Math is Language: A Metaphor-Based Intervention to Promote Women's Interest in Math

By

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Abstract

Despite STEM's growth, women are vastly underrepresented in STEM employment. Women fill almost half of all jobs in the US, yet they only occupy 25 percent of all STEM employment (Beede et al., 2011). This discrepancy between the number of women in the US workforce and the number of women currently in STEM employment is referred to as the STEM gender gap. Researchers have identified many barriers to women's pursuit of STEM in academic settings, including instructor expectations of fixed intelligence; a lack of female role models; gender stereotyping; and perceived values mismatch (Beede et al., 2011; Ginther & Kahn, 2015). The goal of the current research is to highlight an overlooked barrier to STEM—women's conceptions of math —and create a metaphor-framing intervention to address it. Conceptual metaphor theory posits that metaphor is a tool for thought and not just a tool for speech. Metaphors help us understand abstract concepts by relating them to other, more concrete, concepts (Lakoff & Johnson, 1980). The present study used the metaphor "Math is language" to make math feel more approachable by reducing math anxiety among all students. Additionally, metaphor helped students see the potential for math to be a flexible tool for thought and expression; reflecting how language is often thought of (Haave, 2015; Manery, 2007). Surprisingly, both the "Math is language" metaphor and the "College math is high school math" metaphor displayed these benefits. This research suggests that metaphor can help make math more approachable for all students, not just women.

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Introduction

The growth of science, technology, engineering, and math (STEM) has produced 8.6 million jobs as of 2015 and requires increased participation by students (Beede et al., 2011). Despite STEM's growth, women are vastly underrepresented in STEM employment. Women fill almost half of all jobs in the US, yet they only occupy 25 percent of all STEM employment (Beede et al., 2011). This discrepancy between the number of women in the US workforce and the number of women currently in STEM employment is referred to as the STEM gender gap. This gender gap in STEM has garnered the attention of researchers and US government offices alike, due to women representing a largely untapped potential workforce for STEM employment.

The STEM gender gap is additionally concerning because women working in STEM areas earn 33 percent more money than their non-STEM counterparts (Beede et al., 2011). That means that women's underrepresentation limits their earning potential. Considering the potential benefits of pursing STEM degrees and employment, it is concerning to see such a large gender disparity in STEM.

Researchers have identified many barriers to women's pursuit of STEM in academic settings, including: instructor expectations of fixed intelligence; a lack of female role models; gender stereotyping; and perceived values mismatch (Beede et al., 2011; Brown, Smith, Thoman, Allen, & Muragishi, 2015; Diekman et al., 2011; Ginther & Kahn, 2015). From there, researchers have developed several social psychological interventions designed to target these barriers (Harackiewicz & Priniski, 2018; Yeager & Walton, 2011). Each social psychological intervention is targeted to help women overcome specific challenges that hinder STEM pursuit. The goal of the current research is to highlight an overlooked barrier to STEM—women's conceptions of math —and create a new intervention to address it. This intervention is inspired by a theoretical framework provided by conceptual metaphor theory, which posits that metaphor is a tool for thought and not just a tool for speech. That is, metaphor helps us understand more abstract concepts by relating them to more familiar, often concrete terms. As described in greater detail below, this intervention introduces students to a metaphor that encourages them to conceptualize math metaphorically in terms of language. To understand why the current research is focusing on math among several STEM-related topics, and why this intervention might be beneficial, we turn next to a review of research on STEM.

The Changing Landscape of STEM

Why are women less interested than men in pursuing STEM areas? There are likely many factors. For one, STEM fields are generally seen as "cold," with an emphasis on agentic values (e.g., competition, achievement, or wealth) over communal values (e.g., helping others, working with others, forming connections with others) (Brown et al., 2015). Indeed, women and men who highly endorse communal values are less likely to pursue STEM (Diekman et al., 2010).

We can get a more fine-grained picture, however, if we decompose the broad category of STEM and look at women's specific beliefs. Historically, social psychologists have not differentiated the different areas of STEM, treating the many activities entailed by the broad acronym as essentially the same (Brown et al., 2015; Harackiewicz & Priniski, 2018). This is not without good reason, since there is no standard definition for what constitutes a STEM job (Beede et al., 2011). Still, it is important to appreciate that the STEM label covers a broad range of potential careers and the latest changes are not evenly distributed among them. As a result, what can appear to be positive changes look less impressive upon closer inspection. Recent research suggests that women's share of the college-educated workforce increased and the gender gap of women's pursuit of STEM Ph.D.s narrowed by two-thirds (Beede et al., 2011; Ceci et al., 2014). However, these changes seem to be mostly accounted for by pursuit of *non-*

math-intensive STEM careers such as careers in health and biology (Ceci et al., 2014). The differentiation of math-intensive STEM occupations from others is crucial, since mathematical occupations are projected to experience the largest growth from 2015 until the year 2024 (Fayer, Lacey, & Watson, 2017). Additionally, math is a powerful predictor of STEM pursuit in computer science and engineering occupations which comprise 64 percent of all STEM employment (Frayer, Lacey, & Watson, 2017; Levy & Sand, 2015).

In short, math-intensive STEM careers are the fastest growing and are among the most lucrative, and yet show the largest gender gap. Therefore, efforts to address gender disparities in STEM should focus in on these math-intensive areas. Research suggests the fear of poor grades in math is a key factor in women's interest in STEM and may be the biggest factor in predicting women's retention in the STEM pipeline. Research has found that women are 1.5 times more likely to leave the STEM pipeline after Calculus when compared to men. Additionally, high preforming women do just as well as men do in advanced math classes but are less likely to pursue math-intensive STEM careers in the future (Ellis et al., 2016). This research suggests that the difference in retention in the STEM pipeline is more likely due to confidence in math rather than actual math capability (Ellis et al., 2016).

Indeed, the intimidating expectation of math intensity discourages women from pursuing STEM disciplines more so than other discouraging aspects (e.g., expectations of fixed brilliance) (Ellis et al., 2016; Ginther and Khan, 2015). This research suggests that in order to effectively address gender disparities in STEM we must first address women's conceptions about math. That is, if researchers can help change how math is conceptualized, then we can increase interest in math. If this change takes place in the STEM pipeline, high performing students in introductory classes are more likely to pursue more math-intensive majors and thus remain in STEM.

Obstacles to Math Pursuit

Teacher biases and favoritism play a negative role in women's conceptions about math and confidence in their math ability. Despite girls being more favored as students early on in school, boys are more favored in math (Lavy & Sand, 2015). These teacher biases play a role in socializing and reinforcing gender stereotypes of women being poor at math. Fears of confirming these negative stereotypes or being treated differently because of them can directly interfere with performance (Schmader, Johns, & Forbes, 2008; Steele, 1997). Studies have shown that fear of performing poorly in math and science classes are important predictors of women deciding whether to pursue STEM or not (Goldin et al., 2013; Leslie, Cimpian, Meyer, & Freeland, 2015). Consequently, when these harmful stereotypes are chronic, women can dissociate math with their sense of self, and this disidentification with math can undermine motivation (Steele, 1997). This disidentification can become a barrier to women gaining confidence in their math ability despite performance.

There is other evidence that suggests that women's conceptions about math may be influenced by the way math is taught and presented to them early in school. When measuring teacher beliefs and practices in teaching math teachers were found to emphasize math as operations instead of as a tool for thought; focus on correctness rather than understanding; and emphasize teacher control over child engagement (Stipek et al., 2001). These teacher beliefs and practices are associated with negative outcomes on student learning and engagement. These negative practices may be especially harmful for women who already are not favored in math and may disidentify with the subject.

Prior Interventions

As mentioned, social psychologists have recently developed several distinct STEM interventions. Some of these interventions produce positive results on academic motivation and performance (Yeager and Walton, 2015) but other intervention results can be mixed, indicating the need for clearer conceptualization of underlying mechanisms (Hanselman, Rozek, Grigg, & Borman, 2017; Harackiewicz and Priniski, 2018).

