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HOW GOING WITH THE FLOW COULD AID FACTOR LEARNING IN MATHEMATICS

Aaron M. Beuoy

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Abstract

This quasi-experimental study examined the effectiveness of elaborative processing and knowledge maps for learning the steps to factor polynomials with various numbers of terms when math anxiety was accounted for. The study took place in a college classroom during an eight day period when students were learning to factor polynomials. On Day 2, students studied the factoring steps using a list of steps or a flowchart and then engaged in free- and cued-recall tests. Day 3 was similar except that students did not complete a free recall test. Another set of cued recall tests were administered on Day 5, and final cued- and free-recall tests were given about four weeks later. Students were scored on their ability to recall the individual steps (individual item memory), as well as the organization of the steps (relational memory). Separate mixed-model ANCOVAs using math anxiety as a covariate revealed the flowchart was generally a more effective learning aid than the list of steps for relational recall. Students who learned with the flowchart were better able to recall the steps in the correct order. These findings have important pedagogical implications because knowing the order of the steps is important for correctly factoring polynomials.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I: Introduction

Elaborative learning strategies are methods that can be employed to aid in forming strong memories or additional links to a memory, which helps with recall. Decades of research into elaborative learning strategies have mainly focused on lab settings and text or pictures, and little application to mathematical material has been observed. Given the strategies' effectiveness for text, it is reasonable to assume that similar strategies when applied to mathematical material would show similar success. Two previous studies (Beuoy & Waddill, 2018; Beuoy & Waddill, 2019) provide evidence of the elaborative techniques of transfer-appropriate processing and the testing effect being successfully applied to mathematical material; however, those studies were also conducted in a lab setting. The current study extended the methodology used in the lab to the college mathematics classroom to see if those effects would be observed in a real-world setting.

Elaboration

Strategies that go beyond repetition can be used to help encode information into long-term memory. Two terms that are important to know when discussing memory acquisition are *memory trace strength* and *retrieval routes*. A memory trace is essentially the record of learned information that can be accessed, whereas retrieval routes refer to additional ways of accessing the trace (Levin, 1988). Repeated practice can increase strength of the trace and of the individual items in that trace (Roediger & Butler, 2011), but strength alone cannot guarantee the successful recall of a memory. If people repeat the word pair *umbrella-party* several times, they are more likely to recall both words than if they only repeated the pair once or did not repeat it at all. However, a memory breakdown can occur when a person can remember one of the words but not the other in the pair. Thus, a person might remember *umbrella* but be unable to remember *party.* In these sorts of instances, alternate retrieval routes become important because they offer additional ways to retrieve the target words. If the word pair was incorporated into a sentence like *The lady brought her umbrella to the party*, the relationships among the items created by forming a sentence provide additional cues and routes for retrieving and remembering the two target words. The method of creating retrieval pathways with this relational information is called *elaboration.* Elaboration is an umbrella term referring to the improvement of one's memory during learning by using meaning-enhancing additions, constructions, or the generation of study material (Levin, 1988). Elaboration has been studied within a variety of paradigms, including depth of processing, the generation effect, transfer-appropriate processing, and the testing effect.

Depth of Processing

Craik and Lockhart (1972) proposed that rehearsal improves memory only if the material is rehearsed in a deep, meaningful way. Information can be processed at three different levels, each more meaningful than the last. Structural (how it appears) and phonemic (how it sounds) are shallower levels of processing, and semantic (how it may be related to other words, images, past experiences, etc.) is the deepest level of processing. To demonstrate this effect, Craik and Tulving (1975) gave participants words and told them to judge them based on whether they were printed in all capitals (structural), rhymed with another word (phonemic), or fit into a sentence (semantic).

Afterwards, participants were administered a recognition test. Recognition for the semantically encoded words was the greatest, followed by phonemic and then structural encoding. Depth of processing provides a method to encode information better, but depth is not everything, as the strategy of generating to-be-remembered material has shown.

Generation Effect

The generation effect refers to the phenomenon where recall for material is typically better when people come up with (generate) the target information compared to when they just read or copy it. In Slamecka and Graf's (1978) study of word pairs, participants had to use a specific rule to generate a word to complete a word pair. For example, if given the word *sea*, participants might be required to generate a synonym like *ocean*. Regardless of the rule participants had to follow, recall for the word pairs was higher when the material was generated compared to when it was only read. In studies of memory for text, participants who filled in missing letters to generate words within the context of a story showed improved recall for information in the story compared to those who only read the story (Einstein et al., 1984; Einstein et al., 1990; Waddill et al., 1988). Generating material is beneficial because it enhances connections among target items and thus provides retrieval routes individuals can use to recall the material.

Transfer-Appropriate Processing

Another method for creating additional retrieval routes involves matching the specific processes used to study with those used to retrieve the to-be-remembered material. Transfer-appropriate processing (TAP) focuses on the relationship between processes used when encoding information and those used when later recalling it. TAP proposes recall for material is greatest when processes used at retrieval match those used at encoding (Morris et al., 1977). Morris et al. (1977) found that participants who studied words using associations performed better on a standard recognition test compared to those who studied words using rhymes. However, when a rhyming recognition test was given, those who studied rhymes exhibited greater performance than the association group. Graf and Ryan (1990) had participants study words in a backward format and found that recognition performance and recognition time were better when the test consisted of backward words compared to upside down words.

The Testing Effect

In addition to studying the target material, testing oneself over learned material can also provide elaborative benefit. Every semester, students can expect to take at least one test. The purpose of a test is usually to serve as a summative measure for how much a student has learned as measured by a grade or score. However, testing (including self-testing) can also be a powerful learning tool. Butler and Roediger (2007) conducted a classroom study where participants sat through a lecture on three consecutive days. Each day after the lecture, they received a lecture summary, a multiple-choice test, or a short answer test. After a one-month delay a short answer test was given to all the participants. Recall was greatest for the people who had taken a short answer test after each lecture. Halamish and Bjork (2011) found results that bolstered Butler and Roediger’s findings and added an additional element to the testing effect. Their study revealed that participants who engaged in self testing showed better recall when the final test was a more demanding retrieval task (free recall) than when the final test was less demanding (cued-recall). McDaniel et al. (2007) conducted a classroom study where students engaged in read-only, multiple choice (MC), or short answer (SA) quizzes over the span of six weeks; feedback was provided after each quiz for the MC and SA quizzes. After six weeks of quizzes, a final exam consisting of MC questions worded differently (to prevent learning a specific answer for a specific question) was administered and the results indicated SA quizzing produced the best performance. Testing after studying can provide benefits to recall, especially in the long run. The reason self-testing produces better recall is a topic of some debate although it may occur at least in part because forcing oneself to recall the material leads to organization and consolidation, subsequently creating more retrieval routes (Roediger & Butler, 2011).

Despite the power of the testing effect, self-testing is seldom spontaneously used as a study or learning strategy, especially by students expecting an exam. The overwhelming majority of students report rereading notes or textbooks as their primary study strategy. Only about 1% of students report using self-testing as a primary study strategy, and another 10% say it is a strategy they employ some of the time (Karpicke, et al., 2009). The reason behind the lack of self-testing may not be laziness but an absence of awareness for its effectiveness.

A plethora of strategies exist to enhance learning, but most of the research on study strategies has been performed in lab settings with texts and pictures. The exception is the testing effect, which has been studied in a variety of settings. A meta-analysis conducted by Bangert-Drowns et al. (1991) found that students who frequently tested (weekly and bi-weekly) with multiple choice and open-response questions scored higher on a final criterion exam than the group who did not frequently test. Additionally, Beuoy and Waddill (2019) found that participants who self-tested after either copying or assembling math formulas remembered those formulas better than those who did not self-test, regardless of learning strategy. These results indicate the benefit of adding self-testing to other learning strategies.

Knowledge Maps

All the previously listed elaborative strategies can be combined in various ways. One of those methods is a knowledge map. Knowledge maps are useful tools for providing a visual representation of information. Maps are an elaborative strategy that is flexible enough to be applied to many domains and used in many ways while still being effective. A map normally consists of nodes representing ideas that are linked through a series of labels and can serve as a tool for knowledge acquisition, an adjunct for processing, and a cue for retrieval (O'Donnell et al., 2002). Boothby and Alvermann (1984) found that when fourth grade students completed graphic organizers (maps) pertaining to social studies topics (i.e., the tobacco trade) and were given feedback they showed greater free recall for the material both on immediate testing and after a 48-hour delay than the traditional teaching group (control). Hall and O'Donnell (1996) found similar results: participants who studied knowledge maps and completed a free recall test of the material performed better than those who only studied the text. In another study, Hall et al. (1999) had participants write a summary about a knowledge map while examining the map's blank structure and found that this post-organization strategy produced greater free recall after a 24-hour delay than those who just studied the map. The act of having students create (generate) their own knowledge maps can serve as an effective learning tool because the maps roughly reflect a student's cognitive structures (Schau & Mattern, 1997).

Apart from the direct memory benefits, participants who use knowledge maps report higher motivation and concentration toward the material they studied (O'Donnell et al., 2002). The success of knowledge maps can be attributed to their ability to highlight the macrostructure of material, reduce cognitive load, strengthen the representation of relationships, and create additional retrieval routes (O'Donnell et al., 2002). The reduction in cognitive load has important implications for using maps to learn math because math anxiety can negatively impact cognition and math learning.

