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WiP: Metacognitive and social-emotional-learning interventions in first-year Calculus

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Work In Progress: Metacognitive and social-emotional-learning interventions in first-year Calculus

Abstract

Student performance and retention in STEM majors is a major concern in higher education. Individual attention and coaching are effective at improving the retention of under-performing students, but these tools are too labor-intensive for faculty to apply in large introductory courses. Additionally, many struggling students are limited by non-cognitive factors such as fear of failure, social anxiety, and general overwhelm. There is a need for large-format, scalable instructional tools that both engage students in course material and address non-cognitive factors in an appropriate way.

This Work In Progress will present the effects of a remedial intervention, the “reflective knowledge inventory”, at improving student outcomes in Calculus 1. In the intervention, students improve their exam score by submitting a “reflective knowledge inventory”. Expert learners know that new skills are best built on existing knowledge, and that big problems should be broken into smaller tasks. Novice learners are more likely to feel overwhelmed and panicked, especially when they know they are underperforming. We attempted to design a remedial assignment that scaffolds students through the process of identifying technical strengths to build on and breaking weaknesses into manageable chunks. Briefly, students create a glossary of terms and concepts from the class and rank them by their level of understanding. Importantly, the assignment also includes reflections on emotions, barriers, and support networks. The reflective knowledge inventory was developed over several years in post-pandemic sophomore through senior-level engineering classes. Results were promising but inconclusive. The present work scales up this intervention to a large-enrollment first-year class with high populations of at-risk students. This work will combine quantitative analysis of student grades with thematic analysis of student submissions to determine the effectiveness of the intervention.

Introduction: declining math skills and non-cognitive barriers

Academic under-preparedness and student mental health are growing concerns for engineering faculty and staff [1]. Continued fallout from the COVID-19 pandemic has exacerbated previous trends [2], [3]. The pandemic's effect on incoming students' math skills has been directly observed at the College of Engineering at [university] through the Calculus Readiness Exam (CRE), which is taken by all incoming science, engineering, and technical majors. Figure 1a shows incoming student score distributions from 2018- 2022. The average score dropped from 73% to 63% in Fall 2021 (blue markers). More concerning, the fraction of students who scored less than 50% on the exam has increased to almost half of the incoming students (orange/red bar). This decline in incoming student math skills is extremely worrisome because internal data analytics show that the CRE is the number one predictor of student retention from first- to second year. Machine learning feature extraction (Figure 1b) shows that race, gender, and first-generation status do not predict retention any more strongly than co-op cycle, which is essentially random. In contrast, CRE score, first-term math grades (either Calculus or remedial math), and AP credit are strongly correlated with student retention. Because calculus and differential equations are foundational to fluid mechanics, heat transfer, circuit analyses, and many other core engineering courses, inadequate math preparation has repercussions throughout the curriculum.