Until now, social psychological interventions addressing the gender gap in math-intensive STEM broadly tackles women's conceptions of "fit" between the self and math. Justifiably so, since women are socialized from early in school to think math is not "right" for them (Levy & Sand, 2015). These social psychological interventions work by shifting how students view themselves and the social world around them (Wilson, 2011). Therefore, we can categorize existing interventions as either targeting students' self-concept or the culture of math. These two types of prior interventions are reviewed next. Afterward, we introduce a new intervention that focuses more specifically on women's perceptions of math itself.

Self-concept interventions

Interventions targeting the self-concept are designed to target conceptions that math is not "right" for an individual or personally relevant to their lives and goals. Utility value interventions help students find personal relevance in math by either asking students to come up with ways that math can be applied to their daily lives or by communicating the value of the subject to them directly. For example, Harackiewicz and colleagues (2012) implemented a utility value intervention over 15 months in a sample of Wisconsin high schools. The intervention randomly assigned some parents of 9th graders to receive brochures that communicated to those parents the value of mathematics and science courses (i.e., how important science and math is for college preparation). Students in households that received the brochures took more math and science classes on average than students in households that didn't receive the brochures. The important underlying mechanism at play was the process of parents disseminating the value of STEM to their children. This intervention benefitted all students, not just women, by encouraging parents to help students find personal connections between math and their own values and goals. Students in the intervention household were more likely to take more STEM classes and perform better in their STEM related classes. Thus, this intervention worked by promoting a sense of connection to math that students may not have noticed before or may have disidentified from.

Another common social psychological intervention that addresses self-concept is self-affirmation interventions. These interventions are used to address stereotype threat that an individual may face going into a topic area they are negatively stereotyped. It works by affirming a value or identity that is unrelated to a salient stereotype threatened identity. In a classic study Spencer and colleagues (1999) randomly assigned students to take a difficult math test that was described to produce gender differences or had no gender differences. Women who were told that the math test was relevant to gender underperformed on the math test. This is an example of the stereotype threat effect that affirmation interventions are designed to address.

These interventions affirm some other, more global, aspect of the self that is unrelated to the stereotyped group. For example, Cohen and colleagues (2006) randomly assigned 7th grade students to either write a reflection on an important personal value or write about a neutral topic. The results were that both men and women minority students displayed an increase in GPA post intervention.

Interventions targeting the culture of STEM

In addition to interventions targeting women's self-concept, other interventions target the culture that surrounds STEM. A theoretical framework that addresses how the culture of institutions can undermine motivation is cultural mismatch theory. Cultural mismatch theory states that inequality is produced when mainstream institutions' norms do not match the norms among the social groups that are underrepresented in those institutions (Stephens, Fryberg, Markus, Johnson, & Covarrubias, 2012). This means that underrepresented students may hold different values and norms than what institutions communicate to them, resulting in lower feelings of "fit". They tested this theory by randomly assigning some students to receive college orientation materials from the university president that presented the university culture as either independent (e.g., competitive) or interdependent (e.g., working with others). On the subsequent anagram task, first-generation students (students who on average have higher values of interdependence) benefitted the most from messages of interdependence.

This cultural mismatch intervention framework was applied to utility value interventions to increase interest in STEM. Traditional utility value interventions have students think about how the course material they are learning applies to their own lives and goals. Brown and colleagues, 2015, thought it was important for students to not have all the pressure to come up with connections on their own. They also posited that women would get more interest in STEM educational materials that directly communicated interdependent values to them. They had students read directly communicated utility value materials about a biomedical project that either was communicated with independent values or independent values. The interdependent framing gave more perceived utility value and increase in future career motivation for biomedical science for all students, not just women.

Cheryan and colleagues (2017) followed in a similar line of thought and examined the gender gap in math-intensive STEM classes with a lens examining the classroom culture. They tested this idea by manipulating the décor of a computer science classroom by either filling it with Star Trek posters, leaving it without décor, or by filling it with art and nature posters. The results were that women were just as interested in computer science class as boys when the class décor was filled with art and nature posters (Cheryan, Ziegler, Montoya, & Jiang, 2017). Put simply, the “geek” culture of computer science classrooms does not appeal to most women and subsequently undermine their motivation to pursue computer science. This research suggests that the stereotyped culture of many math-intensive STEM fields may be at odds with how many women view themselves, and ultimately women feel like they don’t belong in these STEM fields.

As can be seen from the diversity of the reviewed literature, the interventions developed thus far have taken different approaches in addressing the gender gap in math-intensive STEM. What they have in common, however, is that they target students’ conceptions of their personal identity and their feelings of “fit” with their academic context. In the next section, I will introduce a complementary approach that uses advances in metaphor research to change students’ conception of math itself in ways that promote interest. As mentioned previously, recent research ha identified that women falling out of the STEM pipeline has less to do with math capability and more to do with their confidence in their math ability. Since, math is often thought of being rigid with fixed solutions, students who face challenges approaching math may assume math is not a “for them”. Therefore, new research should focus on changing conceptions about math to help bolster confidence and interest in math.

Conceptual Metaphor Theory and Research

The theoretical background for the proposed intervention is provided by Conceptual Metaphor Theory. Conceptual Metaphor theory posits that metaphors are not just a tool for communication, but also a tool for thought. Metaphors helps us understand abstract concepts by relating those abstract concepts to other, more concrete, concepts (Lakoff & Johnson, 1980; Lakoff & Johnson, 1999).

Many researchers in the past 20 years have tested conceptual metaphor theory’s claim that metaphor is a cognitive tool to understand a concept (called the target) in terms of another (called the source) in several different ways. One common method used by social psychologists is metaphoric framing. Metaphoric framing is a message comparing one concept to another, superficially dissimilar, concept by using metaphoric phrases and images. The reasoning behind this method is that metaphoric framing triggers a corresponding conceptual metaphor in the observers' mind. This, in turn, should lead them to use knowledge about the source to understand and make judgments about the target. It should be expected that observers of the metaphor framing will interpret aspects of the target in terms of the source. Simply put, we use metaphor to help us understand something that is unfamiliar and often abstract by interpreting it similarly to how we would interpret a more concrete or familiar concept.

The metaphoric framing method is illustrated in a study by Ottati and colleagues (1999). College students were randomly assigned to be exposed to a persuasive essay framing a senior thesis requirement in terms of a baseball competition (e.g., "Play ball with the best…") or a parallel essay using literal phrases. Both essays were designed to convince students that the change in the senior thesis requirement is good for the university. However, the baseball metaphor essay increased interest in the thesis requirement especially for students who are interested in sports. This suggests that the metaphoric framing led participants to conceptualize the requirement in terms of the excitement of winning a sports competition, even though the two ideas are very different on the surface.

Metaphor framing has more recently been used in social psychological interventions to help students' academic engagement in college by framing their college academic career as a journey. Landau and colleagues (2014) randomly assigned freshman college students to write about how they envision their academic or social-self years later upon graduation. These responses were recorded on paper that either had an image of a path leading up to senior year or an image of separate trunks representing each year of undergraduate until graduation. The researchers hypothesized that students exposed to the journey metaphor framing image would be better able to appreciate how their academic activities now matter for their success in the distant future, since those ideas are metaphorically placed along a continuous path. Results showed that the journey metaphor was indeed effective at boosting motivation to perform well in school in general.

Although they examined motivation in an academic context, Landau and colleagues (2014) designed the metaphor intervention to change students' perceptions about themselves. Critically, they did not test whether and how provided metaphors might change conceptions about academic activities themselves. In the present study, conceptual metaphor theory is applied using a metaphoric framing methodology to develop and test a metaphor-based intervention. This intervention will attempt to get women to reconceptualize what math is and subsequently boost interest and motivation to engage with math-intensive STEM.

