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Fostering Active Learning and Metacognitive Skills in a Cognitive-Science-based Math Course

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There is a large body of research on how to improve student learning through active learning and metacognition. However, without well-structured guidelines, students do not tend to actively engage with the taught material, peers, and the instructor at a desirable metacognitive level (Deslauriers et al., 2019). To address this problem, a research-driven assessment structure is integrated into a non-traditional course called "Methods for Mathematical Problem Solving" (M^2PS). Methods for Mathematical Problem Solving was designed by the author to teach students effective study principles stemming from cognitive science. The assessments include synchronous check for understanding (CFU) assignments to further investigate the taught material through reading assignments and reflective writings, followed by asynchronous quiz reinforcements, and concluded with journaling to ensure successful implementation of the principles into study schedules. This cycle of learning and implementation is carried throughout the 7 weeks of this hybrid course. The classroom culture, grounded on metacognition and active learning, is purposefully modeled by the instructor. In this article, we focus on a sample of assessments that are tailored to enhancing active learning and metacognitive skills. Assessments are employed in a low-stakes, distributed fashion to reduce anxiety over a curriculum built on an abundance of theoretical and empirical research. These assessments can be easily adopted into traditional classrooms with instructors' deliberate efforts. The purpose of creating these assessments is to improve student learning outcomes by instilling metacognitive skills while turning on the "active learning" mode. The end-of-course celebratory event signified the importance of developing this course, specifically for first-year undergraduates.

Metacognition

Although the term "learn about learning" may not be well-received by some learners, the term "metacognition" is more welcomed since it is a research-grounded term. In the late 1970s, John Flavell (1979) originally coined the word "metacognition" as he defined it as "cognition about cognitive phenomenon," or thinking about thinking. Recent empirical data suggests higher cognitive functions such as metacognition may be critical elements to accelerate learning (Cortese, 2022). Explicitly teaching metacognition to students on how to plan and monitor their studying empowers the students to continue a life-long journey for growth and to become consciously aware of their strengths and shortcomings to identify whether the gaps in learning are content-based, skill-based, or psychology-based, or a combination of these. Pintrich (2002) asserts that "Students who know about the different kinds of strategies for learning, thinking, and problem-solving will be more likely to use them" (p. 222). Note the difference between simply knowing about and intentionally implementing the strategies as incorporated into the M^2PS assessment structure.

Promoting student metacognition is an effective strategy in learning (Stanton et al., 2021; Bransford et al., 1999; Hattie, 2012; Hidayat, 2018; Faradiba, 2019; Karataş & Arpaci, 2021; Anthonysamy, 2021; Cromley & Kunze, 2020). Mathematical Association of America (MAA) stated in their 148-page instructional practices guide (Axtell et al., 2018) that talking to the students about the metacognitive strategies involved in mathematical problem-solving enables them to develop strategies for getting "unstuck" by showing perseverance.

Active Learning

Active learning is a pedagogical technique coined by (Bonwell & Eison, 1991) as instructional activities involving students in doing things and thinking about what they are doing. Although the benefits of using active learning strategies are reported widely, teacher-centered lectures continue to be largely utilized in higher education (Bucklin et al., 2021). However, there are instructional reforms demanded by the industry, and political and educational leaders (Allina, 2018) to shift instruction from teacher-centered practices into student-centered, active-learning practices relevant and meaningful to students. For students to be actively involved, students must engage in such higher order thinking (HOT) tasks as analysis, synthesis, and evaluation. Freeman et al. (2014)in their meta-analysis of active learning concluded that active learning improved the students' exam performance and reduced the failure rate.

Although the importance of active learning was widely demonstrated in the education literature, Deslauriers et al. (2019) stated that when students experience the increased cognitive effort associated with active learning, they initially take that effort to signify poorer learning. To combat this factor that may impair student learning, Deslauriers et al. (2019) proposed strategies for instructors to prepare and coach students for active instruction and to persuade students that they are benefiting from active instruction.