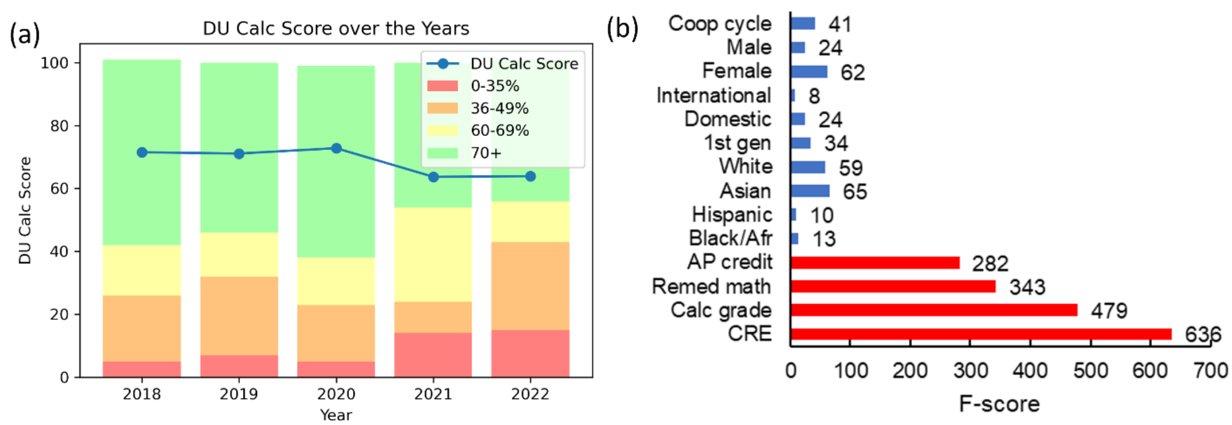

Figure 1: (a) Incoming first-year Calculus Readiness Exam (CRE) scores declined since the pandemic. (b) CRE is the primary predictor of first-year retention. Data: Dr. Ian Marcus, Director of Analytics, College of Engineering

Insufficient technical/mathematical training is a major barrier, but students who score poorly on the Calculus Readiness Exam also typically lack adequate study habits and experience with college expectations. Like many universities, Drexel University offers many programs to support students academically and personally, including academic coaching and remedial courses on academic skills, walk-in math tutoring in academic buildings and residence halls; math study squads; math exam review sessions for high-risk courses, peer tutoring for first-year engineering courses and Matlab/Python, and academic /financial counseling for underrepresented minority

STEM majors. Despite the abundance of student support provided, evidence suggests that these programs are not utilized effectively. Academic support staff all report that services are most frequently used by high-performing students who seek to improve their grades from B+ to A, or from A- to A+. Previous experiments to target high-risk students by restricting program eligibility have been unsuccessful.

Poor utilization of student support services reflects an even broader post-pandemic trend towards reduced student engagement. Instructors across K-12 and higher education have reported plummeting attendance, assignment submission, and student engagement in class[4], [5], [6], [7]. Such withdrawal is a hallmark of emotional distress, rather than intellectual deficiencies, and its rise in college students is consistent with the mental health epidemic[1], [2], [3], [8], [9], [10]. There is therefore an urgent need for remediation and prevention of emotional barriers to learning at our institution and across broader higher education.

Previous work: reflective knowledge inventory and remediation plan.

We have recently developed an innovative remedial intervention that addresses social-emotional factors *within* technical courses. Our key innovation is to recognize that fear of failure, fear of social interactions, and lack of motivation cannot be addressed by more thorough explanations or additional practice problems [11]. Instead, we have attempted to address social-emotional learning (SEL) barriers as directly as possible, drawing on tools from counseling and community organizing to create a “reflective knowledge inventory” [12]. In this assignment, students who score below a cutoff on the midterm (typically ~ 50%) are offered points back in exchange for submitting a remedial assignment. The assignment includes personal reflection on barriers, support networks, and action items as well as a glossary of class terms and concepts, ranked by their level of understanding.

Importantly, this intervention places minimal grading burden or emotional labor on busy instructors and is compatible with the exam-based infrastructure already present in most technical courses. While best-practices may include frequent low-stakes assessment with multiple attempts and standards-based grading, few faculty can afford such drastic course redesigns. Our intervention therefore fills an important need in meeting both students and faculty where they are at. This intervention is currently in its fifth iteration (Table 1). We have experimented with various eligibility cutoffs, and various incentives including a flat score (typically 51, regardless of whether the student scored 49 or 20), or a fixed number of points added to the midterm score.

