Math Labs to Support Engineering Education - NSF Advancing Innovation and Impact in STEM Education at Two-Year Institutions

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Abstract

An early momentum metric of success is completion of a gateway mathematics course in the first year of study [1]. In [name of] two-year college, historically fewer than one-half of incoming students successfully complete a first-year college-level math course, including those who declare an engineering major. Community colleges must develop innovative, skill-building practices in key mathematics courses to meet incoming students at their skill level.

This poster describes a mixed methods evaluation study that explored the implementation and outcomes of mathematics labs with the support of an NSF Advancing Innovation and Impact in STEM Education at Two-Year Institutions grant. This study explored the question: "*What is the effect of math labs on the learning environment and student attitudes about mathematics in College Algebra, Trigonometry, and Calculus 1?*" The team has created, tested, and finalized over 30 labs that address how the first, second, and third derivative are related to each other. Students program robots and in one lab analyze the Back to the Future flux capacitor.

Use of math labs increased from 3 to 24 faculty, with the majority of faculty offering positive feedback and high confidence about labs. Faculty agreed that labs include sufficient instructions and scaffolding and cover necessary class content. Faculty described lively interactions, with students supporting each other in learning, building community, and working together to learn.

Across the three courses, we have course outcome data for 2,946 students who participated in math labs. The vast majority who participated in the evaluation held positive views of the labs. Students across the three courses were equally likely to agree that the labs were interesting, helped them learn math and earn a good grade, offered an enjoyable group experience, and were a good use of class time. Students appreciated the opportunities for collaboration, hands-on learning, and integration of technology. Participants more strongly agreed with the statements, "*I like math*" and *"I understand how the math I learn in this course applies in the real world"* after the course than at the start.

This poster will share information about how to access the labs, lessons learned about faculty professional learning, and the extension of the project into the college's dual enrollment strategy.

Introduction

We have recognized for over 50 years that mathematics curriculum that remains disconnected from everyday life is a critical issue [2] [3], and is the reason that students have been asking the same, frustrating question, "*When will I ever use this*?" Course content that over-emphasizes mathematics theory can add to mathematics anxiety and decrease confidence, resulting in fewer students pursuing STEM pathways [4], which in turn compounds the problem of STEM degree completion [5]. Given the importance of success in gateway mathematics courses in the first year of study as an early momentum metric of success [1], interventions to engage students, build interest, and support success in mathematics courses is critical.

The goal of the project is to improve course outcomes and support student learning through applied math lab activities that address concepts that are difficult and challenging in subsequent courses, highlight the importance of mathematics in daily life, engage learners in meaningful learning activities, and embed essential workplace skills.

Project Materials

The project team created, piloted, and revised 30 lab activities for College Algebra, Trigonometry, Calculus I, collaborating with faculty in the Engineering and Physics departments to ensure strong connections with advanced mathematics and physics courses. The labs are designed for students to work in groups, using robots, Jupyter notebooks, and hands-on activities. Figure 1 lists the topics the mathematics labs address.

College Algebra

- Take your GoPiGo for a ride
- Graph match
- Algebra and composition of functions
- Inverse functions
- Quadratic functions
- Alcohol and driving
- Rational functions

Trigonometry

- Measuring triangles
- Home Alone! (right triangle trigonometry)
- Dance robo-robot dance! (rotary motion)
- Oscillating colors! (periodic functions)
- Color stop! (periodic functions)
- Home Alone 2! (general triangles & vectors)

