufficient data evidence to reject the null hypothesis since the p-values are 0.074 and 0.072 respectively, which are smaller than the alpha value of 0.1. That is, the directed study may have an impact on participants' persistence in problem-solving and sense-making skills in the field of mathematics. On the other hand, based on our test values, there is not enough evidence to state that the study has influenced the students from other aspects. (See *Table 5* and *Table 6*)

Categories	Confidence		Mindset		Real World		Answers		Interest	
	PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO
Mean	-0.1	-0.35	-0.45	-0.35	0.7	0.95	-1.5	-1.33	-0.15	-0.3
SD	2.41	4.45	4.68	5.40	5.91	6.68	5.21	8.57	3.08	5.06
P-value	0.235		0.398		0.165		0.343		0.241	
Result	**Not Reject Null**		**Not Reject Null**		**Not Reject Null**		**Not Reject Null**		**Not Reject Null**	

Table 5 Students' MAPS Scores by Category T-Test Result Pt. 1

Categories	Perssitence		Sense Making	
	PRE	PO	PRE	PO
Mean	-0.45	-0.8	-0.8	-0.4
SD	2.16	3.75	6.72	9.14
P-value	0.074		0.072	
Result	**Reject and Conclude Alter**		**Reject and Conclude Alter**	

Table 6 Students' MAPS Scores by Category T-Test Result Pt. 2

5.2.1.2 Overall Course Survey

In the introductory and post-session survey, besides the basic information regarding participants' educational backgrounds, questions asking participants' self-reported confidence in foundational mathematical topics and perspectives regarding their experiences in this course were also included.

For self-reported confidence in foundational math topics, the questions asked them to rate their understanding and preference in major and essential mathematical topics such as Arithmetic, Algebra, Geometry, Mathematical Analysis, etc. Then, to find the change in their self-reported confidence in the understanding of topics, an overall t-test and a t-test for each topic is performed. The null hypothesis for this test was that this directed-study course had no impact on participants' understanding and preference for overall mathematical concepts or one specific element or topic, while the alternative hypothesis states the opposite. As shown in *Table 7*, based on the survey data and the one-tail p-value calculated through the built in function in excel, the participants' responses cannot provide sufficient evidence to prove the impact of the directed study course on their understanding of a specific topic. With the limitation of the time and sessions, this result was not unexpected.

Topics	**Arithemetic**	**Algebra**	**Geometry**	**Math Analysis/Proof**	**Number Theory**
p-value	0.5	0.377	0.243	0.340	0.411
Result	Not Sufficient Evidence to Reject Null				
Topics	**Combinatorics**	**Calculus**	**Statistics**	**Set Theory**	**Trigonometry**
p-value	0.341	0.330	0.333	0.131	0.400
Result	Not Sufficient Evidence to Reject Null				

Table 7 Participants' Self-Reported Confidence Regarding Fundamental Mathematical Topics

The participants' feedback and overall comments regarding the curriculum and in-class activities can be summarized into three words: visualization, efficiency, and creativity. Specifically, all participants believed that the body movements helped them visualize the mathematical concepts, making them less abstract for them to understand. One of the participants gave an example of using the body to show the second derivatives as the changes in the slope. By utilizing the embodied tools, the participants found learning more efficient because they could connect the concepts with their movements or physical relationships with other participants to make the topics more tangible. Also, most participants mentioned that reviewing these mathematical concepts through embodiment was way more enjoyable than merely listening to lectures during class. In fact, while they were given the opportunity to read math details, they were pushed to think creatively regarding the definition of the concepts.

5.2.2 Micro-Level Survey Results

This section showcases and analysizes the results from micro-level surveys. *Figure 3* demonstrates participants' familiarity with selected mathematical concepts, indicating that students are most familiar with Calculus and least familiar with differential equations on average. *Table 8* indicates their self-reported confidence score for each topic before and after the in-class session.

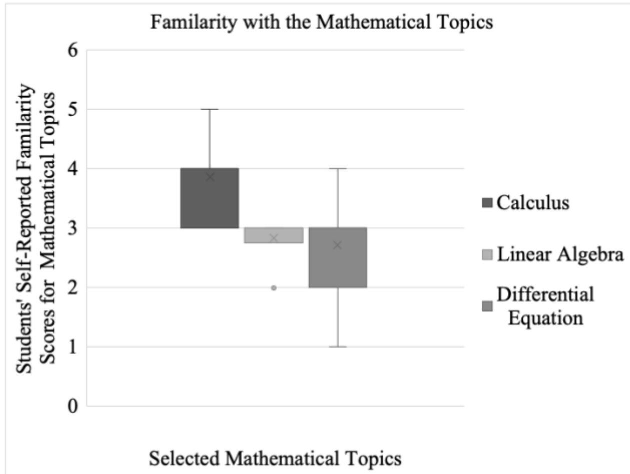

Figure 3 Score Quantiles for Students' Self-Reported Familiarity with Selected Mathematical Topics

Topic	Calculus		Linear Algebra		Differential Equation	
Intervention	Pre Understanding	Po Understanding	Pre Understanding	Po Familarity	Pre Understanding	Pro Familarity
Mean	4.14	4.00	2.17	3.57	3.43	3.43
Percent Change in Understanding	-3.45%		64.84%		0.00%	

Table 8 Participants' self-reported confidence scores for each of the topics before and after the in-class session

5.2.2.1 Calculus

The participants felt, on average, far more knowledgeable about this topic than other math subjects. Due to the foundational nature of calculus across a variety of disciplines, participants may be required to study it multiple times during their academic careers, regardless of their majors. Thus, the majority of participants had considerable understanding and implementation expertise with these principles. Owing to this, their focus would be on the instructor's direction in reviewing and approaching their known idea. Hence, there was no increase in students' self-reported levels of confidence regarding this topic.

For qualitative data, see the question heading "Which notion do you believe you "move" with your body the best? (most precisely?/most self-explanatory?) and the reason why "According to the majority of participants, their movement best exemplifies the combination of integration and derivation. Not only because the two are inverses of one another but also because they learned that visually, interpreting integration as "area" under the curve or the derivative as the inclination or “slope” of the curve at one point, they believed it was much easier to connect their existing knowledge and demonstrate them through the use of their limbs and physical positions. According to their brief responses, even though this session had not altered their approach to certain topics because they only executed what they had already visualized, the concepts were reinforced after the relative sessions.