Anxiety's Contribution to Math Learning

Anxiety influences learning, especially when the learning involves math. A contributing factor to anxiety's influence on math performance is people's belief that math is difficult, leading them to avoid it (Ashcraft, 2002). As a result, people may take fewer math classes, which bolsters math anxiety and increases the avoidance of math related material. Ashcraft (2002) found negative correlations between math anxiety and motivation, self-confidence, competence, achievement, learning new material, and the tendency to take math classes in the future.

Avoiding math or harboring beliefs about the difficulty of math may be caused by many factors and deciphering why a person does poorly on math measures is difficult. Initially, there was a belief that math anxiety did not form until the math curriculum became more difficult, but recent research points to its development as early as first grade (Maloney & Beilock, 2012) including its negative relationship to math achievement (Ramirez et al., 2013). Ashcraft (2002) notes that student anxiety may also be caused by a teacher's strict need for correctness and by little to no support for students who are struggling to learn the material.

Math anxiety is detrimental because it can impact working memory (WM) resources needed for successful performance on math tasks (Beilock, 2008). Eysenck and Calvo (1992) theorized that anxiety in general affects performance effectiveness (quality of performance) and processing efficiency (performance divided by effort). Anxiety tends to impair efficiency more than effectiveness because people dedicate a portion of WM to rehearsing the worries they have, which results in less WM capacity available to rehearse and maintain information needed to perform the task.

Although Eysenck and Calvo's (1992) theory focused on general anxiety and did not specifically focus on anxiety for mathematical tasks, many studies have looked at WM and math anxiety while exposing participants to increasingly greater cognitive loads. Ashcraft and Kirk (2001) conducted two studies in which participants performed a dual-task exercise. Participants had to complete mental math (addition and carrying) while remembering a series of two to six digits. Error rates increased as the series span became longer and participants had to carry for the math task; response times increased more for high anxiety than low anxiety individuals. When the math tasks were simple (whole number arithmetic) and required little WM capacity to complete, performance was at ceiling regardless of anxiety levels (Ashcraft & Krause, 2007). Ashcraft and Krause (2007) suggested the ceiling effect may be due to the fact that simple math tasks elicit mental processes stored in memory that can be retrieved automatically.

Exposure to difficult math problems is not the only way to induce math anxiety. Math anxiety can also be induced through stereotype threats. Stereotype threat can occur when a stereotype becomes salient to people belonging to the stereotyped group (Steele & Aronson, 1995). When the stereotype threat is induced, performance on threat-related tasks can differ from what would normally be expected when no threat was present (Sackett et al., 2004). For example, when women were told about the gender differences in math, their scores differed on math tasks from those who were not informed of the stereotype (Beilock et al., 2007). These findings do not necessarily mean stereotype threat is responsible for reduced performance, but some aspect of the experimental manipulation affected performance. Schmader et al. (2008) had participants complete tasks that required low working memory while under threat or not and found no difference in performance between the groups. Other studies have found item difficulty moderates the effects of stereotype threat and more difficult items show stronger effects (Flore & Wicherts, 2015). The reasons for the poor performance have parallels with math anxiety: ruminating or worrying about the stereotype takes up limited resources in WM and leaves fewer cognitive resources to focus on the task at hand.

Math anxiety creates detriments to performance and is correlated with many other negative factors. However, math anxiety appears to be domain specific. When highly math anxious people were exposed to math material, they exhibited qualities common to regular anxiety: changes in heart rate and sweaty palms (Ashcraft, 2002). However, these individuals did not exhibit a heightened physiological response when performing verbal tasks even as those tasks became more difficult.

Research on methods to alleviate math anxiety have tended to focus on dealing with anxiety at the time of test taking rather than during initial learning. Strategies to reduce math anxiety at testing may not be beneficial when anxiety is experienced during learning. Research on effective mathematical learning strategies is sparse. Rote memorization is an ineffective learning method (Levin, 1988) and susceptible to the effects of anxiety (Ashcraft, 2002). Research into knowledge maps suggest that map processing strategies may use fewer cognitive resources (O'Donnell et al., 2002), and this reduction could translate to greater learning.

Chapter II: Hypotheses

Based on previous research examining elaborative processing and its benefits to memory (e.g., Waddill et al., 1988; McDaniel et al., 1990; Einstein et al., 1990; Butler & Roediger, 2007) and the effectiveness of knowledge maps (e.g., Boothby & Alvermann, 1984; O'Donnell et al., 2002), it was hypothesized that when math anxiety was taken into account a group learning the steps for factoring polynomial equations while using a flowchart (knowledge map) would have greater recall for the steps necessary to solve polynomials than a group learning the steps with a list and the effect would persist over time. More specifically, the flowchart group would show greater recall than the list group for the steps needed to solve polynomials with two, three, and four terms and this advantage would be present immediately after learning the steps and several weeks later.

Additional Research Question

Although the primary focus of the proposed research was on the effectiveness of an elaborative strategy for learning the steps for factoring, it would also be interesting to evaluate the effect of that strategy on actual math performance. So, the relationship between learning the steps and successfully solving polynomials was investigated in order to determine if having learned the steps with a knowledge map produced better factoring performance than having used a list when controlling for math anxiety.

Chapter III: Method

Participants

Data were collected from 39 students enrolled in two sections of Problem Solving in Mathematics (MAT 110) at Murray State University. This math course is designed for students in STEM-H degree programs with math ACT scores less than 21. Students had already chosen which section to enroll in and random assignment of the sections to the control or experimental group was established via a coin flip. There were 21 students enrolled in the control group class and 19 in the experimental group class. However, data analysis was based on 20 students in the control group due one member never attending class and 14 students in the experimental group because five of the students did not consent to their information being used for research purposes. Thus, the final sample size consisted of 34 participants. All participants were treated in accordance with the APA *Ethical Principles of Psychologists and Code of Conduct* (American Psychological Association 2017), and the study was reviewed and approved by the Murray State Institutional Review Board (IRB; see Appendix A).

The mean age for the control group was 19.35 (*SD* = 5.15, *Range* = 16 – 41), and mean age for the experimental group was 18.57 (*SD* = .64, *Range* = 18 – 20). Age did not differ significantly between groups, $t(32) = 0.56$, $p = .580$. The majority of the participants were freshman ($n = 27$), the others were sophomores ($n = 6$) and one was a senior ($n = 1$); there were no juniors. Across both sections 22 students reported their gender as female and the other 12 reported their gender as male. Students were also asked to indicate their college GPA. The mean for those who indicated having a college GPA was 3.14 (*n* = 10; *SD* = 0.37; *Range* = 2.30 – 3.50) for the control group and 3.23 (*n* = 14; *SD* = 0.43; *Range* = 2.21 – 3.80) for the experimental group. GPA did not significantly differ between groups *t*(22) = -0.53, *p* = .600. Previous math exposure was also examined, and the control group (*n* = 19; *M* = 4.47; *SD* = 1.80; *Range* = 0 – 10) did not differ significantly from the experimental group (*n* = 13; *M* = 4.31; *SD* = 0.85; *Range* = 3 – 6) in the reported number of previous math courses, *t*(30) = 0.31, *p* = .761.

Materials

Participants' age, ethnicity, gender, major/minor, cumulative GPA, and previous math exposure were collected via a demographics form (see Appendix B). Anxiety was measured using the Abbreviated Math Anxiety Scale (AMAS; Hopko et al., 2003; see Appendix C). The AMAS is a 9-item scale that measures anxiety for various situations involved in learning and evaluating math. Responses are made on a 5-point Likert scale (1 = *low anxiety;* 5 = *high anxiety*) with higher summed scores indicating greater anxiety. The high internal consistency of the AMAS in this study (α = .85) is close to the value reported by the authors (α = .90), and above the value of .70 recommended for a reliable scale (Cronbach, 1951). Math anxiety score did not significantly differ between the control group (*M* = 22.95; *SD* = 5.74; *Range* = 12 – 32) and experimental group (*M* = 21.14; *SD* = 7.85; *Range* = 13 – 35), *t*(32) = 0.78, *p* = .443.

The target learning material was a presentation of the steps involved in factoring different types of polynomials. The material came in two formats: a list (control format; Appendix D) and a flowchart/knowledge map (experimental format; Appendix E). The flowchart was created by taking the individual items on the list and organizing them into a chart. Two kinds of tests were employed to gauge the students' retention of the target information. The free recall test (Appendix F) asked students to recreate the studied material (list or flowchart) from memory. The cued recall tests (Appendix G) asked students for the steps necessary to solve polynomials with two, three, and four terms.

Procedure

The study took place over an eight day period (Monday – Friday and Monday – Wednesday the following week) in the students' regular classroom around the 11th week in the semester when they were already scheduled to learn how to factor polynomials. The study was initially designed to take place over five days; however, both teachers extended the five day lecture by three days so students could have more exposure to the material. Each section was taught by a different teacher and the class periods for both sections were 50 minutes long. The activities that occurred on each day are detailed below.

Day 1

Students completed the consent process followed by the demographics survey and the AMAS administered by the investigator. After completion of the AMAS, the teachers of both classes introduced students to factoring and went over some examples of how polynomials are factored just as they normally would. Day 1 served the purpose of familiarizing students with factoring and developed context for learning the steps.

