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With a Little Help from My Friends: Integrating Self-Directed Peer Learning to Improve Word Problem Completion in Developmental Math

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Abstract

This mixed-methods study assesses the impact of a self-directed peer learning intervention intended to alleviate known bottlenecks in engaging developmental math students with word problems. Our findings suggest that self-directed peer learning, in which students are provided autonomy in choosing with whom they consult, has the potential to significantly strengthen students' ability to shift from written to mathematical representations as well as decrease anxiety and increase positive engagement in mathematics education as a whole. Implications for overcoming similar bottlenecks outside of mathematics are discussed.

***Keywords*:** word problems, peer learning, developmental math, math anxiety, algebra

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Background

Prof. Smith has 25 students in her developmental math class. 10 students did not complete the two modules of the course that utilized word problems. What percentage of her class is struggling with word problems?

The "word problem" (really a stylized example) listed above describes an increasingly familiar scenario, in which students who have struggled with math seem to face particular challenges when navigating word problems. In some ways, these difficulties seem counter-intuitive, as word problems are intended to serve as bridges between theory and practice, illustrating real-world applications of the mathematics being taught. Indeed, emerging studies in STEM persistence suggest that contextualizing math and science problems can significantly impact student success and retention, especially for women and historically under-served populations (Lehr & Haungs, 2015; Savaria & Monteiro, 2017; Stolk et al., 2021; Vaz, 2012). In practice, however, both instructors and students continue to struggle with the integration of word problems into mathematics instruction. The present study describes and assesses a novel intervention intended to reduce barriers to student engagement with word problems in a small, supplemental mathematics tutorial course for undergraduate students.

Literature Review

The Bottleneck of Word Problems

Navigating word problems is a known bottleneck in mathematics education (Bennett & Dewer, 2013; Schultz & Lovin, 2012). The term "bottleneck" refers to a widely-used theory of difficulty used in educational research to identify, and ultimately address, disciplinary-specific places where students seem to get frequently stuck (Middendorf & Shopkow, 2023; Shopkow & Middendorf, 2019). At the secondary level, researchers have determined that students tend to struggle with word problems at two stages: the translation of the written context into a form where they can apply their mathematical knowledge (Pongskadi et al., 2020, and integrating context clues when determining their solution (Kirkland & McNeil, 2021). These issues are compounded at the tertiary level where studies have noted students' difficulties understanding the context (Duffy et al., 2020; Pagling et al., 2020), students' familiarity with the format and proposed steps for solution (Azzam et al., 2019), and the students' (in)ability to move between written, visual, and mathematical representations of the problem (Fatmanissa et al., 2019). Further, recent studies have suggested that these struggles are exacerbated when the word problem is written in a non-native language or utilizes a cultural context in which the student is unfamiliar (Azzam et al., 2019; Fatminissa & Novanti, 2022; Mallet, 2011).

Other scholars have suggested that the bottlenecks related to word problems may be less cognitive and more affective, especially in terms of attitude or mindset (Khasawneh et al., 2021). As Sheila Tobias points out, most people, including seasoned mathematicians, find the prospect of word problems to be initially daunting (Tobias, 1993). For some, especially those who lack confidence in their abilities to solve problems, this initial anxiety can lead to deterrence or avoidance behaviors, which may precede cognitive engagement (Beilock & Maloney, 2015; Zhang & Wang, 2020). From the perspective of math-anxious students, word problems appear to pose a no-win situation in which they can attempt the problem and likely fail or avoid the problem and definitely fail. The pedagogical challenge is to flip not only these behaviors, but also the assumptions, or attitudes, which enable them. In other words, the question becomes not how to teach students to solve word problems per se, but rather how to get past floundering and persist through the process.

As these affective bottlenecks have become known, subsequent studies have investigated interventions intended to strengthen student's abilities to overcome initial anxiety and engage constructively with word problems (Shearn & Wilding, 2000). These include strategies intended to enable students to identify factors that would affect how they would solve the problem, such as realistic limitations (Chapman, 2006), and using metacognitive skills such as planning their approach to the problem and evaluating the solutions they find (Chapman, 2006; Depaepe et., 2010). Most recently, the use of various alternative grading practices that allow for multiple attempts have shown promise in alleviating math anxiety both broadly speaking and, in a handful of cases, with word problems specifically (Carlisle, 2020; Venkatesh & Piercey, 2021). In practice, however, these strategies have not always proven sufficient to overcome the strength of the students' initial anxiety. As of this writing, there remains no widely shared, evidence-based solution that enables students to approach word problems with a sense of resiliency rather than failure.