5.2.2.2 Linear Algebra

Based on self-reported confidence scores and previous academic records, the majority of students are not very confident in their knowledge of this topic's concepts. Four of the seven participants had prior knowledge or experience with Linear Algebra from prior years. In addition to their facial and body responses during the sessions, individuals appeared to be in a state of confusion or learning when the instructor lectured on concepts such as span and linear transformation.

With the instructor's two sessions of activities and examples, the participants' self-reported confidence grew by 64.84 percent. In particular, the participants' comprehensive remarks revealed that the movement for linear transformation was self-explanatory with the movement activities to its definition. For the mentioned activity, students were asked to design their "initial vector" format, which consisted of a simple action, and then to repeat that movement by modifying a simple factor, such as lowering their body level or switching from two-leg standing to one-leg standing, so as to "multiply" the original vector by a "constant." As said, this practice helped "make the process enjoyable and instructive" by visualizing this abstract operation in terms of movements they could experience with their bodies.

5.2.2.3 Differential Equation

This topic had the lowest self-reported familiarity score among participants. Even though just one student had never taken this course before, the majority of students stated it was too difficult to remember the principles and applications.

Regarding the self-reported comprehension of the topics, there is no percent change in the responses of the pupils. Despite this, participants' brief responses indicated that the exercises were entertaining and beneficial for enhancing their understanding. Especially, they said that limited time and the intricacy of the subjects prevented them from concluding their conversation and receiving answers to all their queries from their peers and instructor. In addition, they mentioned that if the sessions were longer, they would have liked the opportunity to completely grasp the concepts through the class activities because the learning process was so engaging and enjoyable that they would love to learn more. For example, five out of seven students in this session responded that they now approach the concept of "fixed point" differently. This was because the activities not only helped them review the physics of gravitational force, but also helped them visualize the interaction between the variables and initial values. Importantly, they were able to draw linkages between mathematics and movement, mathematics and physics, and physics and movement to describe a common occurrence.

So, despite the fact that the self-reported score had not had a substantial impact on their comprehension, they stated that the sessions were beneficial to their process of identifying and acquiring concepts.

5.3 Interview

As a complementary tool to facilitate the present investigation, interviews gave the participants opportunities to directly address their perspectives regarding the directed-study course and clarify their responses in the survey. Within the interview design, questions were divided into three categories to inquire about students' general thoughts regarding interdisciplinary studies, personal feelings regarding the directed-study course, and their feedback on the study design.

For the first category, all students stated that the directed-study course had expanded their vision to some degree to allow them to see the connections between different subjects or between subjects and some aspects of their lives. For instance, several participants addressed that this course had made them realize the similarities between approaches they took when solving problems for various subjects.

> *Participant D: "Because I am an applied math student and doing integrated visual arts, the small program that we have at Emory, for me, I feel like I just think the same way when I do art or when I do a math problem, or even like a CS problem. I definitely solve all of these problems piece by piece first and then see the big picture. Also, the other day when I climbed, even though it was more physics related, I was thinking about how the angle that my leaning shoulders have with the horizontal line could impact the speed since we did this in the differential class the other day. I found connections everywhere."*

> *Participant E: "The way we dance out the derivatives and integral has reminded me of, even can make me think that we can dance the way I accumulate the functions in java to construct algorithms since they all about accumulating a certain value."*

While these two participants found similarities between mathematics and other subjects through moving, some participants found a connection between other kinds of arts and mathematics as well. Specifically, one student claimed that after the activities in class, "[she had] seen [mathematics] in music or general drawings a lot more." These comments indicated that the participants not only connected the movements with the mathematical concepts, but they also recognized what their body can represent, establishing the relationships between the movements with other knowledge or concepts of which they have known. Accordingly, the directed study course endorsed a habit in them to encourage them to note their behaviors and what meanings they can endue different meanings to simple body language.

The second part of the interview was devoted to particiapnts' supporting examples and personal feelings they did not have space to address in the post-course surveys. In particular, the participants shared similar feelings and emotional changes before and after they experienced each of the sessions.

Participant A: While I always felt tired on Tuesdays, but since this class is interesting, it is not like a burden and it's a way for me to do group activities, making me feel relaxed and gain some sort of energy.

Participant F: A lot of the time I do feel tired in the afternoon. But when I use 30 minutes to move around and with the class being discussion-based, I feel like this class wakes me up and makes me more energized in the end.

Participant E: To be honest, every time, because I am not a math major, I feel stressed going into each of the sessions. But I feel like when I go out and experience the session, I do feel relaxed and gain a sense of relief. Although I have the expectation that this class is going to be fun, without the expectation about what is about to go on in the session, I am stressed a little bit.

Hence, as suggested by the comments, while this class was designed to "teach" mathematical concepts that may bring some academic pressure to the session, the participants gained a sense of relief and relaxation and even felt energized, after they experienced the delivery of math through activities and group-based discussions. Also, the participants believed that the environment altered their mindset when walking into the dance studio instead of a traditional mathematical classroom:

Participant D: I think the change in the environment is challenging in a good way. Because, although it obviously is a weird setting to do math or anything related to that, it gives you the room and flexibility to think of other possibilities in that space. And that was hard at *first because we were not born to think this way throughout the traditional school system and not challenged to think in this environment, it is cool and interesting to experience.*

Participant B: While we have a fundamental code system in math to perform all sorts of calculations, such as plus is to add and minus is to subtract, we do not have that in the dance. This gives us a lot of freedom to make our own code, like treating touching one another as add or multiply. So, this just led to challenges when we tried to build something complex without consistency, but that's also where creativity comes in everybody can have their own definitions. In this way, when everyone is sharing their perspectives, representation, definition, or the code system, you can always learn and exchange your ideas with theirs, making this class fun and increasing one another's creativity.

