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Students' Mathematical Learning During the COVID-19 Pandemic

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Cover Page Footnote

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Synopsis

This paper discusses our new approach to assessing student learning. This approach includes the use of a final project rather than a cumulative exam. In particular, we measure learning by assessing students' ability to connect mathematics to the real world via a final project. We suggest that students taking a deep dive into one particular math concept and being able to make connections between that concept and the real world are educational achievements during this pandemic. We also argue that there is value in online learning because students who learn online choose to use library resources and develop their own interests by attending office hours, all of which benefit their learning.

Keywords: project-based learning, undergraduate students, mathematics teaching

1. Introduction

Many instructors transitioned to distance learning when the COVID-19 pandemic occurred. As a result, certain universities and institutions have changed the way that they assess student learning. Our approach, in particular, includes assessing students' learning with a final project rather than with a

cumulative exam. The final project consists of a final paper and presentation. Students write a research paper based on any mathematical or interdisciplinary topic covered in class. The paper should reflect their study and understanding of the mathematical topic and must contain an application of the topic. In addition, the paper must include at least one related graph or chart that helps explain how the mathematical concept is applied. Students also present their research paper findings to the class.

The final project encourages students to use logic, reasoning, and mathematical tools to develop problem-solving strategies. Students can work with peers, share thoughts, and enjoy learning. Importantly, the project provides an opportunity for students to take a deeper dive into understanding mathematical concepts discussed in the classroom.

When we transitioned to using a final project, we assessed student learning through a project instead of through a cumulative exam. In particular, In what follows, we seek to address the following questions:

Research Question 1 (RQ1): Did learning mathematics through the final assessment process generate an overall positive or negative experience for the students?

Research Question 2 (RQ2): Did the final assessment generate any deeper learning for the students?

Research Question 3 (RQ3): Did the students make the connection between mathematics and the real world through the final assessment process?

Through this work, we also hope to present ideas for how instructors might assess student learning in mathematics courses.

2. Background

The goal of our study was to understand our students' mathematical learning during the pandemic. Menlo College mathematics faculty conducted final assessments for their courses in one of two ways—projects or cumulative exams—during the 2020-2021 academic year. All respondents were enrolled in Math 100, an undergraduate algebra course. We initially hoped to compare the effectiveness of the mathematical experiences in both assessment types. However, 95.5% of students (21 out of 22) chose to do a final project.

The study revealed that 90.9% of the students recommend future math students to undertake a final project rather a cumulative exam. Due to the lack of data for the cumulative exam assessment method, the focus of the study was shifted to the overall mathematical learning of Menlo students during the fall of 2020.

3. Literature Review

First, we want to take a closer look at what has been done with project-based learning. In [6], the author investigates two things: what project-based learning (PBL) looks like in the mathematics classroom, and how effective PBL is in teaching skills. The author states that there is a lack of evidence that PBL in mathematics increases students' mathematical skills. The article suggests that schools that integrate PBL through their math curriculum rather than just stand-alone projects gain more student achievement

Tabuk and Özdemir [7] applied project-based learning in a mathematics lesson to find and understand the effects of multiple intelligence on the students' mathematics achievement. Multiple intelligence means the different ways students learn and acquire information whether in a project-based learning setting or in a more traditional classroom setting. The study was conducted at two different schools. There were 144 students across six math classes in total. Three classes were chosen at random from each school. There were two experimental groups and one control group. A quiz was administered to the students from the selected classes to determine their level of intelligence. They were then separated into two groups, the first of which consisted of students that received the highest marks on the multiple intelligence quiz, and the second of which consisted of students that received the lowest marks on the multiple intelligence quiz. The control group learned math using a traditional method. The data were collected by using a mathematics achievement test and multiple intelligence quiz. In conclusion the authors suggested that there is no statistically significant effect of the multiple intelligence approach in project-based learning if applied to a math lesson.