Day 2

The information on Day 2 was presented by the investigator and focused on the steps to factor polynomials. After class started, students in the experimental group were shown a demonstration of how the flowchart was organized and how to copy it appropriately (e.g., copy all the steps for factoring a two term polynomial before going onto the other terms; pay attention to the connecting lines and how the steps are organized). The demonstration was meant to guide students to focus on the structure of the knowledge map and the connections between the items. The control group received the factoring list along with instructions on how to copy the material (e.g., copy the first statement, including its number; copy the numbered statement below it; copy the next statement with its letter). When the demonstration was completed, students in both classes copied their study material on a blank sheet of paper. After this activity, the original and the copied material were taken away from the students and the free recall test was given. Students were given a blank sheet of paper and told to recreate as much as they could remember of the materials that they had studied and copied. Following the free recall test, a cued recalled test was given and the students had to recall the steps necessary to solve polynomials with two, three, and four terms. The order of the cued recall tests was randomized across participants with the stipulation that the tests for the three-term trial-and-error method and the three-term AC method were not given consecutively. The 50-minute class session ended after the recall tests.

Day 3

Day 3 was similar to Day 2, except that there was no demonstration or free recall test. In the first half of the 50-minute class period, students copied the material as they did on Day 2 and completed the set of cued recall tests in a different random order from Day 2. The tests on Day 3 served as a self-testing session to encourage further learning. The completed cued recall tests were collected from the students and then replaced by a correct, complete copy of the study material (list or flowchart). Students were then instructed to use the correct, completed version to assist further learning. Cued recall accuracy was expected to be different for each student, so replacing the recall sheets with the complete original version of the materials helped ensure all students would have the same, correct study material to use for further learning. From this point on, students could keep the material with them and use it for the rest of the semester.

The second half of Day 3 was then handed back to the instructors who gave students a worksheet with two, three, and four term factoring problems to solve. The students completed these problems both individually and with other classmates while having the list of steps (control condition) or the flowchart (experimental condition) to use as an aid.

Days 4 and 5

On Day 4, the students worked with their instructors to complete more factoring examples with two, three, and four terms and also went over common mistakes that are made when factoring. Students had the steps or flowchart to use during this time.

Day 5 started with the researcher administering a set of cued recall tests in random order as a self-testing activity to encourage continued learning. Afterwards, students worked with their instructors to complete factoring problems on their MyMathLab accounts while using their factoring sheets until the end of class. MyMathLab is an online math software program that teachers can use to assign math homework and other activities for students to complete.

Days 6-8

On Days 6 through 8 the students continued to work on their homework assignment in MyMathLab and completed more factoring examples for added practice. The researcher did not conduct any activities on these days.

End of Semester

During the 15th week of the semester, approximately 30 days after the factoring polynomials lecture on Day 2, the researcher administered the last set of free recall and cued recall tests to assess long-term retention. The following week students took a final exam designed by their respective course instructor for their class. Both final exams contained two factoring problems designed by the instructors and consisting of a two term and a four term polynomial.

Chapter IV: Results

The dependent variables of interest were overall free recall performance and overall cued recall performance. Each dependent variable was operationally defined in two ways. The first was the number of steps correctly recalled regardless of order (referred to as *individual item score*). This score was calculated by awarding one point to each correctly recalled step regardless of the order in which the steps were recalled. The second was the number of steps correctly recalled in the correct order (referred to as *relational score*). In this more stringent measure, one point was awarded only if the step was correct and was recalled in its correct location in the factoring sequence.

The total free recall score (both individual item and relational) was converted to an overall proportion by dividing the total points earned by the maximum points possible, which was 33. The total score on cued recall (both individual item and relational) was calculated by summing the scores across the test items for the four different kinds of polynomials. The summed score was converted to an overall proportion by dividing the sum by the total possible points for CR. Because the four polynomials shared some factoring steps (e.g., Is there a GCF? Can you factor anything else?), the maximum number of possible points for both individual item and relational cued recall was 56. See Appendix H for more detail and an example of how a CR test response was scored.

The level of significance for all analyses was set at .05. Because of the *a priori* hypothesis that the experimental group would show better recall for the material than the control group, the main effect of group was evaluated against a one-tailed *p*-value. All other effects were evaluated against two-tailed *p*-values. Following the recommendation of Schneider et al. (2015), the covariate (AMAS math anxiety score) was first centered by subtracting each individual value from the grand mean of 22. Cued recall tests were administered on four different days, and free recall was only administered on Day 2 and Day 30. To keep all the analyses consistent, only the scores from Day 2 and Day 30 were used for analyses. Table 1 displays the means for each measure by group and day. Table 2 presents the correlations between each measure and math anxiety score as a function of group and day.

Table 1

Mean Proportion Correct as a Function of Group and Day (with SD in Parentheses)

Measure and Day		Group	
		Control[1]	Experimental[2]
Cued Individual Item			
	Day 2	0.08 (.05)	0.11 (.06)
	Day 30	0.12 (.06)	0.13 (.12)
Cued Relational			
	Day 2	0.02 (.03)	0.05 (.05)
	Day 30	0.05 (.05)	0.08 (.12)
Free Recall Individual Item			
	Day 2	0.16 (.08)	0.18 (.12)
	Day 30	0.17 (.15)	0.25 (.19)
Free Recall Relational			
	Day 2	0.05 (.06)	0.14 (.14)
	Day 30	0.07 (.09)	0.16 (.18)

[1]*n* = 20; [2]*n* = 14[1].

Table 2

Spearman's Rho Correlation Coefficients for the Relationship between Math Anxiety and Recall Performance as a Function of Group and Day

Measure and Day		Group	
		Control[1]	Experimental[2]
Cued Individual Item			
	Day 2	-0.42	0.04
	Day 30	0.00	-0.48
Cued Relational			
	Day 2	-0.03	0.02
	Day 30	-0.28	-0.57
Free Recall Individual Item			
	Day 2	-0.16	0.16
	Day 30	-0.26	-0.50
Free Recall Relational			
	Day 2	-0.23	-0.16
	Day 30	0.13	-0.61*

[1]*n* = 20; [2]*n* = 14.

$^{*}p < .05$.

Individual item

For the cued individual item measure, there was no significant main effect of group or day nor were there significant interactions. Table 3 displays the results of the ANCOVA, and Figure 1 presents the unadjusted means for the groups on each day.

Table 3

Mixed ANCOVA on Individual Item Cued Recall

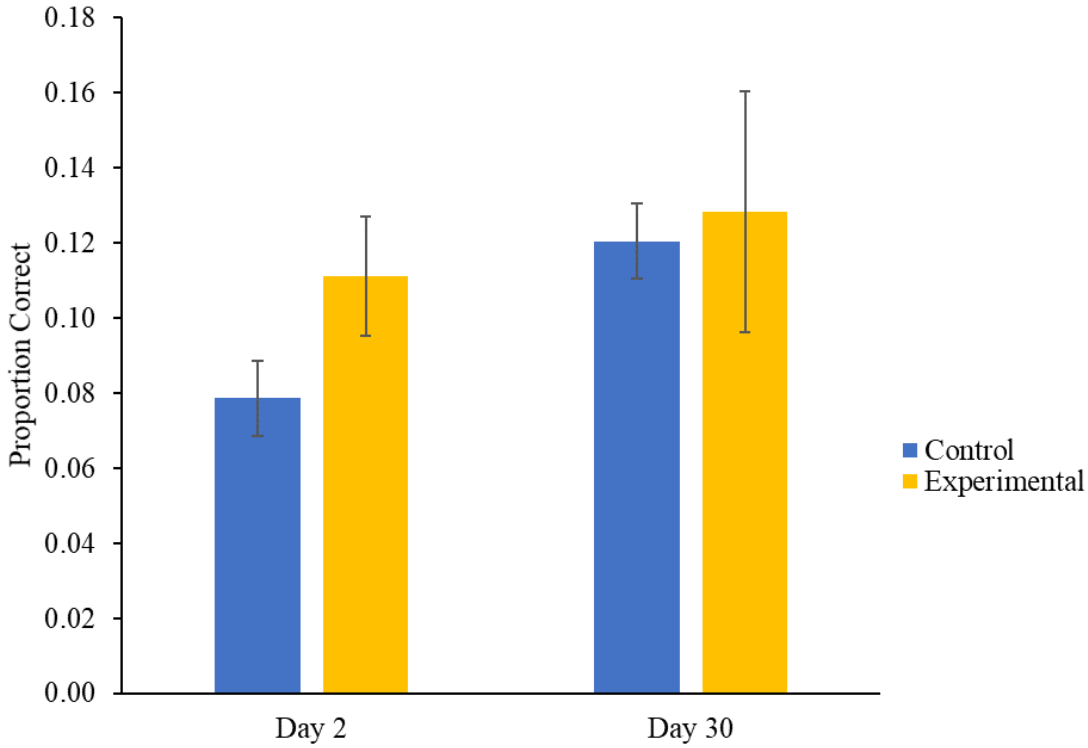
Source	*df*	*F*	*p*
	Between subjects		
Math Anxiety (MA)	1	1.85	0.184
Error (MA)	31	(0.006)	
Group (G)	1	1.05	0.157[a]
Error (G)	32	(0.006)	
	Within Subjects		
Day x Math anxiety (DMA)	1	0.96	0.340
Error (DMA)	31	(0.004)	
Day (D)	1	3.27	0.080
Day x Group (DG)	1	0.56	0.458
Error (D)	32	(0.004)	

Note. All reported *p*-values are two-tailed unless otherwise noted.

[a]one-tailed.

Figure 1

Unadjusted Mean Individual Item Cued Recall by Day and Group



Note. The bars represent standard error

Relational

For cued relational recall, the experimental group performed nominally better than the control group but the difference did not reach statistical significance. However, the main effect of day was significant; participants in both groups performed significantly better on Day 30 than on Day 2. There were no significant interactions. Table 4 displays the results of the ANCOVA, including the covariate. Figure 2 shows the unadjusted means for the groups on each day.