Additionally, when asking participants about how their learning and studying style has influenced their experience in the session, the participants who had believed themselves to be "kinesthetic learners" found the overall design of the class helpful in facilitating them to understand the introduced mathematical topics. They mentioned that,

Participant A: Since I am a kinesthetic learner, I feel like I have to try it to fully understand it. For example, like the sub-space activities done in the linear algebra session. I totally forgot what sub-space was, but then with the activities to jump, stand, and move my limbs to represent vectors in space, I don't think I will ever forget about that because my body gained the memories from that moving experience.

Participant D: I think because I am a kinesthetic learner, and I believed that this learning style definitely helped during my learning in the session. Because I remember we were asked to do our own representation on function, slope, and other topics using our body parts, I feel like I fully understood them after I performed it. Sometimes it took me some time to understand somebody else's logic in representation because I didn't get to do it myself. So, I believe there is a connection between the style and gains from the course.

Then, when the author prompted the participants to provide their overall impression regarding the peers being their mentors and instructors, they answered the following.

Participant C: The instructor and teaching assistant being the professor have made the classroom environment and vibe really cool and interesting. Because [the instructor] is well prepared and we have the facilitator, we had less stress when expressing our perspectives.

Participant D: The sessions allowed me to have a good time with everyone, including the instructors, in the class. It's relaxing because all of us are the same age and there is no authoritative figure, but I feel like I am still learning. It was like a good balance.

> *Participant F: I feel like it's really opened my mind to different learning skills, I guess. Being able to look at a problem, even if I am not moving, or some materials from a different view. Also, just like, being able to use both sides of my brain, being able to move my body, and setting aside what I normally have done is definitely an interesting and fun experience. I think this just opened my eyes to see the possibilities of learning and trying new things.*

> *Participant G: I think the instructors did a great job hosting the activities and explaining the concepts. I enjoyed my time there in the dance studio, and it was really a stress reliever for me.*

As the others shared similar comments, participants expressed their enjoyment and appreciation during the interview. They were especially grateful for how the directed-study course has expanded their vision and opened their eyes to embrace novel approaches to academics or general problems encountered in life.

Chapter 6. Discussion

In this work, the general aim was to study the impact of participants' usage of body movements on their understanding of mathematical concepts. Methods incorporated in this study to explore the empirical evidence are field observation, surveys, and interviews. This chapter summarizes the previous chapter's results, demonstrating the findings reflected in the above methods.

First, all participants had a positive experience with the directed-study course. As shown in the participant's interviews and short responses, they have expressed emotional enjoyment as well as academic gains through participating in the sessions. Even though the class time was set to a later time of the day, which is early in the week, the participants could find a sense of relief during each of the sessions walking into the classroom. Most importantly, instead of merely playing games for emotional gain, the activities and content designed for each class allowed them to gain a deeper understanding or experience a unique approach and view mathematical concepts differently. Accordingly, the interdisciplinary course successfully helped the participants to explore a non-traditional learning approach to mathematics, allowing them to experience a fun way to learn and study.

Secondly, the class settings and course design increased the participants' creativity. To begin with, participants were challenged to think of math problems in a dance studio, a place that would not be generally associated with mathematics. Also, without chairs and tables the participants have no choice but to use their brains and body as tools to facilitate their understanding of the introduced topics. Hence, this new environment and "tools" forced them to think outside the box, making them use these instruments to approach their familiar mathematical topics from different perspectives. Additionally, as one of the participants mentioned in her interview, while there were established rules in mathematics that the participants used to follow, there were no fixed rules to define the meaning and operation of movements. Each participant was free and had the flexibility to develop different representations of the same concept as long as they made sense to them. Meanwhile, they were learning and gaining ideas from one another while being challenged to be creative when completing the assigned tasks. The environment overall endorsed innovative thoughts. However, such an approach also had its downside. According to participants' responses, the participants needed help to show more complex concepts since there were no standards or consensus on a mathematical representation. When communicating more complex topics or topics unfamiliar to everyone, participants found it hard to understand what their peers were representing and showing through their body movements. As a result, such free space and flexibility had the benefits of increasing participants' creativity as well as hindered mathematical communication.

Participants who identify themselves as kinesthetic learners benefited more from the embodied tools, or body movements and the environment. While all participants identified the helpfulness of designed activities from each session, participants who identified as kinesthetic learners in the introductory survey expressed their enjoyment in the analogies aid learning process more than those who did not identify as this kind of learner. In particular, when the evaluator interviewed the participants who claimed to be visual learners, they stated the combination of board use, video watching, and movement helped them engage in the sessions because it was hard for them to move what was drawing in their brain directly. Therefore, this indicates that the usage of embodied tools, especially body movements and physical activity, can prevail among participants who are kinesthetic style learners. For participants with other learning styles, a combination of different instructional tools may be adopted to ensure their learning experience and comprehension of mathematical concepts.

Based on the MAPS and the self-designed macro-level survey, empirical evidence showed that the directed study course impacted participants' attitudes and understanding of mathematical concepts. Specifically, the overall score has improved by 32.72%, indicating that participants' attitude has changed to be more similar to the experts' attitude toward mathematics. Participants' confidence in learning mathematics has improved by 71.42%, participants' interest in mathematical learning has improved by 36.36%, and participants' persistence in mathematical problem-solving has also improved by 32.47%. These show that embodied learning, especially the movement activities designed for each session, enhances participants' learning process by building confidence and establishing interest so that they would persist in their learning and practicing process. Also, based on the comparison between the introductory and post-course survey, it is noted that participants' self-reported preference and comprehension of topics of the differential equation have also increased by 64.84%. While the improvement in the other two topics is less significant, it could be attributed, based on participants' responses in the interviews, to their initial familiarity with the topics and the limited time for each session. So, this study has found that with the directed-study course, participants have an increase in positive mathematical attitudes and develop a deeper comprehension of mathematical topics.

Chapter 7. Conclusion and Future Research

Integrating movement and games into mathematical instruction has been an innovative approach for researchers in different fields. Theoretically, embodied learning can help participants map what they are unfamiliar with to their preferred and more familiar objects so that they can comprehend concepts and terminologies more efficiently with less effort. (Weisberg & Newcombe, 2017) While some researchers put the theory into action to demonstrate the increasing efficiency in teaching and its impacts on participants' mathematical learning, a detailed tracking system and evaluation had not been designed to show how much impact this approach or projecr yielded,d and what the benefits are. So, this study was designed to fill the gap, providing a detailed assessment system for the project..