Another study [5] focused on traditional (TL) versus project-based learning (PBL) in an honors-level math course with two research questions. The first research question explored if there was a difference between students' mean performance scores if students were instructed using project-based learning methods as opposed to traditional learning methods. The second research

question explored if there was a difference in students' motivation if students were instructed using project-based learning methods as opposed to traditional learning methods in an honors math course. The study consisted of the experimental PBL group and the control TL group. The mode of data collection was the end-of-unit tests used in both groups. The results showed that the students that learned using PBL methods performed better than those students who used traditional methods because the experimental PBL group's overall mean score was double that of the control TL group. There was no significant difference in the motivation of students between the two groups.

Similarly, a three-year case study was conducted on two schools with alternative mathematical teaching approaches [3]. One school used a traditional textbook approach, and the other used open-ended activities. The author of [3] states that students exposed to mathematics in an "open, project-based environment" built a more conceptual understanding and the approach prepared them well for participating in both school and non-school settings. She also mentions that "it seemed that the act of using mathematical procedures within authentic activities allowed the students to view the procedures as tools that they could use and adapt" (page 59). Overall, students benefited from this study's open-ended, project-based approach by viewing math as a subject they can use in the real world.

The effectiveness of project-based learning is called into question in such studies. PBL often passes the test with flying colors. For instance, the article [2] focuses on undergraduate students' achievements based on the effects of Project-Based Learning (PBL) techniques in a science teaching course. The study investigated in [2] involved two groups: one treatment group, which uses PBL methods, and one control group, which uses traditional teaching (TT) methods. The authors investigated students' self-efficacy beliefs about science teaching by using the self-efficacy belief scale (SEBS); they used the Science and Technology Teaching Achievement Test (STTAT) to measure student achievement. The SEBS and STTAT were used in pre and post-test assessments. The results indicate that students who were instructed with PBL methods performed better on the Post-SEBS and the Post-STTAT. Thus, the study suggests that students who used PBL methods had higher student achievement and self-efficacy. The article also suggests that the students in the PBL group had more positive opinions about PBL methods compared to students exposed to traditional teaching methods.

It is perhaps worth noting that there is an abundance of articles in the literature that discuss project-based learning at the K-12 levels but not many in college-level math courses. One of the few papers within the college context, [1], suggests that PBL may not be the best practice for mathematical learning under certain conditions such as when there is minimal guidance for students. The author of [1] argues that the PBL approach may not be academically beneficial for all students. One example is when project topics are preselected, which results in some students having adequate topics while others receive topics that are not quite challenging enough to encourage growth. Overall, the author concludes that project-based learning can be successful in some courses and classrooms, and for some students, but not for all.

The purpose of our paper is not to determine if students perform better with project-based learning methods versus traditional learning methods. We believe that it nonetheless contributes to the conversation about the value of PBL in terms of how it benefits student learning and understanding.

The technical aspect of our research was mainly based on identifying patterns and extracting themes from our dataset. Chapter 4 from Volume 2 of the *APA Handbook of Research Methods in Psychology* [4] provides detailed guidelines for effective thematic analysis, and in this paper we used the methods therein.

4. Our Study

We conducted our Math Learning Experiences Survey in the summer of 2021. We sent it 83 students who were enrolled in Math 100 during the fall of 2020. There were six sections of Math 100 in total. Students' participation was voluntary. Students were informed of receiving a gift card before starting and they received a twenty-dollar gift card upon completion.

The survey consisted of twelve questions, both short answers and multiple-choice. Question 1 asked students to provide their email addresses since emails were collected to appropriately send the gift cards. Questions 2-6 were multiple-choice questions. Questions 7-12 were short answer questions. A copy of the survey is included in Appendix A.

Twenty-two student responses were collected via Google Forms. We then went through the dataset to identify patterns, common threads, and themes. At times, the responses suggested the themes while in other cases we looked

for certain traits related to our research questions. Tables were created in a Google spreadsheet for analysis. The patterns were then numerically quantified and visually represented using a Google spreadsheet.