Table 4

Mixed ANCOVA on Relational Cued Recall

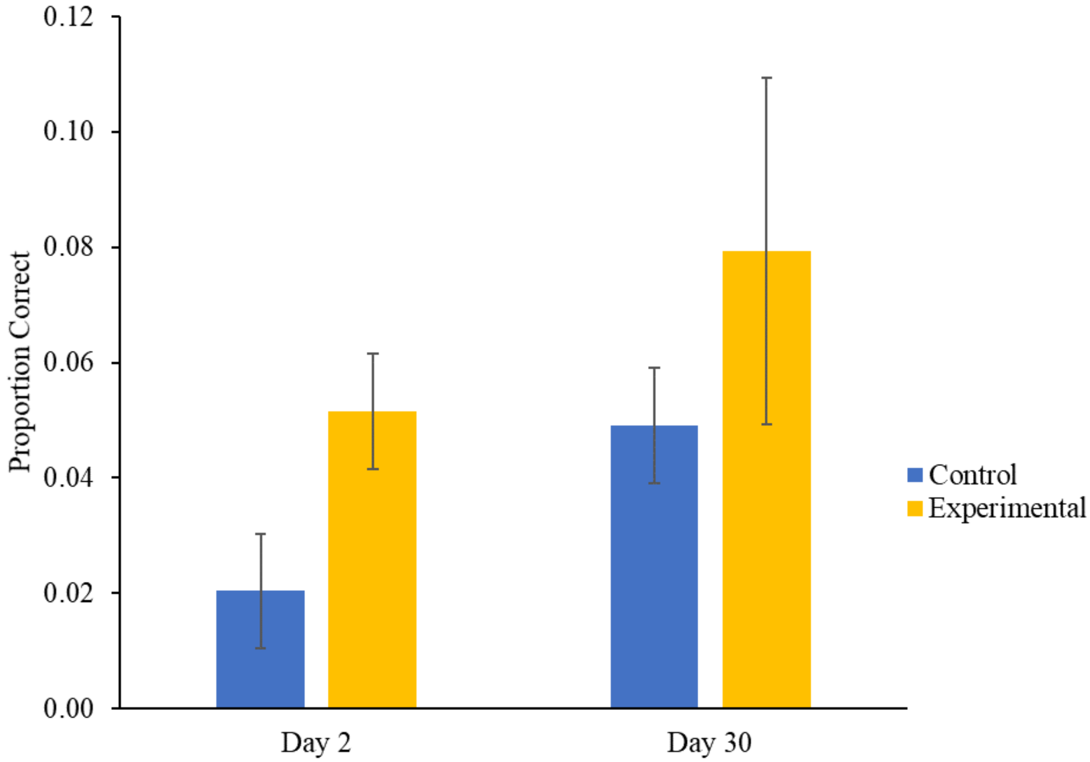
Source	*df*	*F*	*p*
	Between subjects		
Math Anxiety (MA)	1	3.54	0.070
Error (MA)	31	(0.005)	
Group (G)	1	2.72	0.054[a]
Error (G)	32	(0.005)	
	Within Subjects		
Day x Math anxiety (DMA)	1	1.69	0.203
Error (DMA)	31	(0.003)	
Day (D)	1	5.00	0.033
Day x Group (DG)	1	0.00	0.971
Error (D)	32	(0.002)	

Note. All reported *p*-values are two-tailed unless otherwise noted.

[a]one-tailed.

Figure 2

Unadjusted Mean Relational Cued Recall by Day and Group



Note. The bars represent standard error

Free Recall Performance

Each dependent variable was analyzed with a separate 2 x 2 mixed ANCOVA where group (control vs. experimental) served as the between-groups factor, day (Day 2 vs. Day 30) as the within-subjects factor, and math anxiety (AMAS) score as the covariate.

Individual item

Table 5 presents the results of the ANCOVA of individual item free recall. Figure 3 displays the unadjusted means for the groups on each day. There was no significant main effect of group or day, and there was no significant interaction between the group and day. However, there was a significant interaction between math anxiety and day. To follow up the significant interaction, simple slopes analyses were conducted for each day. The analysis for Day 2 indicated no significant relationship between math anxiety and individual item recall, B = -0.0003, β = -0.01, p = .930. However, on Day 30 math anxiety was significantly related to individual item recall, B = -0.0098, β = -0.48, p = .005. Higher math anxiety predicted better long-term individual item recall. The interaction was graphed by inserting low (-1 *SD*) and high (+1 *SD*) values for math anxiety into the regression equation for each day (see Figure 4).

Table 5

Mixed ANCOVA on Individual Item Free Recall

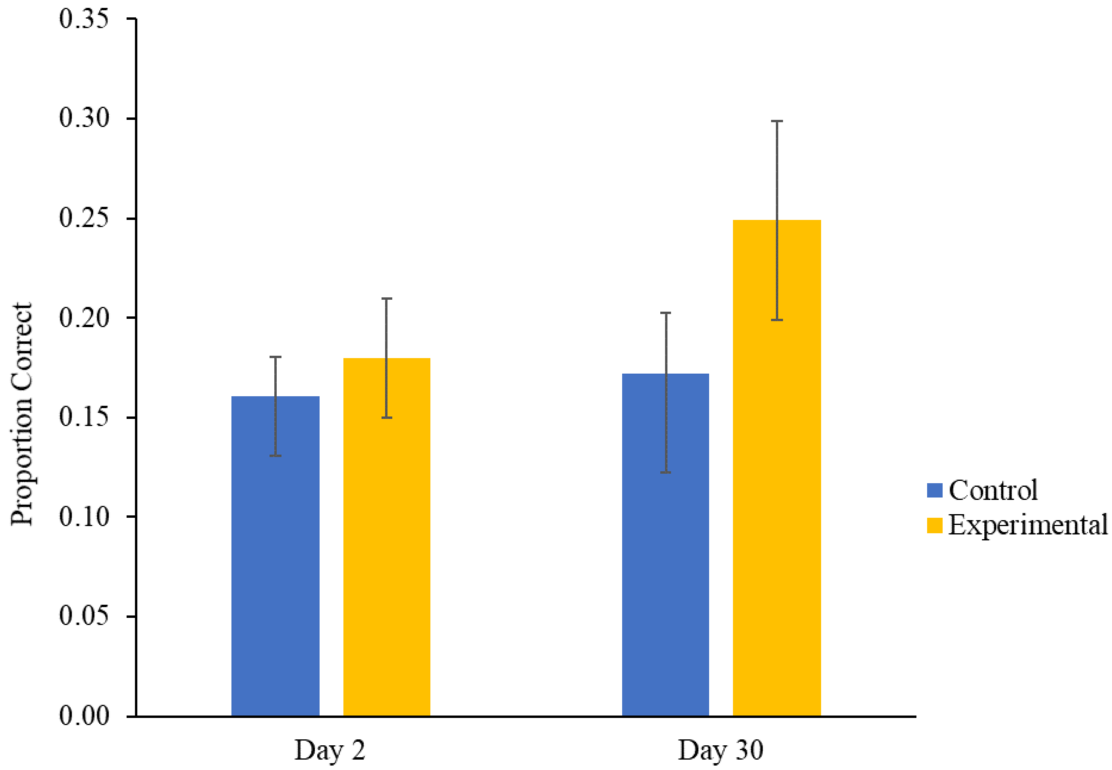
Source	*df*	*F*	*p*
	Between subjects		
Math Anxiety (MA)	1	2.42	0.130
Error (MA)	31	(0.022)	
Group (G)	1	1.59	0.108[a]
Error (G)	32	(0.023)	
	Within Subjects		
Day x Math anxiety (DMA)	1	6.58	0.006
Error (DMA)	31	(0.010)	
Day (D)	1	2.26	0.142
Day x Group (DG)	1	1.12	0.299
Error (D)	32	(0.012)	

Note. All reported *p*-values are two-tailed unless otherwise noted.

[a]one-tailed.

Figure 3

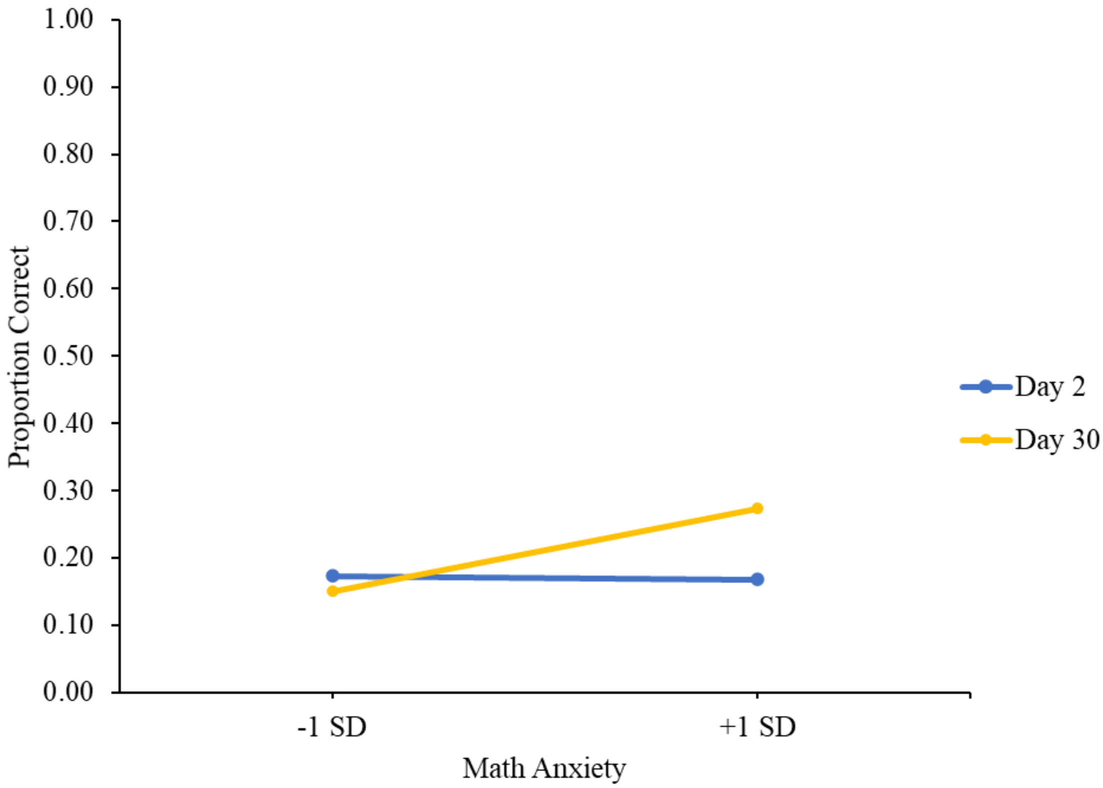
Unadjusted Mean Individual Item Free Recall by Day and Group