While this study has reviewed how movements can impact mathematical instruction, there are many non-answered questions for future researchers to explore.

While this research has demonstrated qualitative and some quantitative data to show growth in participants' attitudes and mathematical comprehension, the overall impact of such embodied tools is not quantified and compared to the standard instructional method to demonstrate the percent change in participants' learning outcomes. Therefore, future researchers can participate in experiments on subject groups to allow them to study some concepts with traditional mathematical instruction for a period of time and study similar-difficulty concepts using innovative tools for another periodof time, and then compare the exam score at the end of both periods to see if there is any significant difference. This will allow the researchers to validate the instruction methods again and show the quantified improvement level.

While kinesthetic learners can benefit from mathematical movement, learners with other learning styles may experience a different level of change in mathematical attitudes and comprehension. Hence, future researchers and instructors can explore how other embodied tools could facilitate participants' mathematical learning. For instance, will visual art or architecture help visual learners study math?

While the directed study course is set alone to mainly give opportunities to the participants to experience the movement aspects of mathematics, such implementation of embodied tools is not used to accompany existing mathematical classes or lectures in the educational system. Thus, future researchers could make the movement-focused mathematical class as a "lab," or accompaniment, for the lecture classes. In these sessions, the professor or teaching assistant could mainly encourage the participants to "move" with the specific goals to study the standard concepts, providing the participants with another lens to re-learn or approach the notes differently. If impact can also be found in this instruction format, this would have a revolutionary effect on mathematical instruction. That is because while moving directly and entirely from the traditional to the innovative instructional method is difficult, this experiment would allow integration between the two, possibly increasing participants' learning efficiency with minimal changes to the traditional educational environment.

To sum up, the study has implemented a directed-study course to examine the relation between movements and participants' mathematical attitudes and comprehension changes. While resources and time are limited, the participants have gained from such experience to approach mathematical concepts differently, proving the effectiveness of such an instructional method. As a result, future researchers should keep exploring strategies to help participants learn more efficiently and with enjoyment.

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Appendix

APPENDIX I: Introductory Survey

Personal Demographic and Educational Information:

This questionnaire should take less than 10 minutes to complete. Please answer questions based on your experience. Your answer is important to our directed research, and this survey will be counted toward your participation grade for the "Move Your Math" class!

1. Name
2. Pronouns
3. Biological Gender
    a. Female
    b. Male
    c. Prefer not to say
4. Expected graduation year
    a. 2023
    b. 2024
    c. 2025
    d. 2026
5. Major(s)/Minor(s)
6. Did you go to a private high school or a public high school?
    a. Private High School
    b. Public High School
7. Are you a transfer student? If so, where are you transferring from?
    a. Yes, ______
    b. No
8. How many years have you been studying at Emory?
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5

Learning Styles:

This session will ask you questions related to your regular learning habits.

9. Among these traditional learning styles, what type of learning works **BEST** for you?
    a. Visual Learning - individuals who prefer to take in their information visually—be that with maps, graphs, diagrams, charts, and others
    b. Auditory learning style – individuals who learn better when they take in information in auditory form when it is heard or spoken
    c. Kinesthetic learning style - individuals who prefer to learn by doing
    d. Reading/Writing – Individuals who consume information best when it’s in words, whether that’s by writing it down or reading it
10. Among these traditional learning styles, what type of learning works **WORST** for you?
    a. Visual Learning

   b. Auditory learning style
   c. Kinesthetic learning style
   d. Reading/Writing
11. Among these learning styles, what type of learning works **BEST** for you?
   a. Logical/Analytical Learner - analytical learners depend on logic and analytical skills to understand a particular subject. These types of learners search for connections, causes, patterns, and results in their learning
   b. Social/Linguistic Learners -- favor educational lessons that include peer work or participation. Social/ linguistic learners get two things out of this participation: socializing (which they love) and a better understanding of a subject.
   c. Solitary Learners -- Solitary learners prefer to study alone without having to interact with other learners.
   d. Nature Learners – nature learners excel when in contact with nature. A nature learner's ideal study environment is calm and relaxing.
12. When you try to comprehend a topic/learning new concepts, do you like to collaborate with others, or do you like to study solo?
   a. Collaborate
   b. Studying Alone
   c. No Preference
13. Describe your **math studying strategy** (for example: doing all kinds of practice problems, watching YouTube videos, organizing notes into the structure, etc..) – Short Answer

Prior Experience with Mathematics:

This session will ask some questions related to your previous experience in math.

14. Do you plan to, or are you pursuing a major in the Math department at Emory?
   a. No
   b. Undecided, but considering majoring in one of the majors in the Math Department
   c. Mathematics BA, BS or Applied Math BS
   d. Applied Mathematics and Statistics BS
   e. Computer Science and Mathematics BS
   a. Economics and Mathematics BA
   b. Political Science and Mathematics BA
   c. Mathematics Minor
   d. Applied Mathematics Minor
15. What Math classes have you taken at Emory **BEFORE** this semester? (Circle the math classes you have taken)

   MATH 111, MATH 112, MATH 116, MATH 190, MATH 210, MATH 211, MATH 212, MATH 221, MATH 250, MATH 275, MATH 315, MATH 318, MATH 328, MATH 344, MATH 346, MATH 351, MATH 361, MATH 385, MATH 411, MATH 421, MATH 425, MATH 485

16. What Math classes are you **CURRENTLY** taking this semester?

   MATH 111, MATH 112, MATH 116, MATH 190, MATH 210, MATH 211, MATH 212, MATH 221, MATH 250, MATH 275, MATH 315, MATH 318, MATH 328, MATH 344, MATH 346, MATH 351, MATH 361, MATH 385, MATH 411, MATH 421, MATH 425, MATH 485

17. What topics in Math do you enjoy studying the most? (Rank the following topics of your favoritism from 1 – 5 with 1 being least preferred, 5 being most preferred, and 0 is not clear)
    a. Arithmetic
    b. Algebra
    c. Geometry
    d. Mathematical Analysis/Proof
    e. Number Theory
    f. Combinatorics
    g. Calculus
    h. Statistics
    i. Set Theory
    j. Trigonometry

Prior experience with Dance or Movements:

This session will ask some questions related to your previous experience in dance and movement.