More than ever, in both K–12 and higher education, active learning strategies are utilized to better prepare digital-age students (Cummings et al, 2017), move students away from memorization to more meaningful learning experiences (Aji & Khan, 2019), improve academic achievement (Hartikainen et al., 2019), and develop life skills and workforce competencies (Ito & Kawazoe, 2015). Bucklin et al. (2021) asserted that "active learning (AL) strategies have been shown to promote better retention and application of new knowledge than listening to passive, information-only imparting lectures." The skills needed to become effective math problem solvers such as having strong content knowledge, critical thinking, and problem-solving abilities, as well as having positive attitudes toward learning are reported to increase by deviating from the traditional lecture-based learning formats (Graffam, 2007). Active learning emphasizes students generating an output of their learning rather than passively being on the receiving end of the information that is generated by the instructor.

The Rationale Behind Course Design

Some students may equate neat note-taking to comprehension of the taught material. Some others may attend classes quietly by relying on their presumptions of how to participate actively, and some others may think the college courses will follow the same structure as what they have been used to for 13 years during their pre-college education. In addition to these assumptions and misconceptions about effective learning, specifically among first-year undergraduate students, some students might not have been taught effective ways of studying and learning Math. Gall et al. (1990) state that "Learning how to learn cannot be left to students. It must be taught." There is a large body of research on the importance of teaching students explicitly about evidence-based strategies for effective learning (Kiewra, 2002; Berry & Chew, 2008; Welsh, 2010). As a co-requisite of learning math content effectively, it is also crucial for students to learn about how people effectively learn, how information is encoded and moved from short-term memory to long-term memory to be retrieved during testing, and how to defend against math anxiety and damaging social norms of mastering math. To close the gap between the ideal learning settings and flawed learning realities among students, an innovative course was designed called Methods for Mathematical Problem Solving (M^2PS).

The course is purposefully designed to offer research-based support for students to improve their understanding, studying, and performance in math classes. The course was offered to students without any co-registration requirements that led to students from different academic levels signing up for the course such as first-year students to senior students whether they are concurrently enrolled in a math course or not.

The Cross-Disciplinary Curriculum Structure

Methods for Mathematical Problem Solving teaches students effective learning principles stemming from cognitive science research to become successful learners not only in math but in other disciplines as well. This novel course is offered as a hybrid, 7-week mini course. The curriculum is constructed in the Canvas learning management system. The course is designed by collecting and synthesizing an enormous amount of research on human learning from various disciplines such as cognitive science, neuroscience, STEM, and mathematics education. However, the authentically designed course curriculum and assessments for effective math learning are not only applicable to these disciplines. The assessments are also easily adaptable by instructors who integrate active learning and metacognition into their traditional classrooms.

The curriculum is designed to first examine the evidence-based strategies explicitly and then offer hands-on practice opportunities for students to implement these strategies in their study sessions. Students are also assessed on their successful implementation of these study strategies. The curriculum components are developed by incorporating case studies, educational videos, news items, surveys, and empirical and theoretical data based on research articles. It should be noted that the course curriculum does not include explicitly teaching math content such as algebra or calculus.

A typical run down for the class session starts with a brief warm-up activity, followed by a brief lecture using the authentically designed Microsoft© PowerPoint slides where a short educational video is watched and discussed as a group, then students are given opportunities to demonstrate their understanding and examine the topic further by completing the synchronous check for understanding CFU assignments. After the CFU submission, the second part of the lecture continues, and the class concludes with a summary of the lesson. The course is built around three essential questions (EQ) which are the main themes as Canvas modules. Each module coverage takes about 2.5 weeks during the 7-week course. Figure 1 shows the authentically developed EQs for the course.

Figure 2 demonstrates the timeline between the initial course proposal and the integration of the re-structured course into the math department curriculum as a math credit-bearing course. As Figure 2 shows, the transformation of the course content took almost 2 years

Figure 1.
Essential Questions for Methods for Mathematical Problem Solving (M^2PS)