Table 1: History of reflective knowledge inventory intervention

Term	Course level	Incentive	Eligibility	Participation
Summer 2021	Sophomore thermodynamics	Remedial; midterm score of 51	Midterm score <50 20% (7/34)	86% (6/7)
Fall 2021	Senior controls	Remedial; midterm score of 51	Midterm score <50 13% (10/76)	60% (6/10)
Winter 2023	Junior mass transfer	Remedial; 8 points or midterm score of 66, whichever lower	Midterm score <65 29% (7/24)	28% (2/7)

Fall 2023	Freshman calculus	Remedial; midterm score of 51	Midterm score <50; 3% (14/520)	21% (3/14)
Fall 2024 (current study)	Freshman calculus (slow-start)	Remedial; midterm score of 51	Midterm score <51 10% (19/195)	52% (10/19)

The first three iterations of the intervention were promising but inconclusive. Across three different sophomore, junior, and senior courses (Summer 2021, Fall 2021, and Winter 2023) 24/134 students were eligible for the intervention (scoring below a cutoff on the first midterm, typically 50%). Four withdrew from the course, and 12 students completed the intervention. As shown in Figure 4, the intervention group improved their final exam scores by an average of 17 points (n=12). Across the class, the average scores on the final and midterm exams scores were equal (n=122). However, comparing the intervention group with the eligible control students (who scored below the cutoff on the midterm but chose not to complete the remedial assignment) showed no statistical difference. Students who complete the intervention may be regressing toward the mean, along with other low-performing students who improve on subsequent assessments.

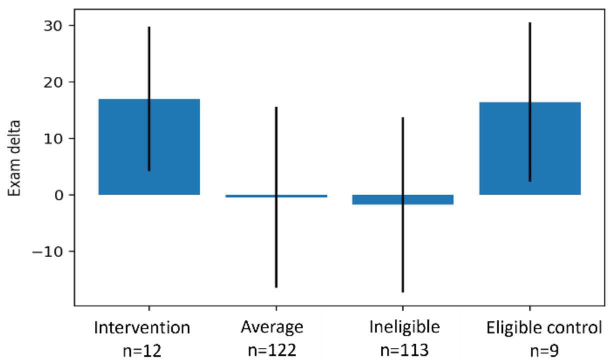

Figure 4: Comparison of exam delta (final exam – midterm exam score) across three upper-division courses. Vertical lines represent one standard deviation. Students who completed the intervention improved over the average, but not over the control.

In Fall 2023, we used a seed grant from KEEN to implement the intervention in Calculus I, which was taught to 520 students across 25 sections. However, only 14 students met the eligibility criteria for the intervention by scoring below 50 on the first midterm, and only three of the 14 submitted the remedial assignment. The low eligibility demonstrated the effectiveness of the math placement process. Larger sample sizes are needed to rigorously determine the effectiveness of the reflective knowledge inventory.

Study design and methodology

In Fall 2024, the reflective knowledge inventory was implemented in Calculus and Functions I (MATH 116), which is a slower-paced version of standard Calculus I. This course primarily covers limits and derivatives, which comprise the first half of content offered in traditional Calculus I. Students who take Calculus and Functions I in Fall term have scored between 36%

and 69% on the Calculus Readiness Exam and have subsequently taken one of two summer prep courses. Historically, the DFW rate in this course ranges from 25-35%.

In Fall 2024, 195 students enrolled over 11 sections. Midterms were given in Weeks 4 and 7 of the 10-week quarter. Students who scored below 50% on the first midterm were offered the opportunity to earn a 51% by completing the reflective knowledge inventory. The assignment prompt provided to students is included as Appendix A. IRB approval was obtained for this exempt study (#2308010053).

Preliminary results and future analysis

As shown in Table 1, 19 students (10%) were eligible for the intervention. 10 (52%) completed the remedial intervention. 3 of these students subsequently withdrew from the course before their points were added. 9 eligible students neither completed the remedial intervention nor withdrew from the course. The control group consists of these eligible non-participants. The intervention group consists of 7 students who completed the intervention and remained enrolled for the entire course. The class average includes the test and control groups in addition to 176 students who were ineligible for the intervention and did not withdraw from the course.