17. Are you currently pursuing a Dance and Movement Studies Major or Minor at Emory?
    a. No
    b. Yes, Dance and Movement Studies Major
    c. Yes, Dance and Movement Studies Minor
18. When you are explaining things, do you include body language? If so, to what extent? (1 being least amount and 5 being most among)
19. Have you taken any dance classes before? (If Yes, the following question will pop up)
    1) Please list the type of dance you have learned before.
    2) How many years have you been trained?
    3) What aspects of moving are you drawn to? (for example: reducing stress, the intensity, the focus, the movement itself, the socializing)
20. Do you have any informal experience with dance (Club at School? Learning on your own?) If yes, the following question will pop up.
    1) What type of dance do you do?
    2) How did you feel when you danced? Do you like your experience with dance?
    3) What aspects of moving are you drawn to? (for example: reducing stress, the intensity, the focus, the movement itself, the socializing)

APPENDIX II: Post-session Survey

Personal Demographic and Educational Information:

This questionnaire should take less than 10 minutes to complete. Please answer questions based on your experience. Your answer is important to our directed research, and this survey will be counted toward your participation grade for the "Move Your Math" class!

1. Name
2. Pronouns
3. Biological Gender
   a. Female
   b. Male
   c. Prefer not to say
4. Expected graduation year
   a. 2023
   b. 2024
   c. 2025
   d. 2026
5. Major(s)/Minor(s)

Learning Styles:

This session will ask you questions related to your regular learning habits.

6. Among these traditional learning styles, what type of learning works **BEST** for you?
   a. Visual Learning - individuals who prefer to take in their information visually—be that with maps, graphs, diagrams, charts, and others
   b. Auditory learning style – individuals who learn better when they take in information in auditory form when it is heard or spoken
   c. Kinesthetic learning style - individuals who prefer to learn by doing
   d. Reading/Writing – Individuals who consume information best when it’s in words, whether that’s by writing it down or reading it
7. Among these traditional learning styles, what type of learning works **WORST** for you?
   a. Visual Learning
   b. Auditory learning style
   c. Kinesthetic learning style
   d. Reading/Writing
8. Among these learning styles, what type of learning works **BEST** for you?
   a. Logical/Analytical Learner - analytical learners depend on logic and analytical skills to understand a particular subject. These types of learners search for connections, causes, patterns, and results in their learning
   b. Social/Linguistic Learners -- favor educational lessons that include peer work or participation. Social/ linguistic learners get two things out of this participation: socializing (which they love) and a better understanding of a subject.
   c. Solitary Learners -- Solitary learners prefer to study alone without having to interact with other learners.
   d. Nature Learners – nature learners excel when in contact with nature. A nature learner’s ideal study environment is calm and relaxing.

9. When you try to comprehend a topic/learning new concepts, do you like to collaborate with others, or do you like to study solo?
    a. Collaborate
    b. Studying Alone
    c. No Preference
10. Describe your **math studying strategy** (for example: doing all kinds of practice problems, watching YouTube videos, organizing notes into the structure, etc..) – Short Answer
11. Did any of your selections from this section change from what you answered in the intro survey? If yes, what made these changes happen or what made you realize you are learning differently now?

Experience with Mathematics:

12. What Math classes are you planning to take next semester?

    MATH 111, MATH 112, MATH 116, MATH 190, MATH 210, MATH 211, MATH 212, MATH 221, MATH 250, MATH 275, MATH 315, MATH 318, MATH 328, MATH 344, MATH 346, MATH 351, MATH 361, MATH 385, MATH 411, MATH 421, MATH 425, MATH 485

13. Did you make any math class selections based on the "Move Your Math" directed research session? If so, how did our session influence your decision?
14. What topics in Math do you enjoy studying the most? (Rank the following topics of your favoritism from 1 – 5 with 1 being least preferred, 5 being most preferred, and 0 is not clear)
    a. Arithmetic
    b. Algebra
    c. Geometry
    d. Mathematical Analysis/Proof
    e. Number Theory
    f. Combinatorics
    g. Calculus
    h. Statistics
    i. Set Theory
    j. Trigonometry

Experience with Dance or Movements:

15. After having Move Your Math sessions, when you are explaining things, will you include more body language? If so, to what extend? (1 being least amount and 5 being most amount)
16. How did your previous experiences with dance influence your experience in Move Your Math sessions?
17. How did you feel when you use movement to understand math?
18. Are there any aspects of movement from our sessions that you were mostly drawn to? (for example, reducing your academic stress, the focus on your body, the movement itself, the socializing)

Final Comments on the Final Project and Overall Directed-study:

19. How did you prepare for your final project?
20. Which mathematical concepts did you want the class to learn in your project?

21. What activities did you design to help your students understand the concepts? What are the purposes of each designed activity?
22. How does the experience of "getting ready to teach" math through movement differ from your experience of being the student?
23. After teaching, did your perspective regarding the role of movement (or arts in general) in deepening your understanding of mathematical concepts change?
24. Do you have any additional comments regarding your experience in "Move Your Math" class? Do you have any suggestions for us to improve the class?

APPENDIX III: Mathematics Attitudes and Perception Survey

MAPS Categories and Corresponding Question Numbers:

Category	Question
Growth Mindset	5, 6, 22, 31
Real World	13, 15, 21, 25
Confidence	1, 14, 17, 20
Interest	12, 26, 32
Persistence	8, 10, 24, 29
Sense Making	3, 4, 11, 18, 23
Answers	2, 7, 9, 16, 28, 30
No category but scored for expertise	27
Filter statement	19
Expertise (expert consensus)	all except 19, 22 and 31

Prompts: (The agreed answer for the experts are in parenthesis)

This is a survey of your attitudes and perceptions about math; these statements all have the response choices Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree, and should take less than 10 minutes. Please choose the response that matches your opinion, not what you think an instructor might say or want to hear.