Cooperative Learning

There are interventions that have been effective in improving student success in mathematics more broadly. In developmental math, for example, there is a long history of research on the benefits of cooperative learning, especially in the form of group work, which has been shown to enhance student success (Davidson & Major, 2014; Prieto-Saborit et al., 2021; Smith et al., 2014). The use of small group work serves to actively engage students in the classroom (Sofroniou & Poutos, 2016), which, in turn, allows students to become more interested in mathematics (Bieg et al., 2017; D'Souza & Wood, 2003; Shreyn & Ell 2014), which decreases gaps in mathematics achievement (Prieto-Saborit et al., 2021; Smith et al., 2014).

Various cognitive perspectives have created lines of reasoning to explain why group work seems to benefit students' learning. These explanations include but are not limited to the recognition that students can draw on the knowledge of each group member as they co-construct new knowledge (Amineh & Asl, 2015; Vygotsky 1978), that students have the chance to explain their thoughts and ideas to others which provides them chances to reinforce their understandings (O'Donnel, 2006), and that students gain opportunities to have more experience with cognitive conflict if there are contradictions between group members' perceptions (Piaget, 1926/1997.

That said, group work is a broad term, and it has been noted that these benefits do not always occur by simply having students collaborate with one another (Diehl et al. 2020, Prieto-Saborit et al. 2021; Sheryn & Ell, 2014; Smith et al., 2014;). While there is the possibility that students reap the benefits stated above, there have also been studies that describe how group work can create inequitable learning environments by a few students having too much influence on the group or the group having passive participants (Esmonde, 2009; Wong, 2018). As researchers investigate group work, some suggestions for creating positive group work situations have been structuring the work to foster positive interdependence and equal participation (Kagan, 2014; Prieto-Saborit et al., 2021) and having group members be able to share ideas and listen to other's contributions (Campbell & Hodges, 2020).

To date, little research has been conducted that looks at how group work, in any structure or format, may (or may not) influence students' willingness and ability to navigate the often-dreaded mathematical word problem specifically. The present study seeks to address that gap through a small-scale, mixed-methods study of a cooperative, peer learning method specifically designed to overcome the challenges students face when engaging with algebra-based word problems in developmental math courses. While the findings of the study are most readily applicable to the mathematics classroom, the self-directed peer learning strategies used have potential implications for overcoming similar learning bottlenecks across a variety of mathematics courses as well as other disciplinary contexts.

The Intervention

The intervention was first designed for a supplemental one-credit tutorial course taken concurrently with an Intermediate Algebra course offered at Penn State-York, a satellite campus with an enrollment of approximately 750 commuter students. Students are enrolled in intermediate algebra based upon results of an institutional placement test and are required to concurrently enroll in the tutorial course. The intermediate algebra course covers linear equations and inequalities, equations of straight lines, and operations on polynomials and quadratic equations, and the tutorial course provides one additional contact hour that allows students time to spend working on this material. Intermediate algebra is considered a review course at Penn State, for which students do not earn credit toward graduation. All nine of the enrolled students participated in this study.

On three different class meetings of the tutorial course across the 15-week semester, the instructor distributed three word problem assignments, each containing ten questions and worth up to 20 extra credit points. The timing of the assignments coincided with the introduction of word problems in the intermediate algebra course, for which the tutorial course served as a supplement, with roughly thirty days between each extra credit assignment. The assignments were intentionally scaffolded, with the first assignment of word problems focused on the use of linear equations in one variable; the second focused on the use of systems of two equations and two unknowns; and the third set focused on quadratic equations with one variable type to solve.

Students were asked to attempt every problem without assistance from others outside of class before submitting them for correction. After grading the initial submissions, corrected assignments were returned to each student with only the point score for each problem and no other added feedback. Students were then given 50 minutes during the tutorial class to work through potential bottlenecks with their peers. Students were permitted to work with whomever they chose, and they could switch partners or move to join different groups as they felt was necessary to meet their learning needs. To earn back points missed on the initial submission, the students made corrections on a separate paper from the earlier submission and handed this in along with the initial submission so that adjustments to the initial extra credit grade could be made.

Research Design

The researchers chose a mixed methods study to assess the impact of the self-directed peer learning process on students' abilities to successfully complete the word problems introduced at three stages of the intermediate algebra course. The study consists of a pre- and post- survey (using a previously validated scale) as well as systematic review of student artifacts, both described below. The design is intended to measure both cognitive (the artifacts) and affective (the survey) outcomes which are known to influence how students navigate word problems (see literature review above). Please note that the impact of this intervention on student grades in the intermediate algebra course is not a component of the study, as the focus was on the change in student attitudes toward word problems.