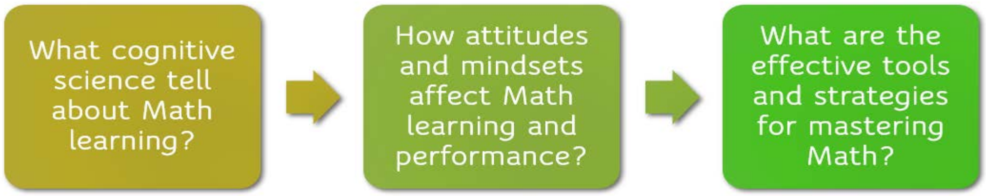
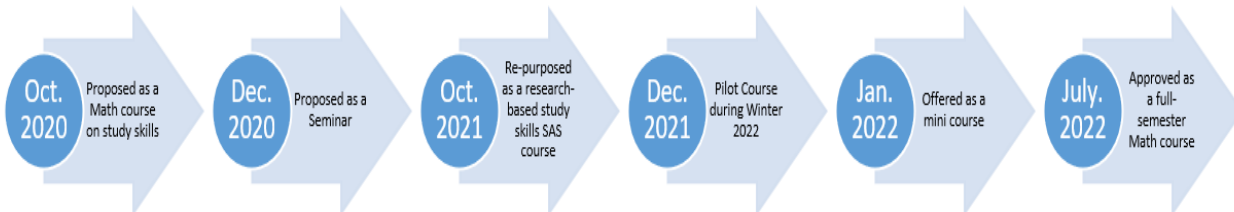


Figure 2.
Course Design & Transformation Timeline



after re-structuring it by incorporating research-based effective math study strategies (Oakley, 2014; Bransford et al., 1999; Boaler, 2015).

Measurable Active Participation

Students are graded based on successful, timely, and correct submissions of the synchronous assignments whether they are in their assigned groups or completing individual work. The grade book component, check for understanding (CFU), is explicitly taught as a part of the Day 1 routine of explaining the syllabus and grading components. Active learning is integrated into the assignment descriptions where students are assigned a task to complete. The action-oriented word "task" is used to describe the assignment deliverables which is a real-time student product, a synchronous student submission in Canvas. The assignments are designed in an objectively measurable manner to enable students to independently convert the text-based assignment instructions into a checklist to assess if all of the conditions are met for a satisfactory outcome. Although students are explicitly taught how to do this conversion, as a muddy point feedback later in the semester, this conversion procedure is re-visited to clarify any potential student confusion.

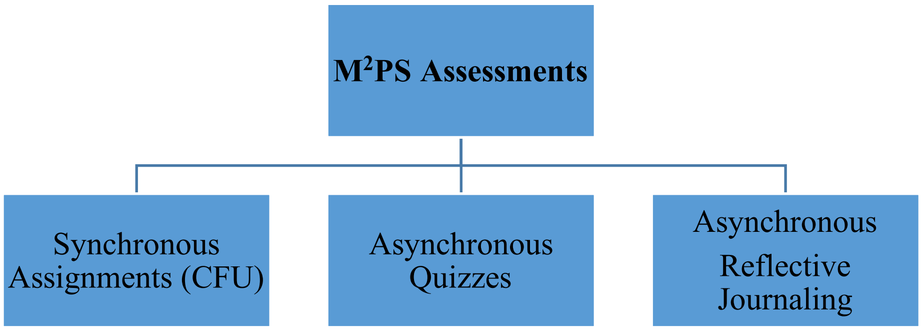
The Assessment Structure Targeting High-Order Thinking Skills

As Tinto (2012) identifies the classroom as the center of student education and emphasizes the importance of frequent and formative assessments for effective learning, the M^2PS course curriculum is purposefully designed to adopt this effective assessment practice by incorporating numerous learning and assessment opportunities in different modalities to support students with diverse learning preferences. In order to align the expectations with the hybrid nature of the class, students are tasked to complete synchronous assignments as CFU, and two types of asynchronous assignments are offered in the form of weekly quizzes on research articles and weekly reflective journaling assignments. Figure 3 shows the three main assessment types designed for M^2PS.

The synchronous online class meetings are held on Tuesdays and Fridays with one or two graded CFU assignments with a total of 15 CFUs for the course. In addition to these graded tasks, there are a few ungraded, short-response poll questions posted on the online Zoom learning platform. The synchronous CFU assessments facilitate learning by promoting students' metacognitive skills and active learning in the forms of warm-ups, muddy points, KWL charts, reading article excerpts with summative and reflective writings, group discussions, and surveys, to name a few.