Note. The bars represent standard error

Figure 4

Mean Estimates of Individual Item Free Recall on Each Day for Low (-1 SD) and High (+1 SD) Anxiety



Relational

Table 6 presents the results of the ANCOVA for relational free recall. Free recall showed a significant main effect of group. There was not a significant main effect of day or an interaction between group and day (see Figure 5). However, there was an interaction between math anxiety and day. To follow up the significant interaction, simple slopes analyses were conducted for each day. The analysis for Day 2 indicated no significant relationship between math anxiety and individual item recall, $B = -0.0005$, $\beta = 0.28$, $p = .870$. However, on Day 30 math anxiety was significantly related to individual item recall, $B = 0.0005$, $\beta = 0.46$, $p = .008$. The interaction was graphed by inserting low (-1 *SD*) and high (+1 *SD*) values for math anxiety into the regression equation for each day (see Figure 6).

Table 6

Mixed ANCOVA on Relational Free Recall

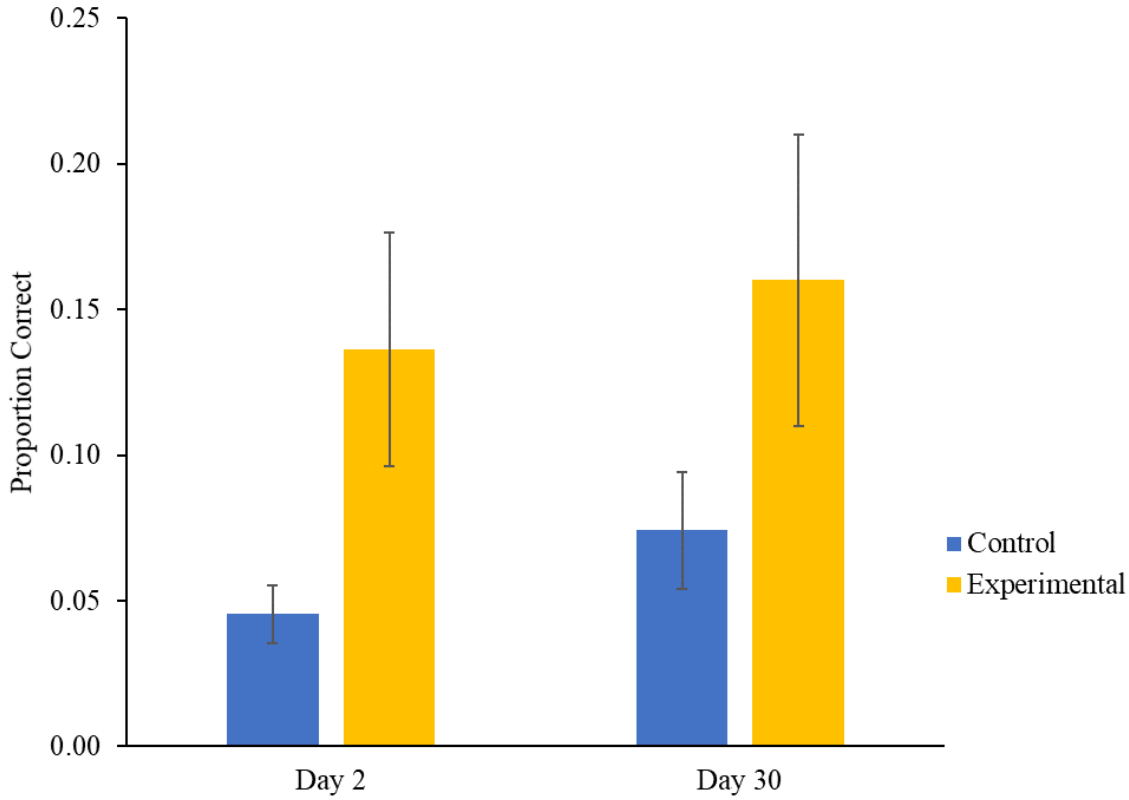
Source	*df*	*F*	*p*
	Between subjects		
Math Anxiety (MA)	1	2.33	0.137
Error (MA)	31	(0.017)	
Group (G)	1	7.20	0.006[a]
Error (G)	32	(0.018)	
	Within Subjects		
Day x Math anxiety (DMA)	1	5.49	0.023
Error (DMA)	31	(0.008)	
Day (D)	1	1.11	0.299
Day x Group (DG)	1	0.01	0.921
Error (D)	32	(0.010)	

Note. All reported *p*-values are two-tailed unless otherwise noted.

[a]one-tailed.

Figure 5

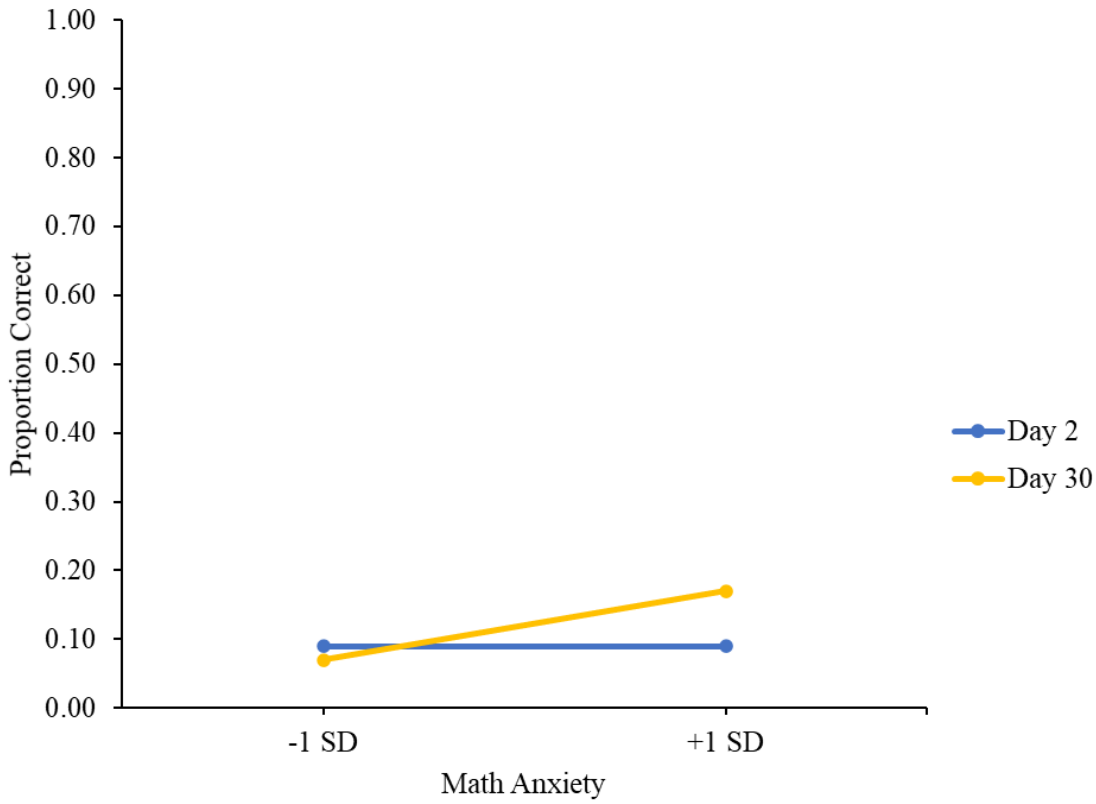
Unadjusted Mean Relational Free Recall by Day and Group



Note. The bars represent standard error

Figure 6

Mean Estimates of Relational Free Recall on Each Day at Low (-1 SD) and High (+1 SD) Anxiety