Pre- and Post Survey

Penn State's IRB (Institutional Review Board) approval was obtained to administer an electronic pre- and post- survey to students regarding attitudes toward word problems (or applications). Approval to analyze student grade information outside of those earned as part of the intervention was not sought nor granted. The pre-survey was administered before the first module that utilized word problems in approximately week 5 of the 15-week semester. The post-survey was administered during the final week of class. The survey used was a previously validated and widely used survey of mathematics anxiety, the Mathematics Anxiety Questionnaire (MAQ) (Wahid et al, 2014; Wigfield & McKee, 1988), with most questions modified from general mathematics anxiety to focus on anxiety (and related affects) regarding word problems. Students rated the extent to which they agreed or disagreed with seven statements using a five-point Likert scale.

It should be noted that the survey did include demographic information for each student, but the researchers chose not to include this data in the analysis. While mathematics learning has been shown to be sensitive to demographic factors, especially gender identity, the researchers felt that the sample size was simply too small for meaningful statistical comparison and that, in at least one instance, the demographic information would be potentially identifying (e.g., there was only one student in the class over 25 years of age). Additional information regarding the sample of students who participated in this study that could be shared would be that all were students whose score on Penn State's mathematics placement test indicated a lack of sufficient basic algebra skills needed to succeed in a subsequent mathematics course that would be needed to satisfy a requirement for degree completion and that all were commuter students (Penn State York does not have on-campus student housing). Additionally, the majority of the students in the sample were of what would be considered traditional college age and were first-year students.

Student Artifact Analysis

In addition to the survey results, six of the nine students provided written consent to the use of course artifacts for research purposes. Because the instructor is also the principal investigator for this study, which presents the potential for bias, the artifact analysis was conducted by a member of the research team who is familiar with mathematics education research, but who was not the instructor of the course. This person evaluated de-identified copies of the word problem worksheets. For each set of the three sets of word problems, consenting students contributed two worksheets: the initial, individual attempt (1) and the second attempt, which followed the peer learning intervention (2), for a total of six worksheets per student.

The reviewer followed a two-stage process. In stage one, the initial worksheets for each of the three sets of word problems were reviewed and coded across three thematic areas: strategies that seemed to assist them in their work (such as splitting fractions into two numbers e.g. $\frac{3x}{2}$ becoming $3 \cdot \frac{1}{2} \cdot x$), strategies that caused the student's answer to be incorrect (such as incorrectly representing information from the problem text), and features of the student's work that were distinctive (such as declaring the meaning of the variables used in the problems).

In stage two, the corrected versions of each worksheet were compared to the initial attempts with the intention of identifying how the second attempt may have differed from the first. Particular attention was given to new strategies the student may have employed to overcome the obstacles identified in the initial attempt. For example, if a student employed a new strategy, such as labelling parts of the problem to correspond to parts of the mathematical equations, then it was presumed the emergent strategy was learned via the peer learning intervention. Both stages of the artifact analysis process were conducted using Microsoft Word. To strengthen trustworthiness, the results of this coding process were reviewed through an iterative peer debriefing process, conducted with the coder, the instructor, and an educational research expert from the university's center for teaching, the latter added as a member check in keeping with best practices in qualitative research (Kornbluh, 2015; Shenton, 2004).

Results

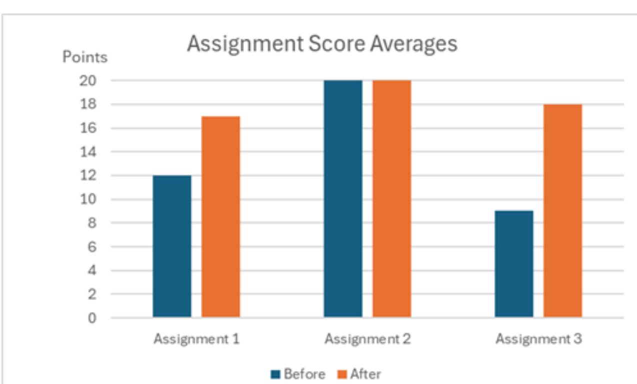
The results of the study included quantitative analysis of survey responses and qualitative analysis of the student artifacts, as well as a research note on achievement measures.