We determined the categorizations that were connected to the research questions. The categories we focused on are shown below.

Category 1 (C1): Students' mathematical experiences during the final project, based on RQ1.

Category 2 (C2): Students' mathematical perspectives after the final project, based on RQ2.

Category 3 (C3): The connections students were able to make between mathematics and the real world in their final project, based on RQ3.

4.1. Category 1: Mathematical experiences

For Category 1, we focused on the student responses to Q8 of the survey: *"Please share your self-experience while preparing for the MTH 100 final (project or cumulative exam)."* The responses generated "positive", "negative", and "neutral" themes.

We read all student responses and looked for implied messages that were positive, negative, or neutral. We used a Google spreadsheet to analyze the data. We then created a table to tally the number of responses that suggested positive, negative, or neutral experiences. After reading each response multiple times, if both researchers agreed that a response conveyed a generally positive experience, then the response was counted as positive. If both researchers agreed that a student response conveyed a generally negative experience, then the response was counted as negative. Responses that conveyed neither positive nor negative experiences were marked neural. Table 1 provides a few examples of student responses that were marked positive, negative, and neutral.

After processing student responses, we found that 47.62% of responses aligned with positive experiences; 42.86% of responses aligned with neutral experiences; 9.52% of responses aligned with negative experiences. Overall, only two responses aligned with negative experiences out of which one ("It was easy but some of it felt unnecessary") was assessed with a project and the other ("stressful") student was assessed with a cumulative final.

Table 1: Examples of student responses for Category 1 (§§4.1)

Themes	Responses
Positive	"I did research on decimals in our world, and it blew my mind the research and how important a decimal is. I finished my slides and talked out loud to prepare for the presentation. I focused on being enthusiastic and engaging" "Personally, I enjoyed preparing for the MTH 100 final project because I was able to show my organization and creativity through this project" "It was a lot less stressful it took a lot of pressure off of finals and I could demonstrate something I liked and was good at"
Negative	"It was easy but some of it felt unnecessary"
Neutral	"I did my layout first on Google Slides. I added slides as needed to give a background of my topic, explain, do an example, and why it was important. After, I did my writing paper which just expanded my explanations from my slides." "I went to the math center 3x a week for tutoring and studied for hours with my friends in the library" "I had to do a lot of research while also putting in my own opinions and thoughts to make it come together"

4.2. Category 2: Mathematical perspectives

For Category 2, we focused on the student responses to Q7 of the survey: *"Has your perspective about mathematical understanding changed after taking the final (project or cumulative exam)? If so, then please explain how."* Overall, 81.82% of the respondents experienced a change in their mathematical perspectives after the final while 18.18% of the respondents did not experience a change in their mathematical perspectives after the final.

In addition, we zeroed in on four key themes that were related to students' mathematical perspectives after the final project, based on student responses to Q9 of the survey: *"How has the final (project or cumulative exam) affected your learning moving forward?"* To do this, we read all student responses multiple times and used a Google spreadsheet to analyze the data. We then created tables to tally the recurrences of themes. Four key themes emerged:

- General positive feeling.
- General negative feeling.

- Resourcefulness.[1]
- Gaining deeper understanding of concepts.[2]

After reading each response multiple times, if both researchers agreed that a student response conveyed the presence of a certain theme, then it was counted towards the particular theme. Table 2 provides examples of responses generating themes that align with "resourcefulness", "gaining deeper understanding", and both together.

Table 2: Examples of themes and responses for Category 2 (§§4.2)

Themes	Responses
Resourcefulness	"It prepared me for future courses and helped develop skills to communicate what I'm learning as well."
Gaining deeper understanding	"It helped me further grasp the information we learned in class"
Resourcefulness and gaining deeper understanding	"It helped me gain a better understanding of different topics and see how most topics are connected to my everyday life."