The Current Research

Let's take a step back and review what the literature suggests is needed for an intervention to reduce the gender disparity in STEM. As previously discussed, the difference in women pursuing math-intensive STEM may be primarily due to math confidence rather than math ability. The first step to addressing math confidence may be to change how math is traditionally taught. Math is often taught in a way that portrays it as a series of procedures with fixed solutions, and not as an adaptive tool for thinking. How else might math be conceptualized?

In 1904, mathematician Edwin Wilson expressed that math can be understood analogically as a language during his foundational discussions in mathematics and science (Carvajalino, 2016). The underlying principle behind this belief is that math is a tool for thought that can and should be applied to a variety of other disciplines. This is intuitive since language, unlike math, is generally portrayed as a flexible tool for thought and personal expression (Haave, 2015; Manery, 2007). Thus, using the metaphor “Math is language” should encourage women to view math, like they do language, as a tool for flexible thought and personal expression. This change in conceptions of what math is may make math seem more approachable and as a flexible tool to comprehend and express ideas.

Another reason why this metaphor might be helpful is that, this metaphor framing compares two subjects in school that have very different cultures. As noted, math-intensive STEM courses are often seen as cold, rigid, and geeky with an emphasis on agentic values (Brown et al., 2015; Cheryan et al., 2017). In contrast, non-STEM related courses like language are generally seen as more warm, flexible, and communal. It is possible to point out the structural similarities between math and language to help students view how flexible and collaborative work in math can be. Since language is familiar and ostensibly something students feel they have a level of mastery over, math anxiety should reduce via metaphor intervention.

The unique power that metaphor provides is that it can prompt people to look past surface-level differences between two concepts and begin to appreciate their underlying similarities of structure. We see this demonstrated, for example, in the aforementioned studies on the journey metaphor. Although academic activities and movement along a physical path are very different on the surface, introducing a metaphoric framing helped students appreciate that their academic career, much like a journey along a path, is a continuous progression of activities that depend on each other. Therefore, I hypothesize that introducing students to the metaphor “Math is language” will facilitate interest in math, reduce anxiety about math, and transfer features commonly associated with language on to the topic of math. This should have positive effects for both women and men but particularly help women identify with math.

Method

This study has three conditions: exposure to the metaphor “Math is language”; exposure to the alternative metaphor “College math is high school math”; and a baseline condition in which no metaphor is introduced. Participants in the manipulation conditions were asked to watch an 8-minute educational video that introduces the metaphor framing and briefly highlights a few examples of the underlying similarities the concepts have with each other (see Appendix F). The “Math is language” video compares how a word is like a number, an equation is like a sentence, a formula is like a paragraph, and an elegant formula is like a story. Similarly, these math concepts (just like the language concepts) can be rearranged while maintaining the same meaning.

The “College math is high school math” condition is important since it still highlights growth in the topic and supports feelings of competence. This condition compared different high school level problems (e.g., geometry) to potential college level problems (e.g., calculus). As mentioned in greater detail in the current research section, the “Math is language” metaphor also should highlight and support feelings of growth and competence, however, the unique aspect of this condition is the mapping of the source (language) features to the target (math). The control condition is meant to test what participants with no metaphoric intervention would respond like.

Procedure

250 Undergraduate students at the University of Kansas (110 female) received course credit to participate in the study. Participants were told that the study is about learning and problem-solving and that we were looking at how undergraduate students perceive math. Participants in the intervention conditions went through a math warm-up exercise (see appendix

E), followed by a video that introduces the metaphor framing, then took a few questionnaires (see appendices). Student-participants assigned to the control condition received the "Math is language" metaphor-framing intervention last. Otherwise the structure of all the conditions mirrored each other.

Outcomes

Lower math anxiety ($\alpha = .91$, 9 item scale; see Appendix A): I will be using the abbreviated math anxiety scale (AMAS) to measure change in math anxiety (Hopko, 2003).

Interest in STEM (20-item scale; see Appendix B): This questionnaire is taken from Tyler Wood and colleagues (2010) that assessed STEM interest and career interest in STEM. This scale is divided up by science interest ($\alpha = .89$), technology interest ($\alpha = .87$), engineering interest ($\alpha = .83$), and math interest ($\alpha = .90$).

Inclusion of other and the self (IOS) (1-item scale; see Appendix C): I adapted the IOS to measure from Aron, Aron and Smollan (1992) to measure how an individual may view math overlapping with their sense of self.

Creativity in math ($\alpha = .86$, 6-item scale; see Appendix D): This was created to measure participants perception of creativity and personal expression afforded to them in math.

PANAS ($\alpha = .90$, 20-item scale; see Appendix F): This was used to measure the affective states of participants before they were told they would take a math exam. This measure was created by Watson et al., 1988.

Results

I used multivariate regression analysis for all measured outcomes with gender as a covariate. These analyses were done and prepared using R statistical software. Out of the 250 participants in our sample 10 were dropped due to them either admitting they were not paying attention during the lab session or them knowing we were particularly interested in women's interest in STEM. For most of the outcomes discussed below there was not a significant main effect of gender. Therefore, unless specifically discussed below, there is no gender main effect or interaction in the regression models.

Math Anxiety

As expected, condition and gender explained a statistically significant amount of variance on math anxiety ($R^2 = .04,\ F(3{,}228) = 2.83,\ p = .04$). Math anxiety was reduced for students in the "Math is language" condition when compared to students in the no intervention condition above and beyond gender (M $= 3.06$, β $=$ $-.56,\ t(229) = -2.374,\ CI = -1.02 - -.10, p = .02$). The "College math is high school math" condition had a marginal reduction in math anxiety when compared to students in the no intervention condition above and beyond gender (M $= 2.76$, β $= -.89,\ t(229) = -1.956,\ CI = -.92 - 0, p = .05$).

To compare between our metaphor-framing interventions we used a Tukey pairwise t-test. Surprisingly, there was no difference found when comparing the "Math is language" condition to "College math is high school math" condition above and beyond gender (β $= .102$, $t(228) = .428,\ p = .90$).

Interest in STEM

Surprisingly, condition and gender did not explain a statistically significant amount of variance on the interest in science scale ($R^2 = .027,\ F(3{,}229) = 2.1,\ p = .101$).

Although condition and gender explained a statistically significant amount of variance on the interest in technology scale (Intercept $= 5.77, R^2 = .047,\ F(3{,}229) = 3.80,\ p = .01$), this effect was driven by gender predicting disinterest in technology (M $= 5.54$, β $= -.41$, $t(229) = -3.02,\ CI = -.68 - -.15,\ p = .002$).

Similarly, condition and gender explained a statistically significant amount of variance on the interest in engineering scale ($R^2 = .05,\ F(3{,}229) = 4.05,\ p = .008$), but this effect was driven by gender predicting disinterest in engineering in the model (Mean $= 4.02, \beta =$ -$.47$, $t(229) =$ -$2.77,\ CI =$ -$.81 -$ -$.14,\ p =$ .006).

Surprisingly, condition and gender did not explain a statistically significant amount of variance on the interest in math scale ($R^2 =$ .027, $F(3{,}229) = 2.10,\ p = .101$).

Inclusion of Math and Self

Surprisingly, condition and gender did not explain a statistically significant amount of variance on the inclusion of math in student's self-concept scale (R^2 = .03, F (3,229) = 2.44, p = .06).

Creativity in Math

As hypothesized, condition and gender explained a statistically significant amount of variance on the creativity in math scale ($R^2 = .079,\ F(3{,}228) = 6.61,\ p < .001$). Students in the "Math is language" condition perceived an increase in creativity in math than students in the no intervention condition, controlling for the variance explained by gender (M $= 5.25, \beta = .65$, $t(228) = 3.70\ \ CI = .31 - .99,\ p < .001$).