Asynchronous assessments are employed to enforce students to actively implement the effective learning strategies taught during synchronous class time. The weekly quizzes are designed based on reading research articles and answering short questions in various formats

Figure 3
Types of Assessments Designed for M^2PS Course



such as 'select all that apply', short answer, and rank-order scaling questions. The quizzes become available on Thursday mornings and are due on Thursday at midnight. This mid-week, mini-quizzes based on short readings enable sustained active learning in a meaningful way. In addition to the quizzes, students are assigned an individual journaling assignment to reflect on and monitor their effective use of the Pomodoro time-based study technique based on cognitive psychology & neuroscience research (Oakley, 2014). The Pomodoro study sessions are applied to Math or any other STEM course, depending on students' priorities and schedules. The journaling assignments are weekly learning logs that are due on Sundays. In other words, students are tasked to recognize and manage impediments to studying and learning such as distractions, procrastination, and peer pressure (Green, 2020). We chose to distribute the assigned tasks throughout the week to enable distributed practice and active learning in and out of the classroom.

Throughout the course schedule, students first develop a foundational understanding of effective learning principles and the strategies to overcome obstacles to success, which is followed by actively applying the learned strategies into their study schedules while mindfully monitoring their progress or lack of it to share their reflections in these graded reflective journaling assignments. This cycle of learning and active implementation enables students to actively engage with the course content by following the three steps Fogarty (1994) suggests as part of a metacognitive process. These three steps are (1) developing a plan to complete a task, (2) monitoring understanding during the task completion, and (3) evaluating thinking after completing the tasks. For example, these three steps are embedded in a sample assignment in M^2PS as the first step involves devising an attainable study schedule for the semester as a first-week assignment, the second step includes monitoring how effectively the study strategies are being incorporated into weekly study sessions, and the third step incorporates evaluating thinking after completing the assigned tasks to become more aware of the obstacles for next week's study session to offer "fix-up strategies."

Through these journaling assignments, we aim to offer a threefold benefit for students that include (1) improving students' study habits, (2) enhancing understanding and learning in a separate math (or other STEM) course, and (3) earning grades in the M^2PS course. Ideally, incorporating the research-based study strategy of Pomodoro effectively enables students to earn grades in other courses due to the expected performance improvements. The asynchronous assessment components are a great way to add sustained active learning, accountability, and self-regulation.

Students are offered opportunities to reach high order thinking (HOT) by designing an individual pathway to apply the taught course content by actively monitoring their progress, meaningfully collaborating with their peers, and reframing their old habits and mindsets into new ones by using evidence-based strategies. These assessments are authentically prepared to target students' high-level cognitive processes based on Fink's Taxonomy of Significant Learning while embracing the significant learning categories of learning how to learn, caring, and human dimensions (Fink, 2013). Incorporating Fink's taxonomy into course design offers a structure that clearly relates the student learning objectives to students' interests and needs for taking this course.

Furthermore, students are tasked to make connections between the metacognitive skills and Pólya's Framework for Problem Solving (1945), specifically Stage 4: Look back/assess the plan. (Boaler, 2008) states that the four stages of Pólya's cycle are neglected or missing in the work of low-achieving students. The meaningful learning connections are also made between the Common Core Mathematical Practice Standard (Common Core Standards Initiative, 2010) of "Make sense of problems and perseverance in problem solving" in the course curriculum. According to Edge & Friedberg (1984), long-term perseverance is among the factors that contribute to student success in calculus courses.

The outcome of this research is analyzed by students as a part of the course content and students are given opportunities to reflect on their habits of studying math and to transform their poor habits into effective ones by completing and integrating the research-driven effective strategies. Students are re-taught that math is not a collection of unrelated formulas, which is the perception of novice learners, but there is a bigger picture that has components from the smaller pieces to make it a whole. Through reading and synthesizing research articles actively as part of graded classwork students are tasked to recognize that perseverance and problem-solving are not only desirable skills in math learning, but are employability and a life skill. Figure 4 demonstrates the four stages of effective math problem-solving (Pólya, 1945).