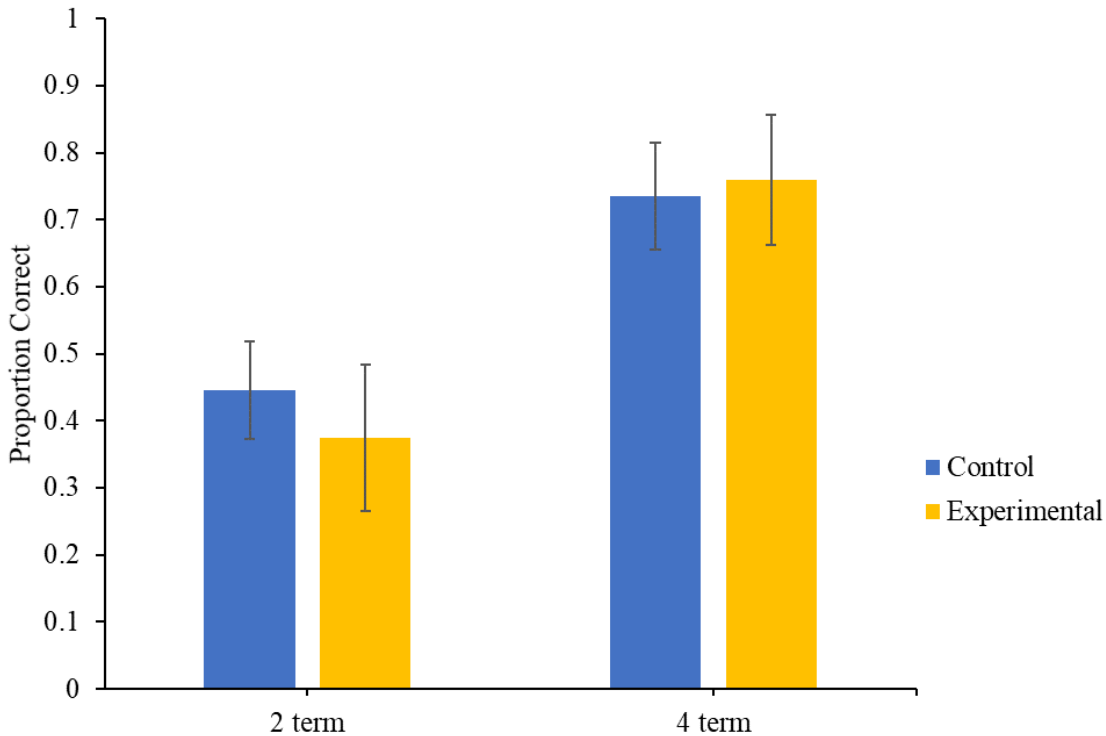
Analysis of Additional Research Question

Mediated regression analyses were conducted to determine if there was a relationship between how well students remembered the factoring steps and how well they factored polynomials on their final exam. The final exam for both classes contained a two term and a four term polynomial that the students had to factor. The scores on each problem were converted into proportion correct. Figure 7 depicts the average factoring performance by group and number of terms. A separate analysis was conducted for each combination of type of cued recall (individual item, relational) and type of polynomial (two-term, four-term) using group as the predictor, Day 30 cued recall as the mediator, and factoring score on the final exam as the dependent variable. Math anxiety was entered into the model as a covariate. Figure 8 presents a diagram of the general design of the mediation analyses. The significance level for all four analyses was set at .05.

Group did not predict scores on two term or four term polynomials (*p*-values ranged from .084 to .953). The only significant direct effect between a predictor and final exam score was for Day 30 individual item recall and two term polynomial score, B = 1.60, β = 0.42, p = .009, 95% CI [0.42, 2.77]. None of the direct effects in the other three analyses were statistically significant (all *p*s > .05 and ranged from .272 to .825). Despite many of the predictors not being significant, the mediation analyses were still conducted because the lack of a direct effect does not constitute the lack of an indirect effect (Hayes, 2009). None of the mediation models yielded a significant indirect effect. The biggest indirect effect was observed for Day 30 individual item recall as the mediator of two term polynomial performance score; the unstandardized indirect effect was (0.05)*(1.59) = 0.09, 95% CI[-0.02, 0.23].

Figure 7

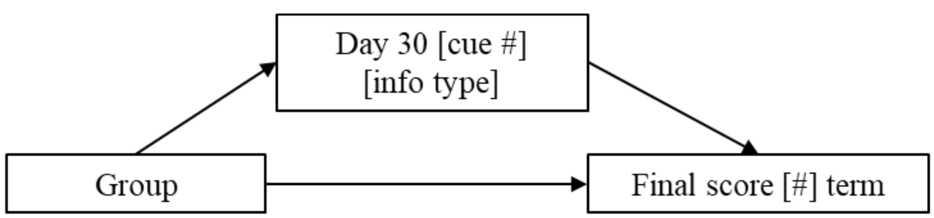
Performance on Factoring Polynomial Problems of the Final Exam by Group and Type of Polynomial



Note. The bars represent standard error

Figure 8

General Design of the Mediation Analyses



Note. Text inside the brackets represents the values that were changed for each analysis.

Chapter V: Discussion

The current study sought to investigate the effect of using an elaborative learning strategy on memory for the steps involved in factoring polynomials when math anxiety was accounted for. More specifically, this study addressed the question of whether or not students who learned with a flowchart produced better individual item and relational recall of the steps than those who learned with a written list.

Learning strategy did not significantly affect memory for the individual steps (individual items) involved in factoring polynomials when math anxiety was taken into account. Those who used a flowchart did not perform better than those who used a list on either cued or free recall. However, the overall pattern of individual item free recall at the beginning and the end of the semester differed as a function of math anxiety. At the start of the semester, anxiety was not significantly related to performance; at the end of the semester, higher anxiety predicted better memory of factoring steps.

On the other hand, memory for the ordering of the steps (relational recall) showed a different pattern from memory for the steps themselves. In general, when math anxiety was taken into account, students who used the flowchart were better than those who received a list at recreating the steps in the correct order and with the correct relationships. This benefit of the flowchart was evident in both cued and free recall performance and persisted across time although it was stronger for free recall than for cued recall. In addition, students in both strategy groups showed better relational cued recall at the end of the semester than at the beginning. As was observed in individual item free recall, the relationship between relational free recall and anxiety differed as a function of time. Performance at the beginning of the semester was not related to level of anxiety; however, at the end of the semester, higher anxiety predicted better free recall of the relationships among the steps.

Overall, the flowchart worked better than lists for recall of the organization of the steps in factoring. The significance of these findings has important implications for education because order of the steps is important. Using the steps in the wrong order is likely to provide little benefit when trying to successfully factor a polynomial, so a method that helps students remember the sequencing of the steps will be beneficial for remembering what to do and in what order. Students in both groups engaged in similar elaborative activities that involved focusing on the meaning of the material (depth of processing), studying the steps in a way that matched what they were asked to do on the recall tasks (transfer-appropriate processing), and self-testing (cued-recall tasks on Days 3 and 5). However, students who used the flowchart received additional elaborative benefits. Firstly, knowledge maps like the flowchart strengthen the representation of relationships and create additional retrieval routes (O'Donnell et al., 2002). These additional retrieval routes can be used at the time of testing to prime and activate the associated information. Secondly, compared to the list, the flowchart organized the material by creating and depicting distinct pathways linking the type of polynomial to the appropriate steps and by highlighting the correct order of those steps. This kind of predefined organization can reduce cognitive load by not requiring learners to use additional resources to mentally organize the material while encoding (O'Donnell et al., 2002). Instead, they can use those cognitive resources to focus on encoding the relationships between the connections.

Contrary to relational recall, individual item recall was not enhanced by the use of a flowchart. Individual item processing occurs when tasks emphasize the unique characteristics of items (Huff & Bodner, 2014). Elaborative encoding strategies like the flowchart employed in this study focus on encoding the relationship between items. Elaborations create additional relational pathways but do not increase the strength of the memory trace of the individual items (Bradshaw & Anderson, 1982). Rehearsal, on the other hand, serves as a major factor for increasing individual item encoding because it can increase the strength and probability of an item being recalled from long-term memory (Craik & Watkins, 1973). In the present study, both groups studied the material the same number of times so the amount of rehearsal for the steps was similar. It is not surprising, therefore, that individual item recall for the two groups was not significantly different.

The finding that higher math anxiety was associated with better long-term free recall was interesting. Math anxiety is assumed to decrease the amount of working memory people have available to complete math tasks (Eysenck & Calvo, 1992). However, a consistent finding in the literature is an inverted-U shaped relationship between arousal and performance: in general, performance is best at moderate levels of arousal (including anxiety) and poorer at lower and higher levels (Hanoch & Vitouch, 2004). In the current study, the average anxiety score was 22 out of a possible 45 and even the highest reported score of 35 was not indicative of extreme anxiety. Thus, the higher anxiety participants in this study may well have been within the range of the moderate arousal levels shown to improve performance. Another consistent finding in the literature is the differential effects of arousal over time. Emotional arousal, including stress, at the time of encoding has been shown either to have no effect (Quevedo et al., 2003) or a negative effect (Lavach, 1973) on immediate memory but to enhance retention of information over the long term (Lavach, 1973; Quevedo et al., 2003). This effect is due in large part to the release of epinephrine, a stress hormone that modulates memory consolidation over time (Cahill & Alkire, 2003). The patterns observed in the current study of no association of anxiety with short term recall but a positive association with recall after one month parallel these findings and highlight the importance of taking time into account when evaluating the role of anxiety in memory.

Although the primary aim of the study was to improve encoding and memory of the steps used to factor polynomials, understanding how memory for the steps related to applying them was also of interest. More specifically, would a particular strategy for learning the steps produce better factoring performance on a final exam and was that a function of memory for the steps? The mediational analyses served the purpose of examining this question. However, none of the analyses produced significant mediations. These null results do not necessarily mean that memory for the steps has no practical effect on performance. The evaluation of this research question was primarily exploratory. There was only one polynomial of each type on the final exam and each of those exam items was worth a maximum of four or five points, so there was limited room for variability in the outcome measure. Future research should include more extensive and varied measures of performance and application.