Surprisingly, students in the "College math is high school math" condition also did better than students in the no intervention condition, controlling for the variance explained by gender (M $= 4.98, \beta = .38,\ t(228) = 2.20,\ CI = .04 - .72,\ p = .029$). Gender predicted less perceived creativity in math while controlling for variance explained by condition (M $=$ $4.25, \beta =$ -$.35,\ t(228) =$ -$2.46,\ CI =$ -$.63 -$ -$.07,\ p = .015$).

To further explore the potential differences between our metaphor-framing interventions we used a Tukey pairwise t-test. Surprisingly, there was no difference found when comparing the "College math is high school math" condition to "Math is language" condition above and beyond gender ($\beta =$ -$.27,\ t(228) =$ -$1.51,\ p = .29$).

PANAS

Unexpectantly, condition and gender did not explain a statistically significant amount of variance on the positive affective negative affective scale (R^2 = .03, F (3,229) = 2.44, p = .06).

General Discussion

Despite the recent growth of STEM, women only occupy 25 percent of all STEM employment (Beede et al., 2011). This means that women represent a large untapped workforce in the US economy. However, STEM encompasses a broad range of potential employment and the rate of growth in STEM is not evenly distributed to all facets of STEM (Fayer et al., 2017). The area of STEM that is expected to experience the most growth until the year 2024 are math-intensive STEM jobs, which experience the largest gender gap in STEM (Ceci et al., 2014; Fayer et al., 2017). Therefore, when trying to address the gender gap in STEM employment, researchers should try to encourage more women to pursue math-intensive STEM careers.

Encouraging women to pursue these STEM careers is difficult since women face potential social psychological barriers upon entry. They are not favored in math from early in school by teachers and are stereotyped to be inherently bad at math (Levy and Sand, 2015; Steele, 1997). When these stereotypes become this chronic and pervasive it can pressure women to disidentify themselves with math (Steele, 1997). Consequently, despite the highest performing women doing just as well in math when compared to high preforming men, they are less likely to pursue math-intensive STEM (Ellis et al., 2016). Women are also 1.5 times more likely to fall out of the STEM pipeline after taking calculus, suggesting math is a key barrier preventing women from staying in STEM.

Social psychologists have used a myriad of intervention techniques to address the gender gap in math-intensive STEM (Cheryan et al., 2017; Cohen et al., 2006; Hanselman et al., 2017; Harackiewicz et al., 2012; Spencer et al., 1999; Stephens et al., 2012). These prior studies’ mechanisms generally work by changing women's self-concept with relation to math or by changing the perceived culture surrounding math (Wilson, 2011). These efforts have had positive effects on women's interest and motivation to pursue math. However, to the authors best knowledge, no research has attempted to address how women understand the concept of math itself until now. It is important to address this facet of the issue directly since math is often conceptualized as a series of procedures designed to solve problems instead of as a tool for thought (Stipek et al., 2001).

The purpose of the present study's intervention is to use metaphor to change how women conceive math itself. Prior work shows that exposing individuals to metaphor framing activates a corresponding conceptual metaphor that, in turn, enables an individual to understand one concept by relating it to another concept (Ottati et al, 1999; Landau et al., 2014). Derived from the aforementioned literature, I designed a study that uses the metaphor framing "Math is language" (as described in more detail above) to attempt to get more women interested in math-intensive STEM.

Limitations

Based on the results, the "Math is language" metaphor framing intervention was effective in lowering math anxiety and changing students' conceptions about math. However, changing how math is conceptualized is only one step in the process of increasing confidence in math ability among women. The next step is to implement the intervention in an environment where students can see consistent feedback on their math performance. For example, if a female participant (exposed to the "Math is language" metaphor) begins to understand math in relation to a language, then she may feel less anxiety approaching math tasks but still lack the confidence to willingly pursue other math-intensive coursework.

Prior literature in intervention science highlights the significance of understanding the context in which an intervention takes place and specify the underlying recursive processes at play (Hanselman, Rozek, Grigg, & Borman, 2017; Harackiewicz and Priniski, 2018; Yeager and Walton, 2011). Recursive processes are repeated systematic steps that happens in the environment that often reinforce mindsets and behaviors (Harackiewicz and Priniski, 2018). In educational contexts, this is often closely associated with the process of studying and taking exams to test learned knowledge. Considering this framework, metaphor alone may help make math more approachable, but good performance in introductory math classes is also needed to increase confidence in math ability and interest in math-intensive STEM.

Although the "Math is language" metaphor framing intervention showed promise in changing students' conceptions about math and lowering math anxiety, the present study failed to properly differentiate between the "Math is language" and the "College math is high school math" metaphor-framing conditions. That being said, it is important to exercise caution in interpreting the "College math is high school math" condition based solely on this lack of differentiation. One reason is the "College math is high school math" condition wasn't statistically different from the control for math anxiety. Therefore, we can't conclude that the "College math is high school math" condition reduces math anxiety at all despite not being statistically different from the "Math is language" condition.

Conceptual metaphor theory claims that metaphor is a cognitive tool to understand a concept (called the target) in terms of another (called the source). When doing a metaphor-framing intervention it is important to understand that a researcher doesn't have complete control over what any one individual may infer about the target domain from the source. That is, people may have certain conceptions about the source domain that are applied toward the target domain that are unexpected or unintended by a researcher. In the context of this study, we anticipated that the students exposed to the “College math is high school math” metaphor-framing would have felt a confidence boost that buffered against their fears of poor performance in math. However, this mapping is a “double-edged sword” because if a student struggled in math in high school, they may have increased math anxiety. This is of particular concern for women since they are generally not favored in math classes early on in school (Levy and Sand, 2015).

It also should be noted that our sample had less women than men. This is an unusual result given the disproportionate number of women available in our student-participant subject pool. It is possible that with enough women in our sample we would find more gender gaps on our outcomes and potential interactions. As expressed in the paragraph above, women in the “College math is high school math” condition may recall difficult experiences in high school math and further distance themselves from the subject.

Lastly, this intervention assumes that participants are confident in their language ability. This is an important assumption: if a participant lacks confidence in their language ability, they may transfer those negative aspects they feel about language to the domain of math. There could be an interaction effect such that low confidence in language would predict lower interest in math.

Future Directions

Future research needs to more closely examine the metaphoric mapping taking place in the “Math is language” condition and the “College math is high school math” conditions. As stated in the limitations section above, a researcher doesn’t have complete control over the source mapping taking place in a metaphor-framing intervention. All researchers can do is carefully structure key source-to-target comparisons they feel are important. When math or language is mentioned to participants what concepts come to mind? How do these concept associations change after participants are exposed to a metaphor-framing?

Conveniently, there is a methodological tool uniquely suited to answering these questions. Semantic network models allow for researchers to find common concepts associated with a topic and provide the ability to map out how often these concepts show up together. For example, future research can look at the common network structure of math and language and see how that structure changes after exposure to metaphor. This will help researchers tailor the structure of key source mapping more effectively as well as predict other potential connections participants may make on their own.

Future research should also test the "Math is language" metaphor against other alternative metaphors with different source mappings. Described in greater detail above, journey was used as a source mapping in social psychological interventions to help students' academic engagement in college by framing their college academic career as a journey (Landau et al., 2014). Journeys are assumed to be a long process that one must take the necessary steps to complete. There may be obstacles in the way, but you must take actions to overcome them. Thus, where language seems suited to make math seem more approachable, the journey metaphor may be better suited in encouraging students to seek out help, when needed, to overcome low math achievement.