Overall, 59.09% of the responses aligned with the theme "resourceful"; 36.36% aligned with the theme "gained deeper understanding". 31.82% of the responses generated a general positive feeling or impression while 13.64% generated a general negative feeling or impression.

4.3. Category 3: Making connections with the real world

For Category 3, we reread all student responses corresponding to the survey question Q7: *"Has your perspective about mathematical understanding changed after taking the final (project or cumulative exam)? If so, then please explain how."* Once again we used a Google spreadsheet to analyze the data. A common thread that emerged was being able to make connections between mathematics and the real world. We created a table to see how much and

[1]In the scope of this paper, "resourcefulness" is defined as the ability to use math in jobs, internships, future courses, and everyday life.

[2]In the scope of this paper, "gaining deeper understanding" is defined as students understanding beyond the surface level and taking a deep dive.

to what extent students made such connections. Some responses pointed to being able to make connections between mathematics and the real world, and some did not. A few suggested no specific alignment. After reading each response multiple times, if both researchers agreed that a student response conveyed the presence of the connection then the response was marked "yes", otherwise "no". Responses that were neutral were tallied under "not enough information." We saw that the majority of students were able to make connections. Table 3 below provides responses that suggested or did not suggest a connection between mathematics and the real world or responses that were neutral.

Table 3: Examples of responses for Category 3 (§§4.3)

Classification	Responses
Suggested connection	"Yes, I realized that we use math in our life more than we think we do. I really enjoyed doing this project because I expanded my thinking and challenged my presentation skills."
Did not suggest a connection	"Entering MTH 100 I thought my final would be the usual, a multiple-choice final. After knowing its would not be that and rather a topic of my choice I loved the idea. Focussing on one topic is helpful because you get to practice a topic and if you are confused on other topics people teach them and sometimes you understand the concept better."
Not enough information	"Yes; due to the fact that you get to learn a more deeper meaning than what you would in the class or over zoom"

An overwhelming majority (59.09%) of student responses suggested a connection between mathematics and the real world while 27.27% did not; 13.64% of responses did not provide enough information. We believe that the project approach encouraged students to develop a deeper understanding of mathematics by allowing them to see how their topic applies to the real world.

Below, we list a few more responses that suggested that students were making connections between mathematics and the real world.

> "Yes since the final was real-world applications, it helped me see how math is active in our everyday life"
>
> "Yes, it made me realize how applicable simple math concepts are to real life."

> "It made me realize how our everyday lives had a little math involved, even when we might not take notice of it."
>
> "This project allowed me to look at math in a different lens and go deeper into a topic. It was something that I haven't really done before so it was very intriguing. I think that this project should continue on for years as it was very fun and interesting."
>
> "Yes, the final project helps emphasize how math is used in everyday life. It is also interesting to see my peers' presentations and how they related their topic to the real world."
>
> "Yes, the project allowed me to apply math to the real world"
>
> "Yes, my perspective on mathematical logic has changed after taking the final by applying these topics into real-world issues. Tying real-life problems with mathematical equations gives me a better understanding on both topics"
>
> "It taught me how to apply math in different perspectives that allow me to apply my knowledge to the real world."
>
> "Yes. Allowing students to do a final Project have myself the chance to do my own research and see how mathematical terms are applied used in other aspects of the world that I did not think about before. It was a positive change that I still find myself remembering today."
>
> "The final project changed my perspective on math because it helped me understand how often we use algebra in our daily lives."

5. Other Factors, Other Takeaways

We believe that project-based learning made a major impact on students' mathematical understanding. But there were probably other contributing factors, too. Through the semester, we incorporated pedagogical adjustments to promote more hands-on mathematical activities. For example, some of the final project topics included parabolic paths, baseball statistics, and compound interest, which involved exponential functions. We used online teaching tools like Zoom, Schoology, and Google Suite to create a better learning environment. Students used `Excel` to create their charts and graphs.