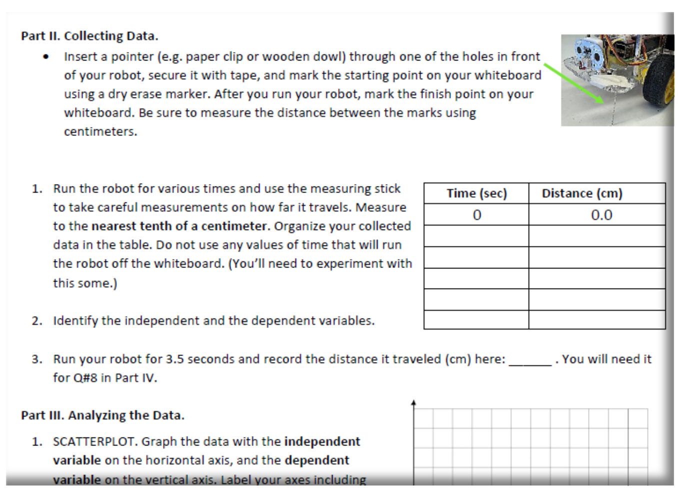
Calculus 1

- Average rate of change
- Back to the future
- Piecewise defined functions
- Instantaneous rate of change
- Derivatives rate of Change
- Graphs of motion
- Velocity function
- Position, velocity and acceleration
- Objects in free fall
- Related rates cone
- Extrema and concavity
- Rocket lab
- Piston lab
- Newton's law of cooling
- Riemann sums
- Integration
- Fundamental theorem of calculus

Figure 1. Project Math Labs

Error! Reference source not found. shows a portion of student materials in one of the calculus labs, highlighting the use of the robot, clear instructions, and guides that support student data analysis.

The project team led 12 professional learning sessions for Sinclair faculty and mentored faculty in using math labs throughout the project period. By the end of the grant period, labs were embedded in all College Algebra, Trigonometry, and Calculus I course. Courses with labs increased in length by an hour each week and 0.7 credit hours.



Part II. Collecting Data.

- Insert a pointer (e.g. paper clip or wooden dowl) through one of the holes in front of your robot, secure it with tape, and mark the starting point on your whiteboard using a dry erase marker. After you run your robot, mark the finish point on your whiteboard. Be sure to measure the distance between the marks using centimeters.

1. Run the robot for various times and use the measuring stick to take careful measurements on how far it travels. Measure to the **nearest tenth of a centimeter**. Organize your collected data in the table. Do not use any values of time that will run the robot off the whiteboard. (You'll need to experiment with this some.)

Time (sec)	Distance (cm)
0	0.0

2. Identify the independent and the dependent variables.

3. Run your robot for 3.5 seconds and record the distance it traveled (cm) here: ______ . You will need it for Q#8 in Part IV.

Part III. Analyzing the Data.

1. SCATTERPLOT. Graph the data with the **independent variable** on the horizontal axis, and the **dependent variable** on the vertical axis. Label your axes including

Figure 2. Sample lab materials

Evaluation Methods

We have course data for 4,488 students who, over the four-year project, participated in the three mathematics gateway courses, 2,946 (66%) of whom experienced math labs. Faculty (n=13) and students (n=2,994) responded to the evaluation survey to offer opinions of math, the labs, and recommendations for improvement. The college provided de-identified data about student course grades, grades in subsequent physics courses, overall GPA, and other indicators.

Findings

Students in the mathematics courses ranged in age from 12, a high school CCP student, to 72, a non-degree student. The average age of the course participants was 22 years.

Figure 3 shows the number of students enrolled in each of the three courses. College Algebra had the highest enrollment, with over one-half of the students in the study enrolled in this course. About ½ of the College Algebra courses, all of the Trigonometry, and ¾ of Calculus courses included labs.

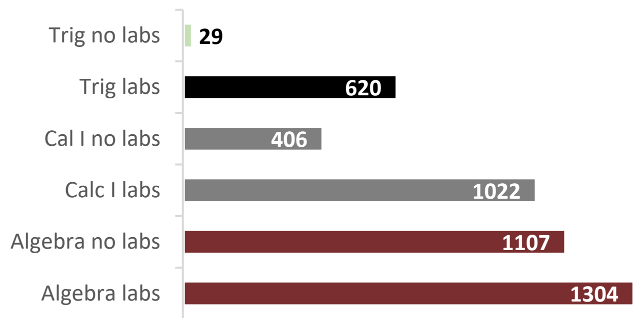


Figure 3. Student Participants across Project Courses

Three quarters (75%) of students were pursuing just eight majors, while the remaining 25% were pursing 105 different majors, illustrating the wide variety of student interests. The two most common majors were *College Credit Plus* (high school dual enrollment) and *No degree*. The most common STEM majors were health sciences, engineering, computer science, biology, and aviation. Among the engineering and computer science programs, ½ completed an algebra course, emphasizing the importance of this course for engineering and computer science degrees at this college.