Finally, these metaphor-framing interventions need to be tested in the field. We need to see whether a change in math conception coupled with positive math performance in introductory math classrooms will lower the math-intensive STEM interest gap. Discussed in further detail in the limitations section, prior literature in intervention science highlights the importance of understanding the context in which an intervention takes place and specify the underlying recursive processes at play (Hanselman, Rozek, Grigg, & Borman, 2017;

Harackiewicz and Priniski, 2018; Yeager and Walton, 2011). This contextual reinforcement is a key mechanism in reducing achievement gaps. Previous literature suggests that women are more likely to fall out of the STEM pipeline after calculus regardless of how well they did (Ellis et al., 2016). Thus, it is best to implement this type of intervention in key introductory math classes before women begin to slip through the STEM pipeline.

In conclusion, the present study suggests that metaphor-framing interventions may be a useful tool to make math more approachable. However, additional research is needed to squeeze the maximum potential out of the intervention and tailor it to the settings that students can benefit from the metaphor-framing the most.

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Figures

Figure 1

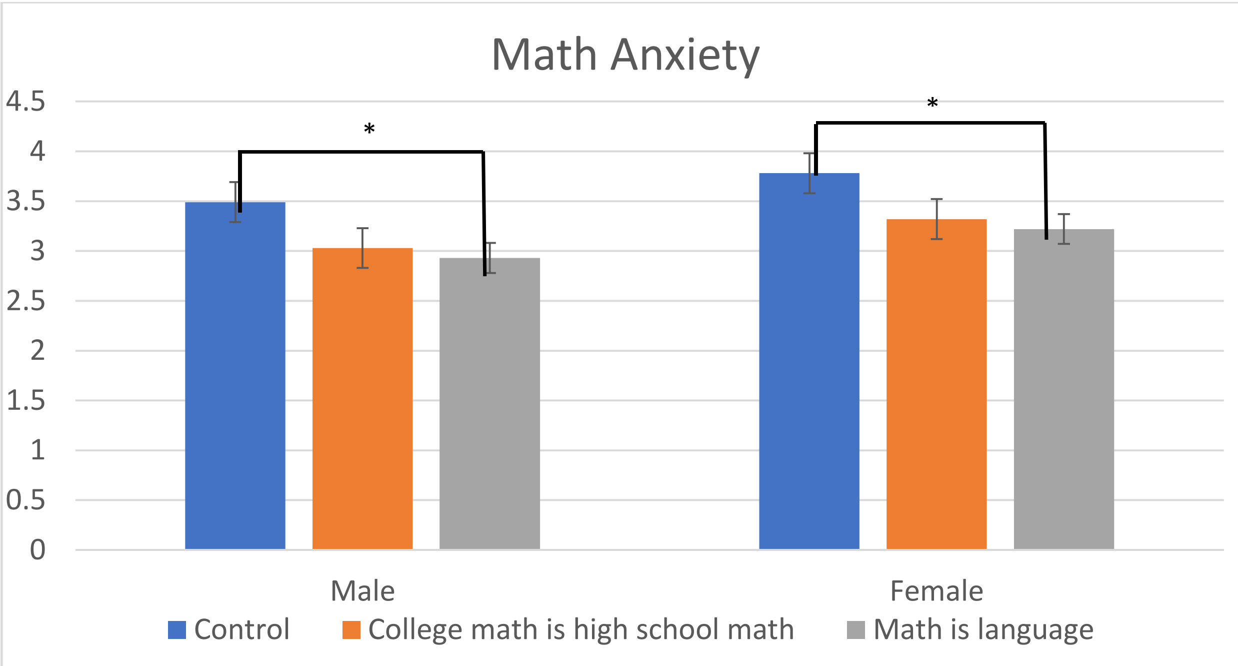


Figure 1: This graph displays the effect of condition on math anxiety ($R^2 = .04,\ F(3{,}228) = 2.83,\ p = .04$). The "Math is language" condition was statistically different from control ($\beta = -.56,\ t(229) = -2.374,\ CI = -1.02 - -.10, p = .02$).

Figure 2

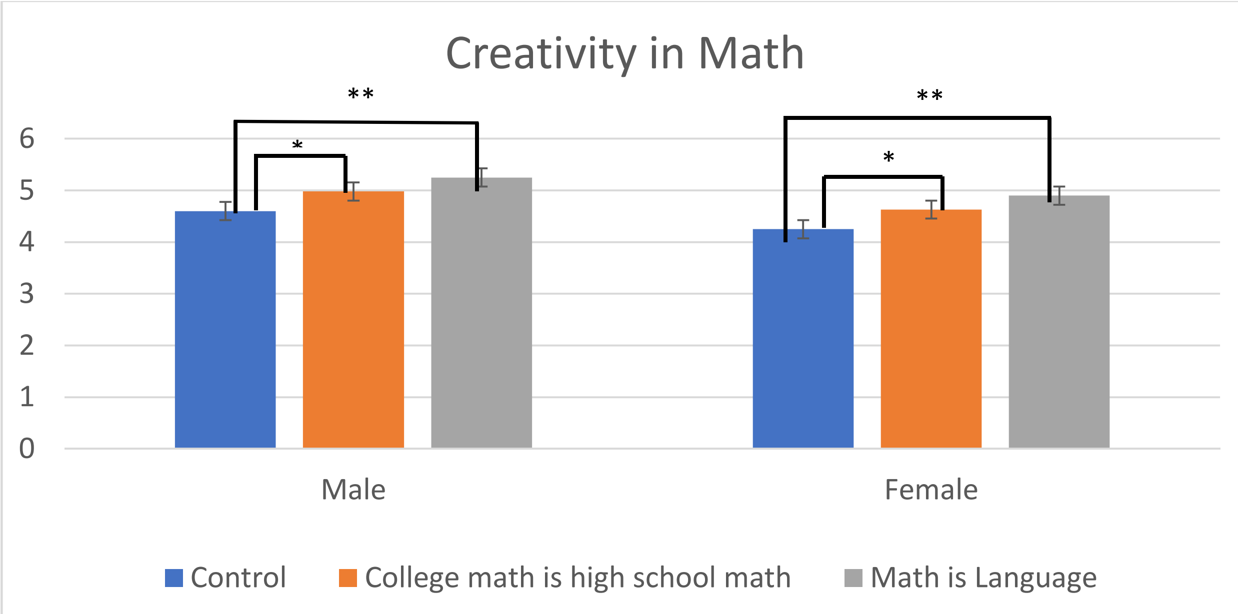


Figure 1: This graph displays the effect of condition on perceptions about math ($R^2 = .079$, $F(3,228) = 6.61,\ p < .001$).The “Math is language” condition and the “College math is high school math” condition was the only one statistically different from control (β = $.65,\ t(228) = 3.70\ CI = .31 - .99,\ p < .001$; β = $.38,\ t(228) = 2.20,\ CI = .04 - .72,\ p = .029$). There is no difference between metaphor condition (β = $-.27,\ t(228) = -1.51,\ p = .29$).

Appendices

Appendix A. Math Anxiety:

Instructions: As you read each situation below, think about how anxious it would make you feel. Click any number to tell us your personal feelings.

Statements:

- Having to use the tables in the back of a mathematics book.
- Thinking about an upcoming mathematics test one day before.
- Watching a teacher work an algebraic equation on the blackboard.
- Taking an examination in a mathematics course.
- Being given a homework assignment of many difficult problems which is due the next class meeting.
- Listening to a lecture in a mathematics class.
- Listening to another student explain a mathematics formula.
- Being given a "pop" quiz in a mathematics class.
- Starting a new chapter in a mathematics book.

Participants are asked to rate each one statement on a scale of 1-5.

Examples:

	Low Anxiety 1	Some Anxiety 2	Moderate Anxiety 3	Quite a bit of Anxiety 4	High Anxiety 5
Having to use the tables in the back of a mathematics book.					
Thinking about an upcoming mathematics test one day before.					
Watching a teacher work an algebraic equation on the blackboard.					

Remember that, before the presentation, we asked you to do some math problems for five minutes? Think back to how you felt and then tell us how much you agree with each statement below.