1. After I study a topic in math and feel that I understand it, I have difficulty solving problems on the same topic. (Disagree)
2. There is usually only one correct approach to solving a math problem. (Disagree)
3. I'm satisfied if I can do the exercises for a math topic, even if I don't understand how everything works. (Disagree)
4. I do not expect formulas to help my understanding of mathematical ideas, they are just for doing calculations. (Disagree)
5. Math ability is something about a person that cannot be changed very much. (Disagree)
6. Nearly everyone is capable of understanding math if they work at it. (Agree)
7. Understanding math means being able to recall something you've read or been shown. (Disagree)
8. If I am stuck on a math problem for more than ten minutes, I give up or get help from someone else. (Disagree)
9. I expect the answers to math problems to be numbers. (Disagree)
10. If I don't remember a particular formula needed to solve a problem on a math exam, there's nothing much I can do to come up with it. (Disagree) 11. In math, it is important for me to make sense out of formulas and procedures before I use them. (Agree)
12. I enjoy solving math problems. (Agree)
13. Learning math changes my ideas about how the world works. (Agree)
14. I often have difficulty organizing my thoughts during a math test. (Disagree)
15. Reasoning skills used to understand math can be helpful to me in my everyday life. (Agree)
16. To learn math, the best approach for me is to memorize solutions to sample problems. (Disagree)
17. No matter how much I prepare, I am still not confident when taking math tests. (Disagree)

18. It is a waste of time to understand where math formulas come from. (Disagree)
19. We use this statement to discard the survey of people who are not reading the questions. Please select Agree (not Strongly Agree) for this question. (Filter statement; discard data for respondents that do not choose Agree here.)
20. I can usually figure out a way to solve math problems. (Agree)
21. School mathematics has little to do with what I experience in the real world. (Disagree)
22. Being good at math requires natural (i.e. innate, inborn) intelligence in math. (Disagree)
23. When I am solving a math problem, if I can see a formula that applies then I don't worry about the underlying concepts. (Disagree)
24. If I get stuck on a math problem, there is no chance that I will figure it out on my own. (Disagree)
25. When learning something new in math, I relate it to what I already know rather than just memorizing it the way it is presented. (Agree)
26. I avoid solving math problems when possible. (Disagree) 27. I think it is unfair to expect me to solve a math problem that is not similar to any example given in class or the textbook, even if the topic has been covered in the course. (Disagree)
28. All I need to solve a math problem is to have the necessary formulas. (Disagree)
29. I get upset easily when I am stuck on a math problem. (Disagree)
30. Showing intermediate steps for a math problem is not important as long as I can find the correct answer. (Disagree)
31. For each person, there are math concepts that they would never be able to understand, even if they tried. (Disagree)
32. I only learn math when it is required. (Disagree)

APPENDIX IV: Sample Pre-session Survey and Post-session Survey

Pre-Session Survey for Calculus

Your answer is **important** to our directed research, and this survey will be counted toward your participation grade for "Move Your Math" class!

This survey should take less than 5 minutes to complete.

1. How familiar are you with Calculus (rate from 1 to 5 with 1 being not familiar at all and 5 being “I can confidently explain calculus topics to others”? Topics in calculus include but are not limited to Limits, Integral Calculus (Integration)
2. Have you taken courses at Emory related to this mathematical concept (MATH 111/112/112Z) or learned about the topic?
   a. If yes
      1) When did you learn it?
      2) How much do you think you understood about this topic when you learned? (rate with 1-5 scale with 1 being not understanding at all and 5 being fully comprehending)
      3) What helped you when you learned this topic?
   b. If no,
      1) What is your understanding of the topic? (You can try to interpret from the name if you have no idea what this topic is about)
      2) What do you expect to learn about this topic?
3. What do you expect to learn from this session?
4. How do you think your movement from this session is going to help you study this topic?

Post-Session Survey for Calculus

1. If you rate now, how familiar you are with this mathematical concept? (rate with 1-5 scale with 1 being not understanding at all and 5 being fully comprehending)
2. Which part of the sessions helped you comprehend topics related to Calculus?
3. Which activity/movement was your favorite from the two sessions with Calculus?
4. Which concept do you think you use your body to "move" the best? (most accurately?/most self-explanatory?) and why?
5. Do you think differently about this mathematical concept after this session?
6. What would you change about this session to make it better? (more informative and engaging)

APPENDIX V: Sample Observation Log for the Sessions of Calculus

Observation Log				
	Student		Instructor	
	Prework Before Class	Studying Materials Requried to Bring to Class	Instructional Tool (PPT?/etc)	Any outside resource (Speakers)
Input	N/A	N/A	Yes	Professor Manetta (Be there to support the warm up, participating in activities with students who are left unpaired, and complete some of the definition of some mathematical termiologies)
	Activities Done in Class		Comment Class Atmosphere/Side Notes	
	Name of the Activity	Comments on the Interaction between Students/Students vs. Instructor	Did the students enjoy this activity?	
Interventi ons	Move the Words	instructors are observing students' discussion and actions in activities	Yes, people choose different words and act it out without using a words and communication	
	Move and Guessing Words	During the session, instructor was asked to teach the students the definition first (cuz one of the student is not a math major), and then the students will know how to move and do it -- Try to learn and perform the concepts/Idea in their own way.	Refresh Students' memories regarding math, students are interpretating the same math words is different; From this activity, students are learning math concepts from different perspectives and enjoy this process more than just listening to lectures	
	Immediate Output		Aasignment after this Session	
	Is there any product produced in class?	Comments on the purpose of the product	Name/Kinds	Requirements for the Students
Session Output	video *1	Allow studenst to see how the TED TALKers is using movement to explan math. Give them an idea of how this could work	https://www.youtube.com/watch?v=Ws2y-cGoWqQ	watch the video
	Writing Reflection	Allow students to think about what they learned and how they could learn math in different ways	Writing: We tried to explain and to guess the concepts with the two activities in-class, do you think they were effective in reminding you some concepts you were vague about? How do you think teaching math with moving would help?	300 words
General Note Session	During the entire session, students were engaged in the activities. Walking in with tired emotion, but this class seemed to changed their emotion			