Sixty-six percent of students in the lab sections (66%) and 65% of students not in a lab section earned a grade of A, B, C, or D. There was no statistically significant difference ($\chi 2$ (1)=.319), p=.572).

Student Feedback

The almost 3,000 students who participated in the labs offered positive feedback, confirming that students appreciated the hands-on, practical approach to learning mathematics through real-world applications and working with robots. Three-quarters of the students who responded to the project survey (N=997) agreed that the labs were useful, interesting, and an enjoyable way to learn math. The attitudes were consistent across courses ($\chi 2$ (4)=2.07, p=.723), with no difference between College Algebra, Trigonometry, or Calculus I in terms of the effect of labs on student interest in mathematics and in pursuing a STEM field.

***25%** of students said that labs increased their interest in math*

***24%** said that the experience made them more sure about pursing a math, science, or engineering field*

-student survey

Student offered the following comments when asked what was the best thing about the labs:

> *Seeing how I can use math in the real world was interesting.*
>
> *The visuals and measuring data in real time helped a lot with different concepts, especially graphs.*
>
> *…using math outside of how math is usually learned.*
>
> *I really liked running through the robots. It was hard, but not too challenging...It was fun!*
>
> *I liked having to explain out the logic of a solution…what does changing the variable affect, or a real-world example of this kind of function.*
>
> *They were very engaging and nice break from the typical worksheets and assignments.*

Students across the three courses were equally likely to agree that the math labs were interesting ($F(2, 339)=2.68$, $p=.07$), helped them learn math ($F(2, 339)=2.26$, $p=.11$), helped them get a good grade ($F(2, 338)=0.80$, $p=.45$), offered an enjoyable group experience ($F(2, 329)=1.75$, $p=.18$), and were a good use of class time ($F(2, 337)=0.83$, $p=.44$). Students appreciated the opportunities for collaboration, hands-on learning, and integration of technology. Participants more strongly agreed with the statement, "*I like math*" after the course (n=402, mean=2.8) than at the start (n=946, mean=2.7; $F(1, 1346)=4.2$, $p=.040$) and "*I understand how the math I learn in this course applies in the real world*" after the course (n=410, mean=2.8) than at the start (n=969, mean=2.7; $F(1, 1379)=15.7$, $p<.001$).

Faculty Feedback

Project faculty piloted the labs to inform improvement. Over the course of the project, the team addressed challenges with technology, including difficulty using classroom sets of laptops to facilitate the labs, long software updates that interrupted class, lack of needed software on class computers, and other IT challenges. They also clarified instructions, streamlined activities, and created student-facing worksheets and materials.

Faculty who used the labs had positive feedback. The majority felt confident about using the labs and agreed that the lab instructions were clear and helpful. Most agreed that labs covered the necessary class materials and offered sufficient scaffolding. Suggestions to improve labs included more variety in subject matter to engage students outside of engineering, making the labs more succinct, reviewing materials for repetition, and stronger connections to careers.

Faculty described lively interactions, with students supporting each other and "*problem solving together – even on those parts of labs they were confused by.*" Another noticed "*stronger engagement, which is very much needed.*" Faculty agreed that students benefited from the labs and persisted to find solutions. Although the majority of students appreciated and enjoyed the lab activities, some did not. Faculty comments included:

> *[Students] prefer the hands-on labs, and some of the robot-based labs bring out the competitive spirit in some students.*
>
> *Students are looking forward to do the labs. They like switching from lecture to lab. They are very interested in visualizing what they just learned.*

Students talk and engage with each other more in a lab class versus a non-lab class. They will talk with each other and help each other complete the lab.

Conclusions and Future Research

Mathematics faculty at the [name of] two-year college recently voted to formally recognize the use of labs in College Algebra, Trigonometry, and Calculus I courses. This widespread support affirms project impact. Faculty from community colleges across the country have requested to use the math lab materials. The team obtained funding for another NSF Improving Undergraduate STEM Education (IUSE) grant to apply, improve, and extend to a broader audience the promising hands-on math lab curricula practices developed in this initial project. Funding began in fall 2025 and will continue through 2028. The newly-funded project will create professional development opportunities and a Community of Practice (CoP) for college and community college faculty and dual enrollment mathematics teachers. The CoP will support instruction that will engage students with hands-on learning in gateway college math courses.

Acknowledgements

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