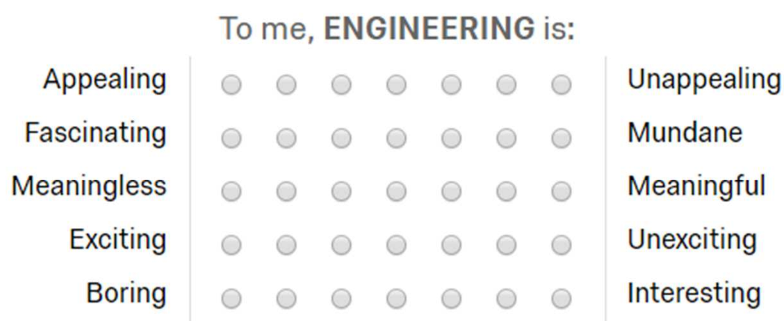
	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
The thought of being in math class makes me feel stressed and nervous.	○	○	○	○	○	○	○
Doing the math work took all of my energy.	○	○	○	○	○	○	○
I felt stressed out as soon as I began my math work.	○	○	○	○	○	○	○
My mind went blank and I was unable to think clearly when doing the math work.	○	○	○	○	○	○	○
I got depressed when I thought about learning math.	○	○	○	○	○	○	○
My whole body became tense when I did the math work.	○	○	○	○	○	○	○

Appendix B. STEM Interest:

Instructions: Choose one bubble between each adjective pair to indicate how you feel about the subject.

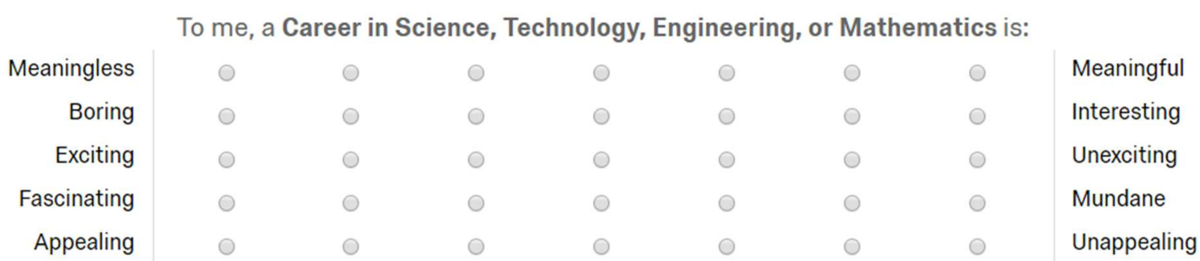
- Participants rate each topic (Engineering, Technology, Mathematics, and Science) on a 7-point scale Likert scale. The measure asks participants to rate how appealing, fascinating, meaningful, exciting, and interesting each topic is.
- Statements are identical to how the example pictures look below.

Example:



To me, **ENGINEERING** is:

Appealing	○	○	○	○	○	○	○	Unappealing
Fascinating	○	○	○	○	○	○	○	Mundane
Meaningless	○	○	○	○	○	○	○	Meaningful
Exciting	○	○	○	○	○	○	○	Unexciting
Boring	○	○	○	○	○	○	○	Interesting



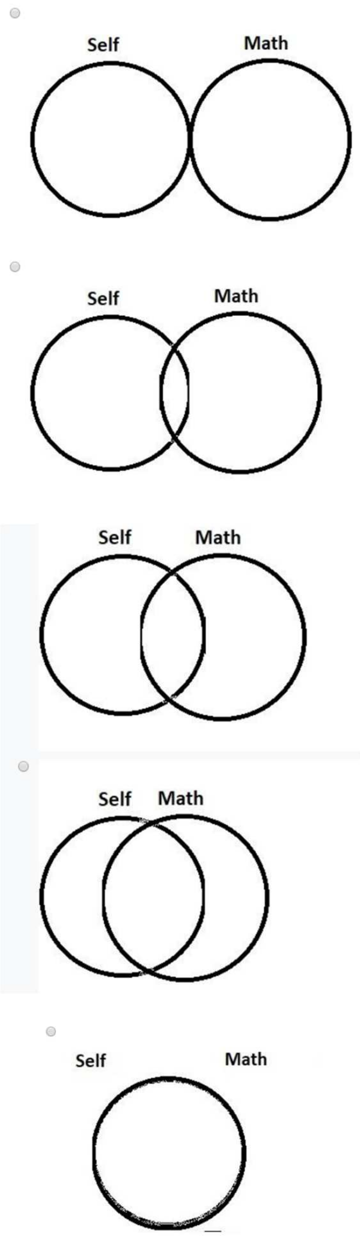
To me, a **Career in Science, Technology, Engineering, or Mathematics** is:

Meaningless	○	○	○	○	○	○	○	Meaningful
Boring	○	○	○	○	○	○	○	Interesting
Exciting	○	○	○	○	○	○	○	Unexciting
Fascinating	○	○	○	○	○	○	○	Mundane
Appealing	○	○	○	○	○	○	○	Unappealing

Appendix C. IOS of Math and the Self:

- Participants will circle the image that represents their conceptions of their sense of self overlapping with math.

Below you'll see pictures showing a circle for math overlapping with a circle for you. How much overlap do you feel right now with math? Click one picture below that best reflects how much overlap you feel.



Appendix D. Creativity in Math:

- Participants will rate their level of agreement with each statement in the image below.

Please indicate your level of agreement with each statement using the scale below.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
There are multiple ways to arrive at a solution in math.							
Creativity is needed in math.							
There is room for personal expression in math.							
Math is rigid and there is only one way to arrive at a solution to a problem.							
There is no creativity in the area of math.							
Math is impersonal and there is no room for personal expression.							

Appendix E. Math Exercise:

- Presented below is the math test participants will take on the computer to test math performance.

74x99

95x22

47x81

66x38

25x33

Appendix F. PANAS:

Below you'll see some words for different feelings and emotions. How much do you feel these feelings and emotions *right now*?

	Very slightly, or not at all 1	A little 2	Moderately 3	Quite a bit 4	Extremely 5
Interested	○	○	○	○	○
Distressed	○	○	○	○	○
Excited	○	○	○	○	○
Upset	○	○	○	○	○
Strong	○	○	○	○	○
Guilty	○	○	○	○	○
Scared	○	○	○	○	○
Hostile	○	○	○	○	○
Enthusiastic	○	○	○	○	○
Proud	○	○	○	○	○

Below you'll see some words for different feelings and emotions. How much do you feel these feelings and emotions *right now*?

	Very slightly, or not at all 1	A little 2	Moderately 3	Quite a bit 4	Extremely 5
Irritable	○	○	○	○	○
Alert	○	○	○	○	○
Ashamed	○	○	○	○	○
Inspired	○	○	○	○	○
Nervous	○	○	○	○	○
Determined	○	○	○	○	○
Attentive	○	○	○	○	○
Jittery	○	○	○	○	○
Active	○	○	○	○	○
Afraid	○	○	○	○	○

Appendix G. Manipulation:

Math is language metaphoric-framing:

Students like you have many different views of Math in college. But what is it, really? What makes Math difficult or easy? We asked leading mathematicians, and the answer was the same: Math is a Language. It's just like the language we use every day to express ourselves and communicate with one another.

Math is a Language

Consider Math's Building Blocks:

Math Values can be numbers (like 5), letters (like X), or symbols (like ∑)

Values are like Nouns such as memory, notebook, and sadness

An Operation is a Sentence

Both an operation and a sentence establish a relationship between things:

X + Y	Jordan received chocolate
X - Y	Jordan gave away chocolate
(X)(Y) x Z	The more chocolate Jordan eats, the more his allergies act up
$\frac{Y}{4}$	The chocolate bar was broken into four parts

An Equation is the same as using different words to express the same idea or relationship.