Achievement

It is common for studies of math education to include some measure of student achievement. This intervention took place in the context of a supplementary tutorial course with assignments that were graded largely for growth, not achievement. As Figure 1(below) demonstrates, all of the students were able to successfully complete the word problems (at a B level or above) following the peer learning intervention. Given the developmental nature of the intermediate algebra course in which these students were enrolled, this outcome would, however, be expected.

Figure 1

Student achievement in the study's word problem assignments, before and after self-directed peer learning intervention (20 points maximum per extra-credit assignment)



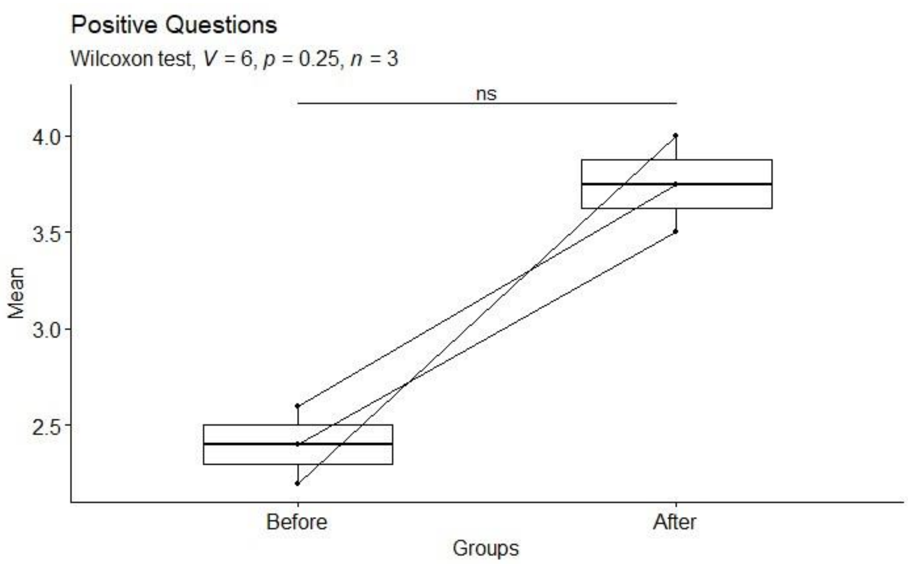
Because these results were not surprising, we chose to focus the study on outcomes other than achievement, specifically the cognitive and affective bottlenecks related to word problems.

Survey Responses

The survey results indicated that students experienced clear reductions in their anxiety levels related to word problems. As Figures 2a and 2b (below) indicate, mean student responses shifted across all survey items, with initially high responses falling for negatively worded items and initially low responses rising for positively worded items, indicating a noticeable decrease in overall anxiety. In Figures 2a and 2b, each left-to-right line corresponds to a scaled survey item, and the box plots reflect the overall pre- and post- mean and standard deviation.

Figure 2a

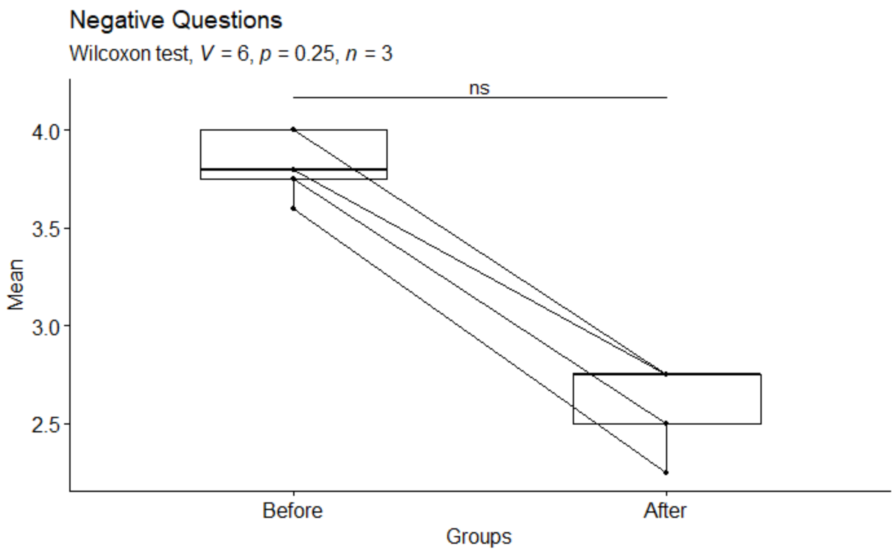
Changes in mean response to positively worded questions, modified Math Anxiety Questionnaire (MAQ), pre (before) and post (after) responses



Note. Results are indicative of Wilcoxon tests (Rey & Neuhäuser, 2011) for non-parametric data (V=6, p=0.25, n=3).