Observation Log				
Input	Student		Instructor	
	Prework Before Class	Studying Materials Requried to Bring to Class	Instructional Tool (PPT?/etc)	Any outside resource (Speakers)
	HW from last time	N/A	Y	Professor Lori
Interventions	Activities Done in Class		Comment Class Atmosphere/Side Notes	
	Name of the Activity	Comments on the Interaction between Students/Students vs. Instructor	Did the students enjoy this activity?	
	warm up	dependent: Students are trying to perform the independent variable, dependent variable, and their relation using their body	Yes, students realized that there are different and many ways to display a function in group. Some are using movements, and other are just using some stable "pose" or finger numbers to show variety of different quations.	
		gravity shifting: Students are getting into groups to show full reliance on one another -- This would actually signaling the relationship between one another	Yes, while students were not rely on each other that much, they become so after a while. One students is fully relying on another student such that the two students can even walk, run, while relying on one another. Later, a game is played that a student is pushing another students' stable position, this is game is for the testing of the "stability" of the students, to see if they are in a stable state.	
		showing different functions: using the curve of our body to display different functions -- cubic/quadratic	Students have different kinds of functions to show, a horizontal line, a linear function, a cubic function	
	First derivative	Displaying first derivative and second derivative of a function while moving	There are many ways to show changes in slop and many other things, we can see the video to show how people are using their body to display the change in magnitude in slope, and the direction; particularly, we showed sin and cos as a group	
Session Output	Immediate Output		Asignment after this Session	
	Is there any product produced in class?	Comments on the purpose of the product	Name/Kinds	Requirements for the Students
	First derivative and second derivative performing ideas for functions	Fullfill the class activity	form-- https://forms.gle/VBL3mzYUFtHNTnqF8	"recommend you do the first few questions earlier since they require you to remember what you did in class. There is also a short reading to answer one question and it is attached in this email"
			Reading - Chan&Stern-Movement&Math-Bridges2016-FINAL copy	
General Note Session	Similar to Previous Observation			

APPENDIX VI: Survey Quantitative Results

MAPS Survey: Researchers' Appraoch (see [2])

Category	Question#	A		B		C		D		E		F		G	
		PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO
Sense Making	3	1	0	1	0	1	0	1	0	1	1	0	0	1	0
	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	11	1	1	1	1	0	1	1	1	1	1	1	1	1	1
	18	1	1	1	1	0	0	1	1	1	1	1	1	1	1
	23	1	1	1	1	0	0	1	0	1	1	0	1	0	1
Natures of Answers	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	7	0	0	1	0	1	0	0	0	1	1	0	1	1	1
	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	16	1	1	1	1	1	0	1	0	1	1	0	0	1	1
	28	1	1	1	1	0	0	1	1	0	1	1	0	0	1
	30	1	1	1	1	0	0	1	1	1	1	1	1	1	1
Growth Mindset	5	1	1	1	1	1	0	1	1	1	1	1	0	1	1
	6	0	1	1	1	0	1	1	1	1	1	1	1	1	1
	22	0	1	0	0	0	0	1	1	1	1	0	0	1	1
	31	0	0	0	0	0	0	0	1	1	0	0	0	1	1
Real World	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	15	1	1	1	1	0	1	1	1	1	1	1	1	1	1
	21	1	1	1	1	0	1	1	0	1	1	1	0	1	1
	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Confidence	1	1	1	0	1	0	0	1	0	1	0	0	0	0	1
	14	1	1	1	1	0	0	1	1	0	1	0	0	0	1
	17	1	1	1	1	0	0	1	0	0	0	0	1	0	1
	20	1	1	0	1	1	1	0	1	0	1	1	0	1	1
Interest	12	1	1	1	1	0	1	0	1	1	1	1	0	1	1
	26	1	1	1	1	0	0	1	1	1	1	1	0	1	0
	32	1	1	1	1	0	0	0	1	1	1	0	0	0	1
Persistence	8	1	1	1	1	0	0	0	1	1	1	0	0	1	0
	10	1	1	1	1	0	0	1	1	1	1	0	1	1	1
	24	1	1	1	1	0	0	1	1	0	1	0	0	1	1
	29	0	1	0	0	1	0	0	0	0	0	0	0	0	1
Scored Question	27	1	0	1	1	0	0	0	0	1	1	0	1	0	1
Mean		0.839	0.871	0.839	0.839	0.355	0.355	0.742	0.710	0.806	0.871	0.516	0.484	0.742	0.903

Table 9 MAPS Survey Students' Score and Its Mean

MAPS Survey: Pared t-test Appraoch

Categories	Confidence		Mindset		Real World		Perssitence		Interest		Sense Making		Answers	
	PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO	PRE	PO
Survey Result	1,14,17,20		5,6,22,31		13,15,21,25		8,10,24,29		12,26,32		3,4,11,18,23		2,7,9,16,28,30	
	0	0	0	0	6	4	0	0	0	0	2	6	0	0
	1	0	0	2	2	5	1	1	1	0	4	4	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-3	-2	-5	-2	0	0	-3	-3	-3	-5	0	0	-4	-5
	0	-4	-2	-6	0	0	0	-4	0	0	0	0	-4	-4
	0	0	2	2	4	4	0	0	2	4	0	2	0	0
	2	1	3	4	3	5	1	2	3	4	0	1	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-3	-3	-1	-2	-1	0	-2	-3	0	0	-5	-1	-3	-2
	0	0	0	0	0	0	-2	-2	0	0	0	0	-6	-10
Coded as Following:	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Strongly Agree = 2	3	1	2	2	0	1	0	0	1	0	0	0	1	1
Agree = 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neutral = 0	-3	-4	-1	-3	-4	-5	-4	-4	-5	-4	-5	-7	-1	-2
Disagree = -1	0	-2	-6	-2	-2	0	-2	-4	0	0	-2	0	-6	-2
Strongly Disagree = -2	0	0	0	0	0	0	2	2	0	0	0	0	0	0
	2	6	2	2	6	6	1	1	1	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	-1	0	-1	0	0	-1	-1	-2	-3	-5	-1	-2	-4	-4
	0	0	-2	-4	0	0	0	0	0	0	-8	-8	-4	-4
											0	0	0	0
											0	1	1	2
											0	0	0	0
											-3	-4	-3	-3
											-2	-2	-2	-2
													0	0
													0	0
													0	0
													0	-1
													-10	-8
Null Hypothesis	PO=PRE Mean of Pre-study MAPs Result = Mean of the Post-study MAPs Result; that is this directed-study course has no impact on students' perceptions tow													
Alter. Hypothesis	PO>PRE Mean of Pre-study MAPs Result < Mean of the Post-study MAPs Result; that is this directed-study course has impact on students' perceptions toward													
Calculation														
Mean	-0.1	-0.35	-0.45	-0.35	0.7	0.95	-0.45	-0.8	-0.15	-0.3	-0.8	-0.4	-1.5	-1.33
Standard Deviation	2.41	4.45	4.68	5.40	5.91	6.68	2.16	3.75	3.08	5.06	6.72	9.14	5.21	8.57
P-value(t > t-value)	0.235		0.398		0.165		0.074		0.241		0.072		0.343	
Result (alpha = 0.1)	**Not Reject Null**		**Not Reject Null**		**Not Reject Null**		**Reject and Conclude Alter.**		**Not Reject Null**		**Reject and Conclude Alter.**		**Not Reject Null**	