The aim of this study was to see if techniques that work in the highly controlled environment of the research lab translate to the more flexible setting of the real-world classroom. Field research presents its own set of challenges and this study was no exception. The current study had its limitations. The university intentionally limits the size of the MAT 110 classes in order for students to receive more individualized attention, so sample size was an issue for this study. The effect of small sample size is evidenced by the large standard errors (SE) and standard deviations (SD), especially on Day 30 for the experimental group. The large SE may indicate the sample mean was not an accurate representation of the population mean, and the high SD indicates a high amount of variability, both of which contributed to lower statistical power.

One of the difficulties with moving an experimental design into the field is that it is not possible to fully duplicate the tightly controlled conditions of the laboratory in the real-life environment of the classroom and the controls that can be implemented may seem out of place to the participants (i.e., students). Participants who volunteer to take part in a lab-based research study enter a formal environment where they are likely to expect to be faced with unusual tasks. The current study, on the other hand, was conducted in the students' familiar classroom environment by someone unfamiliar to them (the investigator) who presented tasks that were different from the routine they had been used to for more than ten weeks. Observational evidence indicated that on the first day of the experimental interventions (Day 2) when students began the studying activities, they may not have clearly understood the importance of the unfamiliar learning tasks they were being asked to perform. In an attempt to increase their understanding and engagement in what were admittedly rather unexciting study activities, the teachers and researcher talked to each of the classes about the importance of the tasks for learning, memory, and application. However, going into too much detail about their importance would have revealed too much information about the study and potentially biased the results. Interference can also hamper the learning of difficult new material (Winocur, 1984) because it competes with limited working memory resources. In the current study, participants who finished an activity before the time limit often then talked with a neighbor or pulled out their cell phone, which could have interfered with other students' encoding of the material.

As previously noted, because this was an experimental study, the investigator did not incorporate additional activities to increase students' engagement with, attention to, or motivation toward the learning tasks, unlike what a teacher would do if using the materials in the context of the regular classroom. Motivation is important for learning new material (Butler & Roediger, 2011), and the effectiveness of the flowchart might be further enhanced by deliberately incorporating activities to engage students with the material.

The overall levels of recall were low, ranging between .02 to .17 for the control group and .05 to .25 for the experimental group. Nevertheless, these patterns are consistent findings from laboratory studies of the effects of elaborative vs. non-elaborative encoding on memory for expository (factual) text. Waddill et al. (1988) found immediate recall rates ranging from .10 to .21 for information in expository passages, and Einstein et al. (1990) reported values ranging from .19 to .43 after a one-week delay. Expository material in general is difficult to recall, which further underlines the value of using elaborative techniques for encoding it.

This study sought to answer the question of whether elaborative strategies that were found to be effective in the lab can also work in the real-world classroom. The answer appears to be “yes.” In spite of the limitations imposed by conducting this research in the field, this study provides valuable insight into the effectiveness of flowcharts for learning the steps to factoring. Future research could focus on extending these techniques to students in different math courses and with different kinds of mathematical operations. The students in the math classes used in the current study are assumed to have less math experience than those in upper level math courses, so how effective would flowcharts be for more experienced math students? Further investigating cognitive load as it pertains to the flowchart of factoring steps as well as its relation to math anxiety would also be important. Doing so would add to our understanding of when, and for whom, this intervention works best and how it can effectively be incorporated into the mathematics classroom.

Appendix A: IRB Approval Letter and Consent Document

MURRAY STATE
UNIVERSITY

Institutional Review Board

328 Wells Hall
Murray, KY 42071-3318
270-809-2916• msu.irb@murraystate.edu

TO: Paula Waddill, Psychology

FROM: Jonathan Baskin, IRB Coordinator JB

DATE: 10/29/2019

RE: Human Subjects Protocol I.D. – IRB # 20-078

The IRB has completed its review of your student's Level 1 protocol entitled *How Going with the Flow Could Aid Factor Learning*. After review and consideration, the IRB has determined that the research, as described in the protocol form, will be conducted in compliance with Murray State University guidelines for the protection of human participants.

The forms and materials that have been approved for use in this research study are attached to the email containing this letter. These are the forms and materials that must be presented to the subjects. Use of any process or forms other than those approved by the IRB will be considered misconduct in research as stated in the MSU IRB Procedures and Guidelines section 20.3.

Your stated data collection period is from 11/4/2019 to 6/12/2020.

If data collection extends beyond this period, please submit an Amendment to an Approved Protocol form detailing the new data collection period and the reason for the change.

This Level 1 approval is valid until 10/28/2020.

If data collection and analysis extends beyond this date, the research project must be reviewed as a continuation project by the IRB prior to the end of the approval period, 10/28/2020. You must reapply for IRB approval by submitting a Project Update and Closure form (available at murraystate.edu/irb). You must allow ample time for IRB processing and decision prior to your expiration date, or your research must stop until such time that IRB approval is received. If the research project is completed by the end of the approval period, then a Project Update and Closure form must be submitted for IRB review so that your protocol may be closed. It is your responsibility to submit the appropriate paperwork in a timely manner.

The protocol is approved. You may begin data collection now.

Opportunity
afforded

murraystate.edu

Permission to Use MAT 110 Course Data for Research Purposes
Primary Investigator: Aaron Beuoy (graduate student)
Faculty sponsor: Dr. Paula J. Waddill MSU Department of Psychology, (270) 809-3539, pwaddill@murraystate.edu

We are interested in investigating different strategies for teaching the steps used in factoring polynomials. As part of your MAT 110 course, there will be a variety of activities provided to teach you factoring. Some of these activities will be provided by your course instructor and some will be provided by Aaron Beuoy who is a graduate student doing research on ways to improve teaching math. During the regular class period, Aaron will provide you with materials that illustrate the steps in factoring, instructions for how to study those materials, measures of what you remember after studying the materials, a survey of demographic information about yourself (like your age, gender, and GPA), and a survey about your feelings about math. Your MAT 110 teacher will be explaining factoring to you and working through problems and practice activities. She will also be giving you regular course tests that include factoring problems as well as other material you've learned in the course. These are the same tests that your teacher would use even if Aaron were not evaluating different teaching methods for factoring. However, in addition to your teacher using the tests to evaluate your individual performance, Aaron also wishes to use the information from the test items on factoring to assess how effective the strategies were.

You are being asked to give your permission for Aaron to use your performance on the test items in this course for research purposes in addition to your teacher's usual purpose of evaluating your individual progress in the course. If you agree to allow Aaron to use your performance information, then your test scores will be included with other students' scores to provide a general data set for analysis. Your individual performance will not be analyzed or reported for research purposes. If you do not agree to allow your information to be used, then Aaron will not include it in the data set that is analyzed. You will still complete the same tests and activities regardless of whether or not you give permission to have your data included in the research, and your individual performance (i.e., your test grades and final course grade) will be based upon the same sources of evaluation regardless of whether or not you give permission for your information to be used for research.

You should view your permission as completely voluntary. You will suffer no penalty in any form if you choose not to allow your information to be used. In particular, your decision of whether or not to participate will have no impact on your course grade or your grades on the individual tests. Your teacher will not be aware of whether or not you've given permission for Aaron to use your information for the research study. You are also free to withdraw your permission to use your data. If you initially agree to allow Aaron to use your information but change your mind later, simply contact the Aaron's faculty research mentor Dr. Paula Waddill at (270) 809-3539 or pwaddill@murraystate.edu.

Your performance information will be kept confidential. You will be asked to put your name on your materials only so that your responses from the activities can be matched with each other to provide a complete set of your material for data analysis. Your data will be numerically coded and data analysis will be conducted using only your numerical code, not your name. The faculty sponsor will keep the signed informed consent documents and all other identifying information related to this study in a secure location for at least three years after completion of this study, after which all such documents and identifying information will be destroyed. Neither your name nor any identifying information about you will be included in any presentations or articles in which the results of the research are discussed.

Please indicate your decision by initialing one statement. You will be given a copy of this form to keep.

_______ I give Aaron Beuoy permission to use my test performance information in his data analysis.
initials

_______ I **do not** give Aaron Beuoy permission to use my test performance information in his data analysis.
initials

The dated approval stamp on this document indicates that this project has been reviewed and approved by the Murray State University Institutional Review Board (IRB) for the Protection of Human Subjects. If you have any questions about your rights as a research participant, you should contact the MSU IRB Coordinator at (270) 809-2916 or msu.irb@murraystate.edu.

Name (print): ____

Signature: ______________________________ Date: __________

MURRAY STATE
UNIVERSITY
Institutional Review Board
Approved: 10/29/19 Expires: 10/28/20

Appendix B: Demographics Survey

Name: ___________________________________

Your age: ____________________

Your gender (circle one): *Male* *Female* *Other (please specify):* _________

Classification (circle one): *Freshman* *Sophomore* *Junior* *Senior*

What is your major/area? ____

What is your minor/second major? ____

What is your cumulative GPA**?** ______________

Are you a first-semester freshman? *Yes* *No*

What was your high school GPA? ______________

What is your ethnicity/race? ____

How many math courses have you taken prior to this course including high school? ____

Appendix C: Abbreviated Math Anxiety Scale

Name: ___________________________________

AMAS

For each item below, please *circle the number* that indicates how anxious you would feel during the event specified. There are no right or wrong or good or bad answers. Please be honest in your ratings of how you would really feel.