Figure 2b

Changes in mean response to negatively worded questions, modified Math Anxiety Questionnaire (MAQ), pre (before) and post (after) responses



Note. Results are indicative of Wilcoxon tests (Rey & Neuhäuser, 2011) for non-parametric data (V=6, p=0.25, n=3).

It should be noted that the sample size is too small to estimate significant differences with full confidence, but the unilateral nature of the pre- and post- shift in responses is encouraging.

Student Artifact Analysis

The artifact analysis revealed that the major challenge students faced was in translating the text of the word problem into an equation that they could then solve. In other words, their difficulties came not from solving the equations themselves, but in correctly interpreting the problem to mathematical form. For example, when student D worked on a word problem utilizing systems of equations, they incorrectly interpreted the given percentages to be the coefficients of the terms in their equations (see Figure 3a). In this case, the student's work led to a situation where solutions they found did not make sense within the context. After collaborating with their peers, the student was able to understand the need to convert the percentages to decimal form and to then use those decimals as the coefficients of the terms of their equations in the system of equations representing the problem (see Figure 3b).

Figure 3a

Example of systems of equations problem given to the students

5. Joanne has a total of $6000 to deposit in two accounts. One account earns 3.5% simple interest and the other earns 2.5% simple interest. If the total amount of interest at the end of one year is $195, find the amount she deposits in each account. Write a system of two linear equations to represent this problem, then solve that system to find the amount of money deposited in each account.

Student D's initial work on the systems of equations problem (incorrectly solved)

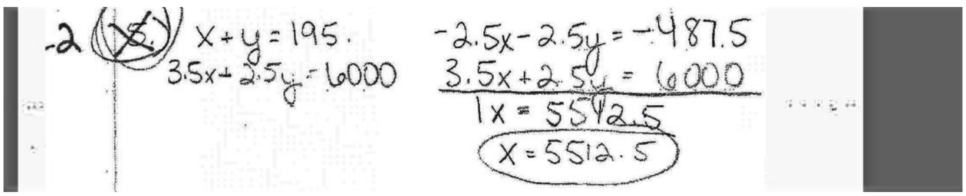
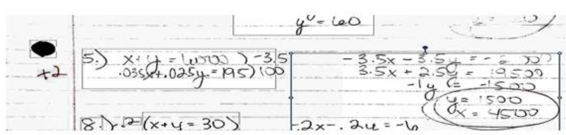


Figure 3b

Student D's correct work to solve the systems of equations problem after self-directed peer learning



When the effects of the peer consultation could be identified in the artifact analysis (through the process described above), the analysis revealed that peer consultations were most efficacious in enabling students to correctly interpret the context of the problem into a solvable mathematical equation (a known bottleneck described in the literature review above). One example of this could be seen in the linear equation assignment completed by Student A. Student A was the only student who had not declared what was represented by the variables in the equation before starting the problem. Notably, Student A lost the most credit by incorrectly translating the context of the problem into an equation. Student A's second submission showed they adopted the practice their classmates used and were able to resolve their mistakes. Peer consultation seemed to serve to strengthen students' ability to move between written and mathematical representations of the problem (Fatmanissa et al., 2019), and this increased ability persisted as the word problems changed in format and level of difficulty over the course of the semester.

Discussion and Implications

This mixed methods study does suggest that a self-directed peer learning intervention has the potential to alleviate the cognitive and affective bottlenecks associated with word problems. Previous attempts by the instructor to address the challenges felt by students toward word problems had focused on identified cognitive and metacognitive solutions, such as directing students' attention to the problem's context clues and guidance in the development of the creation of a plan to solve the word problems (Chapman, 2006; Depaepe et al., 2010). In these cases, the strategies yielded little perceptible decrease in students' anxiety associated with word problems, and avoidance behavior persisted. Indeed, completion of assignments involving word problems remained low as a result of student unwillingness to attempt them, thus perpetuating affective bottlenecks and completing the circle of poor math performance (Ma & Xu, 2004).