(X)(Y) = V	Jordan loves chocolate is the same as saying In Jordan's eyes, chocolate is the best
J + T = ϕ	Jordan and Taylor recently married so they are now regarded as the Smith family.
$\sum_{i=1}^{3}(X+Y)_i$ = (X + Y) + (X + Y) + (X + Y)...etc	Saying, "Jordan got chocolate on Monday, Wednesday, Saturday this week" is the same as saying, "Jordan got chocolate on three different days this week.

A Math Formula is a Paragraph

$$s^2 = \frac{\sum(x_i - \bar{x})^2}{n-1}$$

A lazy grasshopper laughed at a little ant as she was always busy gathering food. "why are you working so hard?" he asked, "come into the sunshine and listen to my merry notes." "But the ant went on her work. She said" I am lying in a store for the winter. Sunny days won't last for ever." "Winter is so far away yet, "laughed the grasshopper back. And when the winter came, the ant settled down in her snug house. She had plenty of food to last the whole winter. The grasshopper had nothing to eat so, he went to the ant and begged her for a little corn. "No", replied the ant, "you laughed at me when I worked. You yourself sang through the summer. So you had better dance the winter away."

A Math Proof is a Story

Prove: $\sum_{k=1}^{n} k = 1+2+3+4+\ldots+n = \frac{n(n+1)}{2}$

Step1: Show true for n = 1:

$1 = \frac{(1)(1+1)}{2}$ so 1 = 1.

Notice that it is also true for n = 2:

$1+2 = \frac{(2)(2+1)}{2}$ so 3 = 3.

Step 2: Suppose that it is true for n = k:

$1+2+3+\ldots+k = \frac{k(k+1)}{2}$

Step 3: Show it is true for n = k + 1:

$1+2+3+\ldots+k+(k+1) = \frac{(k+1)(k+2)}{2}$

Substitute step 2 in step 3 by replacing the first k terms with $\frac{k(k+1)}{2}$

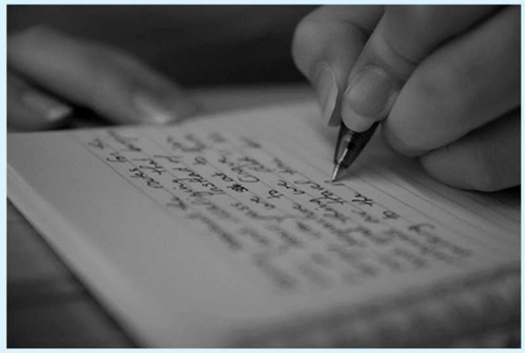
This yields $\frac{k(k+1)}{2} + (k+1) = \frac{(k+1)(k+2)}{2}$

Simplifying the left side: $\frac{k(k+1)}{2} + \frac{2(k+1)}{2} = \frac{(k+1)(k+2)}{2}$

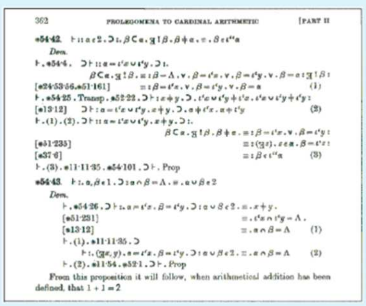
$\frac{k^2+k+2k+2}{2} = \frac{(k+1)(k+2)}{2}$

$\frac{k^2+3k+2}{2} = \frac{(k+1)(k+2)}{2}$

Factoring. $\frac{(k+1)(k+2)}{2} = \frac{(k+1)(k+2)}{2}$



An Elegant Proof is an Elegant Story



362 PROLEGOMENA TO CARDINAL ARITHMETIC [PART II

$*54{\cdot}42.\ \vdash :: \alpha \in 2 . \supset :. \beta \subset \alpha . \exists ! \beta . \beta \neq \alpha . \equiv . \beta \in \iota``\alpha$

Dem.

$\vdash . *54{\cdot}4 . \supset \vdash :: \alpha = \iota`x \cup \iota`y . \supset :.$

$\beta \subset \alpha . \exists ! \beta . \equiv : \beta = \Lambda . \vee . \beta = \iota`x . \vee . \beta = \iota`y . \vee . \beta = \alpha : \exists ! \beta :$

$[*24{\cdot}53{\cdot}56 . *51{\cdot}161] \quad \equiv : \beta = \iota`x . \vee . \beta = \iota`y . \vee . \beta = \alpha \quad (1)$

$\vdash . *54{\cdot}25 . \mathrm{Transp} . *52{\cdot}22 . \supset \vdash : x \neq y . \supset . \iota`x \cup \iota`y \neq \iota`x . \iota`x \cup \iota`y \neq \iota`y :$

$[*13{\cdot}12] \quad \supset \vdash : \alpha = \iota`x \cup \iota`y . x \neq y . \supset . \alpha \neq \iota`x . \alpha \neq \iota`y \quad (2)$

$\vdash . (1) . (2) . \supset \vdash :: \alpha = \iota`x \cup \iota`y . x \neq y . \supset :.$

$\beta \subset \alpha . \exists ! \beta . \beta \neq \alpha . \equiv : \beta = \iota`x . \vee . \beta = \iota`y :$

$[*51{\cdot}235] \quad \equiv : (\exists z) . z \in \alpha . \beta = \iota`z :$

$[*37{\cdot}6] \quad \equiv : \beta \in \iota``\alpha \quad (3)$

$\vdash . (3) . *11{\cdot}11{\cdot}35 . *54{\cdot}101 . \supset \vdash .$ Prop

$*54{\cdot}43.\ \vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

Dem.

$\vdash . *54{\cdot}26 . \supset \vdash :. \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

$[*51{\cdot}231] \quad \equiv . \iota`x \cap \iota`y = \Lambda .$

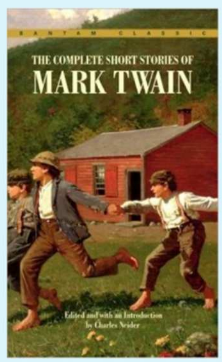
$[*13{\cdot}12] \quad \equiv . \alpha \cap \beta = \Lambda \quad (1)$

$\vdash . (1) . *11{\cdot}11{\cdot}35 . \supset$

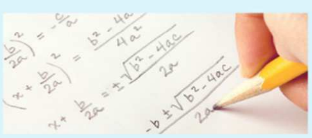
$\vdash :. (\exists x, y) . \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda \quad (2)$

$\vdash . (2) . *11{\cdot}54 . *52{\cdot}1 . \supset \vdash .$ Prop

From this proposition it will follow, when arithmetical addition has been defined, that 1 + 1 = 2



You Doing College Math is you Writing your own Stories



High school math is college math metaphoric-framing:

Students like you have many different views of Math in college. But what is it, really? What makes Math difficult or easy? We asked leading mathematicians, and the answer was the same: College Math is High School Math. It's just like the Math you're used to, except the elements are more complex.