The Bigger Picture: Enhancing Metacognition Through Research-Driven Assessments

As the teaching practices encourage active learning in M²PS, the instructional content is purposefully developed to explicitly teach students the importance of metacognition and how to use metacognitive skills in different settings. In the M²PS course, metacognitive activities are intentionally, explicitly, and frequently designed and integrated into the curriculum to enhance students' metacognition and engagement with the content, their peers, and the instructor herself. In this section, we apply the structure developed by Tanner (2012) to a sample of assessments in the M²PS course that are primarily focused on metacognition and active learning. As we explain the research-based assessment structure, we strongly emphasize how these assessments cultivate metacognitive skills.

The metacognitive assignments explicitly defined by Tanner (2012) follow the format of (1) Preassessments—encouraging students to examine their current thinking, (2) The Muddiest Point—giving students practice in identifying confusions, (3) Retrospective Post-assessments—pushing students to recognize conceptual change, (4) Reflective Journals—providing a forum in which students monitor their own thinking. The following Table 1 summarizes how these metacognitive assessments are aligned with specific assignments in the M²PS curriculum. Then, we briefly explain the content of each assignment from a metacognition perspective.

KWL Chart

The acronym KWL is the title of a teaching model originally developed for the active reading of the expository text (Ogle, 1986). The acronym stands for "Know-Wonder-Learn" specifying what learners already (K)new about a topic by retrieving prior knowledge, what they wonder or (W)ant to learn, followed by asking the learners to reflect on what they (L)earned after the learning process took place. These three cognitive steps are displayed in a format of three columns in a typical KWL chart. Know-wonder-learn strategy is part of an inquiry-based learning technique (Bhattacharyya, 2021). This strategy increases achievement (Aseeri, 2020), metacognition (Tok, 2013) and fosters active learning (Fritz, 2002). In M²PS, students' first CFU assignment is to write a response to the KW component of the KWL chart by (**K**) What do you already **k**now about the content of our class? (**W**) What do you **w**ant to get out of this class? On the first day of M²PS class, students are given a CFU task to activate their prior knowledge by responding to the ***K*** of the KWL chart, then students' expectations from taking this novel course are retrieved by responding to the ***W*** of the KWL chart. A portion of the final class time is dedicated to students reflecting on and responding to key takeaways from what they learned in the course as part of the ***L*** of the KWL chart. Based on the essential questions of the course, the intended two key takeaways from the course include understanding the effectiveness of the Pomodoro study technique and the surprising negative effect of math anxiety on math performance.

Muddiest Point

Muddiest point assignments are brief questions that ask about the most confusing or unclear part of a taught material. In the M²PS course, these assignments are incorporated at the end of each module that tasks students to review the module handouts and to provide one muddiest point of the module. Students are initially informed of this as an upcoming assignment via a Canvas announcement and during the last class meeting to facilitate the prompt submission of the assignment as a whole class. Students are timed to submit it via a Canvas assignment where their short reflection content is quantified in terms of the number of words used to guide students to concisely express their reflections. Then, the instructor reviews and identifies the common "muddy points" to re-teach and review at the beginning of the next lesson. This activity allowed students to metacognitively think about the module to give feedback to the instructor about the topics they did not fully comprehend.

Retrospective Post-Assessments

When it comes to math learning, there are several myths and misconceptions that exist in our society about how to study the content (in)effectively which in turn affects students' perceptions, learning, and performances. Addressing the myths, unacceptably wide

Figure 4
Four Stages of Effective Math Problem Solving by Pólya Who Is Considered the Father of Mathematical Problem Solving