Table 10 Self-Coded MAPS Survey Students' Score and the Paired t-test

Self-Designed Macro-Level Survey: Self-Reported Confidence Level in Mathematical Topics

Topics	Arithemetic		Algebra		Geometry	
	PRE	PO	PRE	PO	PRE	PO
Result	3	5	3	5	4	3
	3	4	3	4	4	4
	4	4	4	4	2	1
	5	4	5	4	4	1
	4	3	4	3	2	3
	5	5	5	5	5	5
	4	3	5	5	5	5
T Test (p-value)	0.5		0.377		0.243	
Result (alpha = 0.1)	Not Sufficient Evidence to Reject Null					

Table 11 Self-Designed Macro-Level Survey Students' Self-Reported Confidence Level in Mathematical Topics Part I

Topics	Math Analysis/Proof		Number Theory		Combinatorics		Calculus	
	PRE	PO	PRE	PO	PRE	PO	PRE	PO
Result	3	1	2	1	2	2	5	5
	2	3	3	2	3	3	4	5
	4	5	4	4	4	4	4	5
	1	2	1	3	1	3	5	4
	4	2	3	2	5	2	5	4
	1	3	1	3	1	3	3	1
	2	3	1	1	1	2	5	5
T Test (p-value)	0.339815678		0.411		0.341		0.330	
Result (alpha = 0.1)	Not Sufficient Evidence to Reject Null							

Table 12 Self-Designed Macro-Level Survey Students' Self-Reported Confidence Level in Mathematical Topics Part II

Topics	Statistics		Set Theory		Trigonometry		Overall
	PRE	PO	PRE	PO	PRE	PO	T Test (p-value)
Result	3	4	3	2	3	4	0.397137966
	3	3	3	2	3	4	
	4	4	4	4	4	4	
	4	2	3	4	3	2	
	1	3	3	2	3	3	
	1	1	4	1	3	1	
	3	4	1	1	3	5	Not Sufficient Evidence to Reject
T Test (p-value)	0.332661939		0.131		0.400		
Result (alpha = 0.1)	Not Sufficient Evidence to Reject Null						

Table 13 Self-Designed Macro-Level Survey Students' Self-Reported Confidence Level in Mathematical Topics Part II

Micro-Level Survey Students' Self-Reported Familarity and Confidence Score

Topic	Calculus			Linear Algebra			Differential Equation		
Intervention	Familarity	Pre	Po	Familarity	Pre	Po	Familarity	Pre	Pro
		Understanding	Understanding		Understanding	Familarity		Understanding	Familarity
Result	4	5	5	2	2	3	1	0	4
	4	5	3	3	4	4	3	4	2
	4	4	5	3	0	3	2	5	3
	3	3	4	3	0	4	4	4	3
	5	5	4	3	4	4	3	3	4
	4	4	3	3	3	3	3	3	4
	3	3				4	3	5	4
Mean	3.85714286	4.14	4.00	2.83	2.17	3.57	2.71	3.43	3.43
Percent Change in Understanding	/	-3.45%		/	64.84%		/	0.00%	

Table 14 Micro-Level Survey Students' Self-Reported Familarity and Confidence Score

APPENDIX VII: Interview Questions

Note: Based on participants' survey responses, not all questions are asked during all interviews because some participants have addressed them in their answers.

Interview Questions for Directed Class (MATH 495R)

For each question provide the answer you would have given before this experience/class and share anything that has changed after taking this course.

1. How would you describe the connections between math and the arts?
2. What other majors/minors do you have? Does this class help you think of the connection between math and the other major?

Then the following question is about your experience prior to each session:

1. Do you feel like you are prepared for each session?
2. Do the pre-session materials give you a preview for each session?
3. How does your body feel in general when you walk into a session? (start with this one)
4. What word would you use if you need to fill out the sentence to describe your experience:
    - When I feel _________, I am eager to move

Next, I have some questions about your perspectives regarding the content and settings of the sessions:

1. Which session was the most memorable for you? Why?
2. Which session(s) helped you deepen your understanding of the corresponding mathematical concepts? Why?
3. Which in-class activity was the most engaging? (You feel it is easy to follow the instruction and it is fun and easy to interact with the instructor)
4. Which in-class activity helped you understand a mathematical concept?
5. How do you feel when you do math in a different environment? What is your intention here?
6. How do you feel about the instructor being a peer/student?
7. How effective were the setups/structures of each session?

Lastly, we will end the interview with some general questions regarding your overall feelings and reflections about this directed study course:

1. Which concepts do you think this directed study class helped you understand? Why?
2. Have your perceptions changed regarding the movement's role in learning?
3. How might you incorporate math and movement after you experience this session?
4. Will you incorporate this approach to learning in Math based on these experiences?