Item	Low Anxiety	Some Anxiety	Moderate Anxiety	Quite a bit of Anxiety	High Anxiety
Having to use the tables in the back of a mathematics book.	1	2	3	4	5
Thinking about an upcoming mathematics test 1 day before.	1	2	3	4	5
Watching a teacher work an algebraic equation on the blackboard.	1	2	3	4	5
Taking an examination in a mathematics course.	1	2	3	4	5
Being given a homework assignment of many difficult problems that is due the next class meeting.	1	2	3	4	5
Listening to a lecture in mathematics class.	1	2	3	4	5
Listening to another student explain a mathematics formula.	1	2	3	4	5
Being given a “pop” quiz in math class.	1	2	3	4	5
Starting a new chapter in a math book.	1	2	3	4	5

Appendix D: Factoring Steps – Control Group

1. Is there a Greatest Common Factor (GCF) to factor out?

2. How many terms are there? (How many terms are left if you factored out a GCF?)
   a. FOUR TERMS:
      Try Factor By Grouping:

      Make two equal size groups and ask 'what does each group have in common'?

      Now, what does each term have in common?

   b. THREE TERMS:

      You need to look at the polynomial in this form: $Ax^2 + Bx + C$

      Try the Trial and Error Method

      Create two binomials

      Try two terms that multiply to give the first term in the trinomial

      Then try to find two factors that multiply to give you the last term

      Try the AC Method (Turn into four term Factor by Grouping Problem)

      Remember to look the polynomial in this form: $Ax^2 + Bx + C$

      Multiply the A & C to get product AC

      Find factors of AC that combine to give you B

      Make the polynomial four terms by replacing the "Bx" term with the new factors

      Now use Factor by Grouping

   c. TWO TERMS:

      Is it a Difference of Squares? (Are you subtracting two terms that are squares?)

      Use $A^2 - B^2 = (A + B)(A - B)$

      What do you square to get the first term?

      What do you square to get the second term?

      Use what you square for each term in the difference of squares formula

      Is it a Sum of Cubes? Is it a Difference of Cubes?

      Follow the process for Difference of Squares but use these formulas:

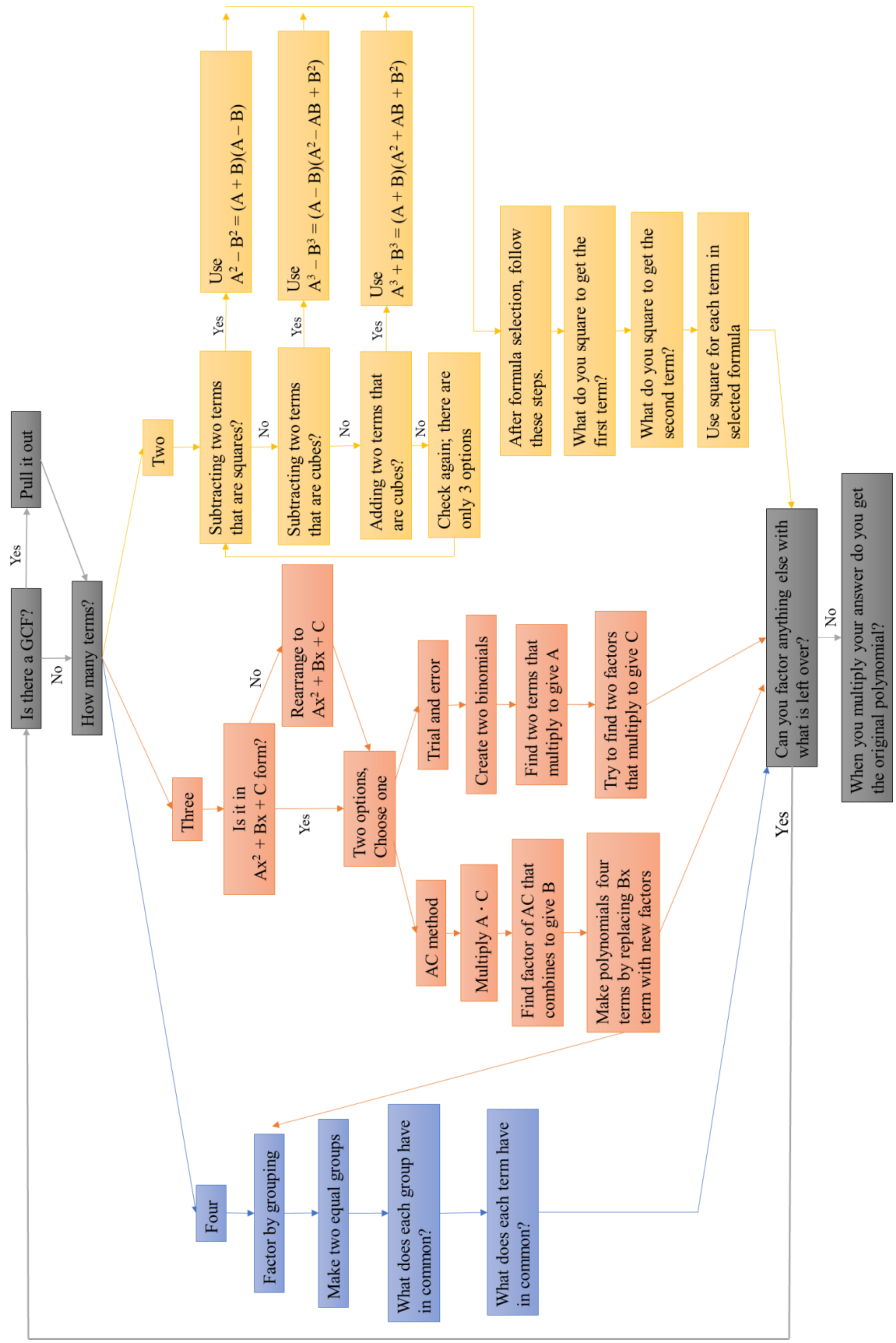
      $A^3 + B^3 = (A + B)(A^2 - AB + B^2)$

      $A^3 - B^3 = (A - B)(A^2 + AB + B^2)$

3. Can you factor anything else with what is leftover? (Go back and repeat step 1 and 2)

4. Check your answer by multiplying. When you multiply, do you get back to the original polynomial?

Appendix E: Factoring Flowchart– Experimental Group



Appendix F: Free Recall Test
(Each group's recall task and instructions was presented on a separate sheet)

[Control group]

Name: ____________________________

Please write down all the steps for factoring that you just studied and copied. Please write the steps in order and as quickly and accurately as possible. If you can't remember the exact words for a step, use words that are as close to the original as possible.

[Experimental group]

Name: ____________________________

Please draw the diagram of steps for factoring that you just studied and copied. Please write the steps in order and draw the arrows. Draw as quickly and accurately as possible. If you can't remember the exact words for a step, use words that are as close to the original as possible

Appendix G: Cued Recall Tests for Two-, Three-, and Four-term Polynomials (Each cued recall task and instructions was presented on a separate sheet)

Name: ____________________________

In the material you studied for factoring, steps were given to solve polynomials with different terms. In the space below, please list **ALL** of the steps you would follow to solve a polynomial with **TWO** terms. Please write the steps in order and as quickly and accurately as possible. If you cannot remember the exact words for a step, use words that are as close to the original as possible.

Name: ____________________________

In the material you studied for factoring, steps were given to solve polynomials with different terms. In the space below, please list **ALL** of the steps you would follow to solve a polynomial with **THREE** terms using the **AC method.** Please write the steps in order and as quickly and accurately as possible. If you cannot remember the exact words for a step, use words that are as close to the original as possible.

Name: ____________________________

In the material you studied for factoring, steps were given to solve polynomials with different terms. In the space below, please list **ALL** of the steps you would follow to solve a polynomial with **THREE** terms using the **Trial and Error method.** Please write the steps in order and as quickly and accurately as possible. If you cannot remember the exact words for a step, use words that are as close to the original as possible.

Name: ____________________________

In the material you studied for factoring, steps were given to solve polynomials with different terms. In the space below, please list **ALL** of the steps you would follow to solve a polynomial with **FOUR** terms. Please write the steps in order and as quickly and accurately as possible. If you cannot remember the exact words for a step, use words that are as close to the original as possible.

Appendix H: Cued Recall Scoring Example

Cued recall test item

In the material you studied for factoring, steps were given to solve polynomials with different terms. In the space below, please list **ALL** of the steps you would follow to solve a polynomial with **FOUR** terms. Please write the steps in order and as quickly and accurately as possible. If you cannot remember the exact words for a step, use words that are as close to the original as possible.

Scoring key: The 10 steps and their sequence in factoring a four-term polynomial

- Is there a GCF?
- Pull it out
- How many terms
- Four
- Factor by grouping
- Make two equal groups
- What does each group have in common?
- What does each term have in common?
- Can you factor anything with what is left over?
- When you multiply the answer, do you get the original polynomial

Sample of student answer

Factor by grouping
Make two equal groups
What does each group have in common?
Can you factor anything else with what is left over?

Scoring of the CR question

Individual item score = 4: the four items in the answer are all correct steps; order does not matter. Each correct step receives 1 point.

Relational score = 3: The first set of three items in the answer are correct steps written in the correct order; therefore, each receives 1 point. However, the fourth item in the answer receives 0 points because in the correct sequence it does not come directly after *What does each group have in common?*

Total score

The individual item score on this CR item would be added to the individual item scores on the other three CR test items and converted to an overall proportion correct by dividing the sum by 56 (total possible individual item points). The relational score on this CR item would be added to the relational scores on the other three CR items and converted to an overall proportion correct by dividing the sum by 33 (total possible relational points).

References

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