As mentioned before, 95.5% of respondents (21 out of 22) took the project-based final. While working on the projects, they gained the ability to connect mathematics with the real world. They also began to see their mathematical knowledge as part of a range of resources they could pull from when solving a problem; they found that they could use other resources to supplement their mathematics learning. 31.8% of the respondents used resources like on-campus peer tutoring while preparing for the final, which promoted peer connection and resourcefulness. In addition, 50% of the students used library resources to study for the final—whether project or cumulative exam—which also revealed skills that evolved throughout the learning process. Lastly, 22.7% of the students valued discussion with the instructor. The availability of Zoom breakout sessions helped instructors to go beyond the traditional lecture delivery mode and encouraged more discussion-based learning.

6. Closing Remarks

The COVID pandemic changed how educators teach students and measure learning. We responded to the pandemic by choosing to assess student learning with a final project that consisted of a research paper and presentation. We measured student learning by seeing if students could make connections between mathematics and the real world, and we were happy to see that a majority of the students made such connections.

There is something to be said about students completing a focused final project and diving deep into one particular math concept rather than taking a cumulative exam that covers multiple concepts. We believe that this allowed our students to make connections with the real world much more readily. We also believe that, in times of crisis such as this pandemic, we should be satisfied if our students can make such connections and should view it as an achievement on its own. Furthermore, we see value in project-based learning because the students independently used library resources and visited office hours on their own due to the final project. We will continue to assess students using a project-based approach in our future math courses.

Notes

Our research was approved through the Menlo College IRB Committee's ethical review processes.

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A. Math Learning Experiences Student Survey

In the following pages, we include the Math Learning Experiences survey we had students fill out that this study was based on.

Math Learning Experiences Survey

This surveys intends to capture your learning experiences in the math courses (MTH 100) at Menlo. The data collected from this survey will be used to study and understand methods/approaches to create better mathematical experiences for Menlo students and beyond. The responses collected in this survey will remain confidential and will be shared only in aggregate form. Your participation is voluntary. As a token of our gratitude, you will receive a gift card (worth $20), upon completion of the survey. The survey is not anonymous since emails will be collected to appropriately send the gift cards.

This survey contains 11 questions and can be completed under 10 minutes. Thank you for filling out this form and we sincerely appreciate your support in creating a stronger math community.

The respondent's email (**null**) was recorded on submission of this form.
* Required

1. Email *

2. Which of the following have you completed as the final in your Math 100 course? *

   Mark only one oval.

   - ◯ Final Project (Worked on an application, final paper and presentation)
   - ◯ Cumulative Final (Took a test that was multiple choice and/or short answer)

3. Based on which final you completed, how would you rate your level of preparedness for the next course? *

   Mark only one oval.

	1	2	3	4	5	
Not Prepared	◯	◯	◯	◯	◯	Very Well Prepared

4. What resource have you used most in preparing for your MTH 100 final (project or cumulative) *

   Mark only one oval.

   - ◯ On campus tutoring
   - ◯ Discussion with peers
   - ◯ Discussion with instructor
   - ◯ Self study (using textbook, lecture notes or other resources)
   - ◯ Other: _____

5. Have you used library resources (literature study onsite/online) to prepare for your MTH 100 final (project or cumulative)? *

   Mark only one oval.

   - ◯ Yes
   - ◯ No

6. Which of the following would you recommend for future math students at Menlo? *

   Mark only one oval.

   - ◯ Final Project
   - ◯ Final Cumulative Exam

7. Have your perspective about mathematical understanding changed after taking the final (project or cumulative exam)? if so, then please explain how. *

   _____

8. Please share your self experience while preparing for the MTH 100 final (project or cumulative)? *

9. How has the final (project or cumulative exam) affected your mathematical learning moving forward? *

10. How has your knowledge from MTH 100 helped you prepare towards your major? *

11. How has your knowledge from MTH 100 helped you prepare for future internships? *

12. How has your knowledge from MTH 100 helped you prepare for workforce in Silicon Valley and outside? *