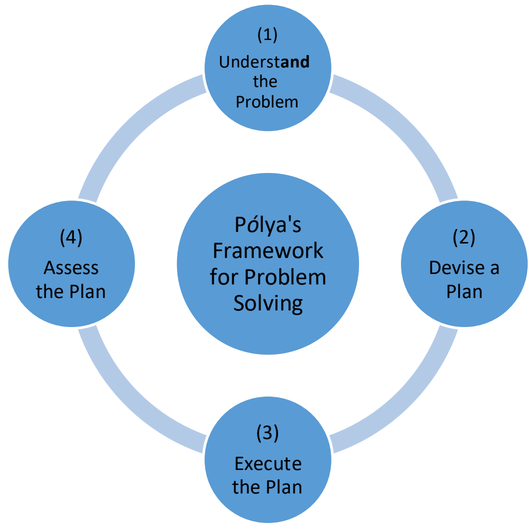


Table 1
Graded Assignments to Promote Student Metacognition

Activity	M^2PS Assessment	Modality	Curriculum Component
Preassessments	KWL Chart	Synchronous	Entire Curriculum
The Muddiest Point	Muddiest Point	Synchronous	After Each Module
Retrospective Post-Assessments	Short Reflective Essays	Synchronous	After Reading Assignments
Reflective Journals	Weekly Journaling	Asynchronous	After Pomodoro Sessions

social "norms," stereotyping, anxieties, (mis)perceptions, and mindsets about math learning is one of the components of this newly designed course. A simple tool for explicitly charging students to think about how their ideas are (or are not) changing is a retrospective Post-assessment (Tanner, 2012). During synchronous class time, short reading assignments followed up by individual reflective writing tasks are assigned to students. For example, we asked students to read and answer a few questions in an article about growth mindset (Dweck, 2008). In this specific assignment, students are tasked to reflect on one incident about their math learning experiences when they felt their fixed-mindset persona showed up to react in an unproductive way. Then students are tasked to reflect on how to transform their old reactions into a more constructive outcome with a growth-mindset approach. This explicitly described assignment enables students to self-question "How my thinking is changing over time, through the concepts taught in this course?" Another retrospective post-assessment is a brief reflective writing about an article on the myth of a math brain.

Reflective Journals

During asynchronous class time, students are assigned an individual journaling activity to monitor their use of the Pomodoro technique, which is a time-management study system developed by Francesco Cirillo in the 1980s (Oakley, 2014). Students were given a checklist to self-assess the effectiveness of Pomodoro sessions such as being in a distraction-free study space, timing constraints for the study session, and using metacognitive skills to reflect on the effectiveness of their study session. Additionally, students are tasked to document and upload a clear picture of the study session product as "Effort Evidence" such as a handwritten scrap paper to solve math problems and other homework. An important but sometimes neglected part of a study session is to reward the effort, therefore, students are also reminded to include how they rewarded their effort and studying. Ideally, the reasons that made the previous study sessions ineffective are rectified in the following study session by using metacognitive skills. Figure 5 shows the Pomodoro study sessions assignment guidelines embedded as a Canvas individual journaling assignment.

Developing a Classroom Culture Based on Metacognition

General practices that promote a metacognitive culture in a classroom setting are established by Tanner (2012). In this section, we demonstrate how this classroom culture is developed through instructional and assessment practices in the M^2PS course. For example, in addition to answering the question "what is metacognition?" students are assigned tasks to show how metacognition is applied to different settings and when to apply metacognition to their own learning experiences. Ideally, the theory and consistent, hands-on applications of metacognition support students to mature into self-directed learners and develop transferable skills that apply to any discipline. These intentionally developed classroom practices also signify that students are at the center of a classroom culture that promotes metacognition as a habit of mind.

Giving Students License to Identify Confusions within the Classroom Culture

The lessons are designed in a way to acknowledge the complexity of learning math and how it is different from language-based classes. In a group activity of analyzing a calculus question, students were broken into breakout rooms and assigned the task of listing the number of different concepts to solve one calculus question. This group activity was designed to release the responsibility of analyzing the problem without the support of the instructor first, after the timed activity is concluded a general discussion allowed students to understand the demanding nature of mathematics. In other words, to accurately solve one calculus question a learner needs to know and master several prerequisite skills and calculus skills. This demonstrates that calculus is a discipline that relies on the idea of a sequential learning pattern (Nolting, 1994).

Integrating Reflection into Credited Course Work

The final project has six choices in which every student must choose three tasks to complete. An intermediate checkpoint is integrated into the final project to enable student reflection and progress monitoring. The purpose of this checkpoint is to help students to become aware of their progress and the lack of it to meet the project deadline and to produce a proficient project outcome. The intentional decision to make this reflection (checkpoint) as part of a final project enabled students to bring a more metacognitive attitude to their higher stakes coursework component.