College Math is High School Math

Consider Math's Building Blocks:

Complex values in College Math (0.5 x 10^6 or μ) are like values in High School Math

Math Values can be numbers (like 5), letters (like X), or symbols (like ∑)

A College Operation is a High School Operation

Both kinds of operations establish a relationship between things:

$X + Y \longleftrightarrow (-3) + (8)$

$X - Y \longleftrightarrow (-3) - (8)$

$(X)(Y) \times Z \longleftrightarrow (-3)(8)(-9)$

$\frac{Y}{4} \longleftrightarrow (-8)/(4)$

A College Equation is the same as a H.S. Equation with more complexity:

$(X)(Y) = V \longleftrightarrow (X)(Y) = (3)(-8)$

$J + T = \phi \longleftrightarrow J + T = (10) + (-2)$

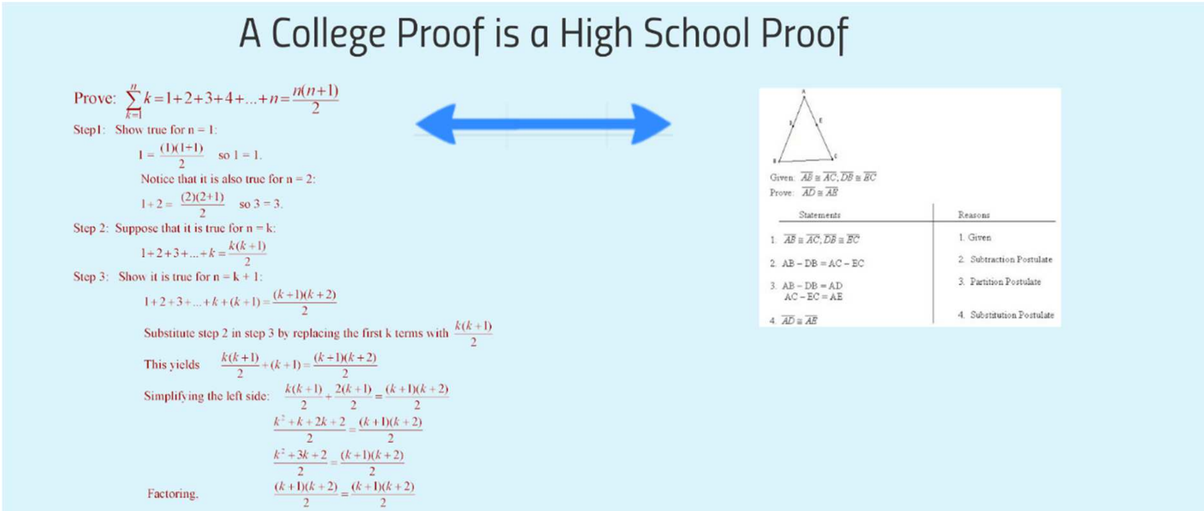
$\sum_{i=1}^{3}(X+Y)_i \overset{=}{\longleftrightarrow} (X + Y) + (X + Y) + (X + Y)$

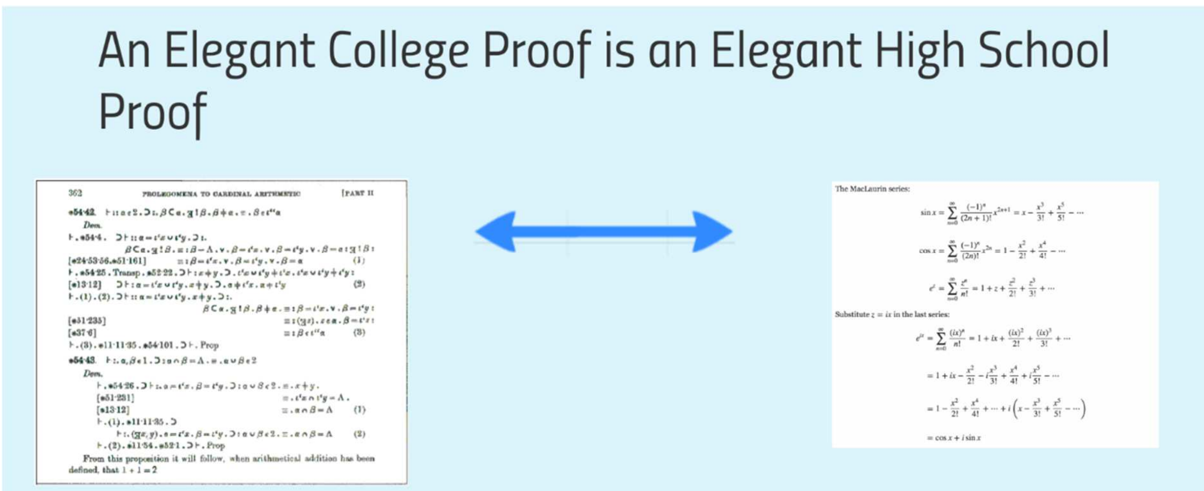
A College Formula is a High School Formula

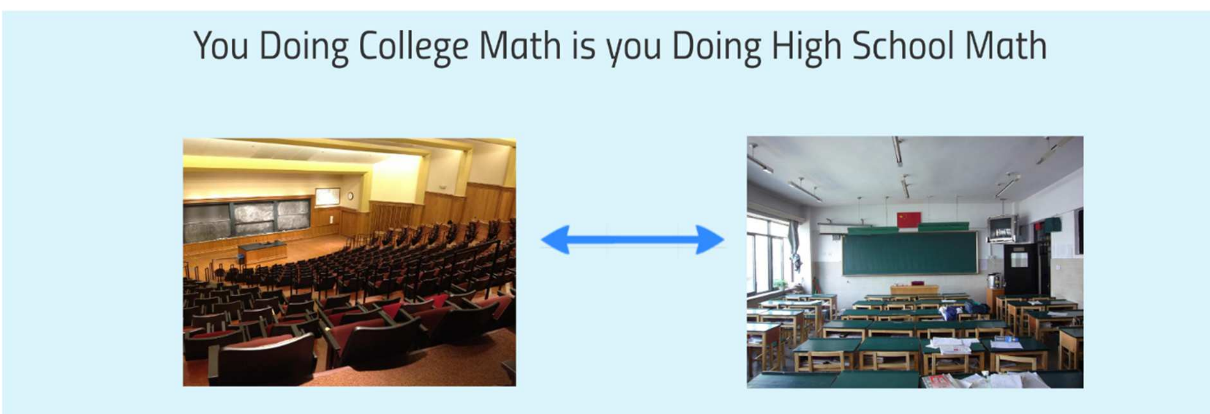
$$s^2 = \frac{\sum(x_i - \bar{x})^2}{n-1} \longleftrightarrow$$

Quadratic Formula

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$


A College Proof is a High School Proof
Prove: $\sum_{k=1}^{n} k = 1+2+3+4+...+n = \frac{n(n+1)}{2}$
Step1: Show true for n = 1:
$1 = \frac{(1)(1+1)}{2}$ so 1 = 1.
Notice that it is also true for n = 2:
$1+2 = \frac{(2)(2+1)}{2}$ so 3 = 3.
Step 2: Suppose that it is true for n = k:
$1+2+3+...+k = \frac{k(k+1)}{2}$
Step 3: Show it is true for n = k + 1:
$1+2+3+...+k+(k+1) = \frac{(k+1)(k+2)}{2}$
Substitute step 2 in step 3 by replacing the first k terms with $\frac{k(k+1)}{2}$
This yields $\frac{k(k+1)}{2} + (k+1) = \frac{(k+1)(k+2)}{2}$
Simplifying the left side: $\frac{k(k+1)}{2} + \frac{2(k+1)}{2} = \frac{(k+1)(k+2)}{2}$
$\frac{k^2+k+2k+2}{2} = \frac{(k+1)(k+2)}{2}$
$\frac{k^2+3k+2}{2} = \frac{(k+1)(k+2)}{2}$
Factoring. $\frac{(k+1)(k+2)}{2} = \frac{(k+1)(k+2)}{2}$
Given: $\overline{AB} \cong \overline{AC}, \overline{DB} \cong \overline{BC}$
Prove: $\overline{AD} \cong \overline{AE}$
Statements
Reasons
1. $\overline{AB} \cong \overline{AC}, \overline{DB} \cong \overline{EC}$
1. Given
2. AB − DB = AC − EC
2. Subtraction Postulate
3. AB − DB = AD
AC − EC = AE
3. Partition Postulate
4. $\overline{AD} \cong \overline{AE}$
4. Substitution Postulate


An Elegant College Proof is an Elegant High School Proof
From this proposition it will follow, when arithmetical addition has been defined, that 1 + 1 = 2
The MacLaurin series:
Substitute $z = ix$ in the last series:
$= \cos x + i \sin x$


You Doing College Math is you Doing High School Math