Preliminary analysis was carried out for the present data using single-factor Analysis of Variance (ANOVA) to draw relationships between groups (Table 2). As expected, both the intervention and control groups had lower final grades than the ineligible students, and the difference between ineligible students and eligible students was statistically significant. However, comparing the changes in Midterm 2 and Midterm 1 scores across the intervention, eligible control, and ineligible groups with single factor ANOVA showed no significant difference in means of groups. Finally, comparing the exam delta (first midterm to final exam) of eligible control and intervention groups showed no rejection of the null hypothesis, considering a mean decrease of 18.4 for the intervention group and a mean decrease of 10.3 points for the control group. These preliminary results do not support the hypothesis that the reflective knowledge inventory improves social-emotional learning skills.

Table 2: Preliminary results from Fall 2024. Data represents mean ± one standard deviation.

Group	Intervention (n=7)	Control (n=9)	Ineligible (n=176)
Final grade	31.7 ± 18.0	42.7 ± 11.7	78.9 ± 14.1
Exam delta (Midterm 2 – Midterm 1)	-7.6 ± 16.2	-19.2 ± 12	-8.7 ± 16.3
Exam delta (Final – Midterm 1)	-18.4 ± 18.2	-10.3 ± 24.5	-9.6 ± 18.7

Future work will include thematic analysis of student submissions to identify academic and social-emotional barriers to performance and engagement as well as more direct measurements of social-emotional learning skills using validated instruments.

Appendix A: Knowledge inventory intervention (Fall 2024)

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Math 116 First Midterm, Fall 2024
Reflective Knowledge Inventory and Extra Credit

Students who scored below 50 can increase their score to a 51 by completing the following three parts. The completion times are estimates to help you plan. Try not to rush this assignment and be nice to yourself. Building these skills takes a lifetime.

Part 1. Self-assessment: what's holding you back?

Estimated time: 30 minutes

It's almost impossible to do hard things without a supportive environment, so first we are going to think about what you need to succeed and the strengths and assets you can use to get that. Anyone is allowed to help you on this part.

1. <u>Privately</u>, list people who care about you and would support you in a tough time. They don't have to be from [university]. Family, friends from home, members of a faith or community organization, etc. all count. Virtual connections from an online community (e.g. Reddit, Discord) are also great.

2. <u>Privately</u>, list your personal barriers to doing well in class. They may be time constraints, for example if you have a job or caretaker duties. Some may be distractions, for example if your game system is right next to your study desk. If you are not attending class, or if you struggle with procrastination, try to ask yourself why. Do you dislike your major? Are you worried that other students will see you looking dumb? Are you so worried about other things that it's hard to focus on school? These details may not be appropriate to share. They are important for you to identify.

3. Look at your weekly schedule and figure out your "Math catch up time" for the rest of the quarter. <u>Write down the times and places that you will study</u>. Be realistic.

4. Pick one barrier from your second list that you are comfortable sharing and <u>write down one action item</u> you can take to reduce that barrier or avoid the situation. Then pick one person/group from your first list and write down one way that they can help hold you accountable. Finally, make sure this plan works with your schedule. Some hypothetical examples:

    - *"When I'm home I get pulled into stuff around the house or goofing off instead of studying. I can help avoid this by staying on campus after class on Monday and Wednesday until 7 instead of going straight home. My friend A will help me stick to this goal by meeting me after class in the library and we agreed to keep each other on task instead of socializing"*

    - *"My laptop apps give me alerts on the corner of the screen and then I get distracted reading and messaging. I just went into the settings of my computer and disabled all the* *popup alerts. I asked my group text string to help and they agreed to go dark between 4-6pm every weekday so I'm not as tempted to chat in those study hours."*