Metacognitive Modeling by the Instructor for Students

When learning about Pólya's framework for problem-solving, the instructor modeled how to solve a sample precalculus and a calculus question. In order to model the expected thinking process when solving a math problem, the "thinking out loud" process is demonstrated by the instructor by intentionally injecting an error and using Stage 4 of Pólya's Problem Solving Framework to reflect on the answer to discover it as an unreasonable answer. The problem is then reworked by taking a step back and carefully correcting the error. Not only did students learn to use metacognition, but they also actively became part of the thinking process on the importance of sense-making and valuing mistakes (Boaler, 2015).

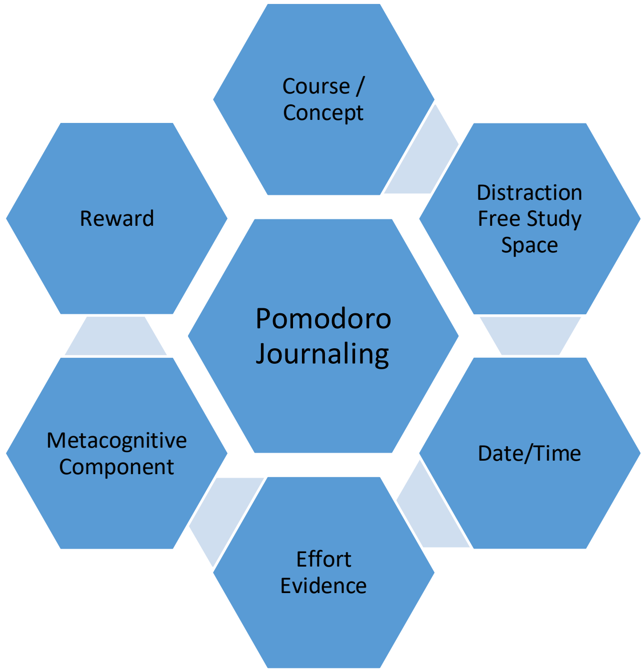
Contributions to Research

One of the challenges for all educators in the instruction domain is to improve students' active participation and metacognition. Our article adds to the body of knowledge by proposing a low-stakes, easy-to-integrate, research-based assessment structure in a novel course stemming from cognitive science principles for effective math studying. The student-centered learning activities enable students to become metacognitively aware of the limitations of their approaches to studying and learning math and offer them the practical tools to reshape them into evidence-based effective approaches. The research-based strategies are explicitly taught and then students are offered opportunities to implement them into their daily studying schedules. Different learning preferences are supported such as visual images, animations, educational videos, and text in Microsoft PowerPoint© presentations followed by a low-stakes assessment to be completed during the synchronous class time. This classroom routine is followed by asynchronous enforcement through assigned tasks to complete.

Conclusion and Future Directions

The research-to-practice gap and students' assumptions of effective learning are among the factors that contribute to low student performance. Developing evidence-based course curricula and assessment structure, as demonstrated in this article, address these negative factors that impede student success. Incorporating measurable, well-structured, frequent low-stakes assessments in synchronous and asynchronous

Figure 5
Pomodoro Journaling Assignment Guidelines



formats enhance students' metacognitive skills and active learning. Generating an attainable study schedule and incorporating the taught learning strategies conscientiously and regularly enables students to develop awareness toward the non-negotiable fact in a student-centered classroom culture that they are at the center of the instructional and assessment practices. The sample strategies and assessments presented in this article can be incorporated into non-math classrooms with minimal effort by students and instructors alike. As more findings are uncovered in the science of learning, the author will purposefully examine more ways to adopt and develop student-centered strategies to enrich the learning experiences of the learners in her novel, non-traditional course curriculum.

Although the course provided the necessary tools and strategies for students to learn to study effectively, the format of the course is a mini-course reducing the outcomes of the taught and implemented strategies. To offer a more significant and extended support for student learning, the course format was changed to a full-semester, face-to-face course starting Fall 2022 semester, as proposed by the author. As educators, we know that the curriculum is a living document. The author is in the process of devising Canvas mastery paths to offer more individualized student learning experiences as a part of the Provost Teaching Fellowship program at her institution.

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