Peer learning presented a potential pathway forward. The idea of drawing upon peer support to reduce gaps in achievement in mathematics has been studied and shown to be beneficial in other mathematics contexts. Prieto-Saborit et al. (2021) and Smith et al. (2014), for example, have demonstrated the power of group work in bridging gaps in mathematics learning and other studies mentioned in the literature review support this result. However, there were associated negative side effects of group work, among them inequities in mathematical and communication skills among group members and in participation levels by individual members toward the goal of completion of the common task (Esmonde, 2009; Kagan, 2014; Prieto-Saborit et al., 2021; Wong, 2018). The present study stemmed from the integration of a self-directed peer learning model intended to cultivate the cognitive and affective benefits of peer learning while minimizing these negative associations.

The self-directed modality of peer learning used in this study, which did not rely on more traditional group work configurations in which the instructor determines the members and size of each group, was a key component to its success with students overcoming cognitive bottlenecks to solving word problems. The students had the autonomy to select which classmates they worked with and could move from one group to another, which they did. As the artifact analysis indicated, this movement enabled students to strategically mitigate known cognitive challenges in interpreting and contextualizing word problems. Over time, the students came to know the relative strengths of other students in the class and were able to tailor their peer consultations to leverage those strengths, resulting in fewer, but more targeted, movements between and across groups allowing them to better translate the written content of the problem into the required equations needed and to ultimately solve them.

Similarly, the level of autonomy students had over how and with whom they worked to correct their word problem work appeared to contribute to a larger feeling that students were in a safe space, thereby strengthening a sense of community and belonging, a potential outcome that could be evaluated in a future study. In this safer space, students relaxed and demonstrated greater willingness to take chances in attempting to solve word problems, thus reducing feelings of anxiety associated with them, a significant affective bottleneck to their success in this kind of course work. This change in attitude was reflected by the changes in their responses from pre- to post-survey.

In addition to easing of both cognitive and affective bottlenecks, there were unexpected benefits from the self-directed aspect of the peer learning intervention. From what the instructor observed, the social learning space that opened up as a result of the peer learning contributed to more positive attitudes towards other kinds of challenging math tasks, not just word problems. It was observed, too, that group work allowed typically "quieter" students the chance to demonstrate their strengths in ways they may not have been able to before. Elevating classroom observations as part of the data would have been beneficial; however, these were not included in the results due to the limitations of IRB approval for this project. Collection and analysis of such observations might be included in a future project. Future research could also be designed to evaluate the link between affective changes and a range of both short-term and long-term student success measures, including persistence and graduation rates, especially in fields that make extensive use of mathematics, such as science and engineering.

Another unexpected implication from this intervention was the importance of movement in the peer work, a finding which affirms recent research on embodied learning and affective learning outcomes (Abrahamson & Bakker, 2016; Gerofsky, 2015; Hrach, 2021). In this case, students moved around the classroom to join different groups, with some working on the classroom blackboards (using them as a canvas on which to think, share, and work) or joining others in seated groups. As the instructor herself noted, "I have asked students to work on practice problems in their seats in classrooms for many years; never during those years did I have a reaction anywhere near as positive as when the students needed to get up and move somewhere else to work with a group of peers." It seems possible, too, that the opportunity to move and work with others after listening to an instructor presentation may provide additional benefits, and possibly challenges, for neurodiverse students. These observations of movement were unexpected, so they were not included in the prior ethical clearance for the present study, but capturing this enhanced use of the learning space could potentially serve as the foundation for subsequent studies.

While this intervention was conducted as part of a developmental math course, there are broader implications for alleviating persistent, and even emergent, affective bottlenecks in other disciplines. Social learning models developed prior to the remote learning during the COVID-19 pandemic, for example, have been challenged by the effects of prolonged social quarantine. The present intervention, in which students do not work in formal groups or persistent teams, has potential to serve as a bridge between formal and informal social learning spaces, allowing students to develop critical social learning skills that may have been either lost or neglected under remote learning conditions. This modality may be especially applicable to fields in which affective barriers, such as anxiety or apathy, are especially persistent.

Conclusion

This was a small-scale study of a single classroom at a single institution, so the results should be read as suggestive rather than generalizable. That said, the peer learning interventions described in this study did appear to alleviate cognitive and affective bottlenecks associated with word problems in developmental mathematics courses. For this project, participating students reported consistently higher positive affect when approaching word problems. More data will be needed to determine if this self-reported improvement in attitude can be linked to long-term student success. Additional data collected from the student artifacts suggest that the self-directed modality of peer learning may be especially efficacious in alleviating the negative affect associated with both word problems and peer learning activities. There may be potential applications of this self-directed modality to peer learning and group work in other disciplines. To paraphrase the Beatles, the students in this study were better able to get through a challenging remediation with a little help from their friends.

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