- *"I've been feeling pretty isolated recently and thinking about classes when I'm doing so poorly just makes me feel worse. I can help myself get over this by going to Student Group X meetings to meet people / make friends. The meetings are Tuesday at 5 and my mom will text at 4:30 to remind me to go."*
- *"I look at the news or Twitter and that turns into doomscrolling and then it's been an hour and I feel so terrible that I just crawl back into bed. I installed apps that block the apps that make me feel so terrible. When I have the urge to check feeds I am going to text my sibling instead and they know this and will reply with something supportive."*

5. Choose one or more of the following university resources and make an appointment. You don't have to tell the professor which one you pick.
    a. If you feel underprepared from high school or previous classes: Math Resource Center [link redacted]
    b. If you struggle with procrastination or time management: academic coaching [link]
    c. If it feels overwhelming to just get out of bed: student health services [link redacted]
    d. If you just feel unsure of yourself and don't know where you fit: your academic advisor [link redacted]

Part 2. Knowledge inventory: what do you know that you can build on?

Estimated time: 30 minutes.

Now that you've thought about the environment you need to succeed, it's time to start on the technical part. By creating an inventory of skills and topics for our class, sorted by how well you understand them, you will identify the things you need to learn. Remember, this will take some time, and that time is an investment. There is no shortcut to learning engineering. You can also come to the [tutoring center] for help with this list.

6. Midterm List of Topics at the top of Page 3. Find one technical term you know or problem you know how to solve and copy it into Column A on the table of Page 3.
7. Write a few sentences about what you know for that item. Example: *"I can find intercepts of a function because the x-intercept is where the curve goes through the bottom axis and the y-intercept is where the curve goes through the side axis. To find intercepts without a picture I set x=0 and solve for y (y-intercept) or y = 0 and solve for x (x-intercept)."*
8. Do this for as many items as you can. If you know one technical word, but not the whole bullet point, write just the word in the column, and list the things you do know. Remember, the more you can write, the better off you will be.

9. Look at your list. Think about how little of these things you knew one year ago and congratulate yourself on how much you have learned so far! If that feels too difficult, ask someone from your list in Part 1 to provide encouragement.

Part 3: Identify the holes. What do you need to work on?
Estimated time: 60 minutes.

10. Go back to the Midterm List of Topics and decide if the remaining items should go into Column B, *c*<u>oncepts you have seen but don't really understand</u>, or Column C, <u>Technical terms that float by in a haze.</u> Type each item into Columns B and C. It's ok if you need to split items into different columns.
11. For each item in B, write down the details that you do and don't understand. Example: *"I know that when we find limits we usually make x = 0 or infinity and find y but sometimes we don't and I don't understand when.*"
12. Finally, do the same thing for Column C. Do your best to come up with something for each item, even if feels trivial. Example: *"I know piecewise is something about when the line breaks but I don't know how to solve any problems"*
13. Remember you can go to office hours / [tutoring center] for help with this list.

What to turn in

Submit your schedule for # 3, your self-assessment action item for #4, and your table of Columns A, B, and C as a .docx or .pdf attachment to [LMS] by the deadline**.** Your professor will provide feedback on your table to identify any errors and suggest which items in Column B and C to focus on.

Midterm List of Concepts:

Functions

- Identify a function algebraically and graphically
- Use function notation correctly
- Find the domain of a function

Piecewise Functions

- Graph a piecewise function
- Rewrite an absolute value function as a piecewise function

Composite Functions

- Create a composition of two functions
- Decompose a function

Rational Functions

- Find domain, intercepts, and asymptotes of a rational function
- Graph a rational function

Inverse Functions

- Determine if two functions are inverses
- Find the inverse of a function
- Find the range of a function by using its inverse
- Determine if a function is one-to-one
- Know the graphical relationship between a function and its inverse

Limits

- Understand the concept of a limit and find limits graphically
- Compute limits algebraically
- Find limits of functions as they approach infinity

Knowledge Inventory for Part 2 and Part 3. Add more lines if you need.

Concepts I Understand or Know How To Use In Problems	Concepts I Have Seen But Don't Really Understand	Technical Words That Float By In A Haze