Importance of Students' Attitude Towards Mathematics in Learning and How Game-Based Learning Can Promote Positive Attitude

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Abstract

Educators and educational researchers are constantly looking for ways to enhance students' learning. One such effort to enhance mathematics learning is through influencing students' attitude towards math, which reflects their value, self-confidence, enjoyment, motivation, and anxiety about math. Research demonstrates a bidirectional relationship between attitude towards math and learning outcomes such that attitude towards math is positively associated with achievement and achievement helps shape attitude towards math. Even young children in the early years of elementary school show signs of negative attitude towards math, such as math anxiety that directly and indirectly — by interfering with cognitive functioning — impairs students' learning experience and learning outcomes. The emergence of digital game-based learning presents a promising solution to address students' attitude towards mathematics. Students' preference for video games as a form of entertainment makes digital game-based learning an endearing approach to enhance their motivation and engagement in learning math.

Research on person-level factors impacting mathematics learning has investigated the parallel process of cognitive influences (e.g., working memory, number sense) and affective influences (e.g., attitude towards mathematics, math anxiety). While studies of students' cognitive abilities have enjoyed a much longer history, there has been an increasing awareness of the importance of affect in mathematics learning (Ma & Xu, 2004). In the following sections we present a brief discussion of a) how affect impacts math learning and b) how educational games can promote positive affect.

Affect and Its Impact on Math Learning

Affect is a psychological construct that, according to the American Psychological Association, refers to any experience of feeling or emotion, including mood and emotional reaction. Researchers studying affect often consider it on a continuum that ranges from positive to negative affect. *Attitude towards mathematics* is one affective state that has garnered great interest in mathematics education research. Attitude towards mathematics encompasses a wide range of feelings and emotions that students may experience, including the liking or disliking of math, preference to engage in or avoid math tasks, believing or not believing in one's math abilities, as well as belief about the value and usefulness of mathematics (Haciomeroglu, 2017). The experience of these feelings and emotions reflects students' value, self-confidence, enjoyment, motivation, and anxiety with regard to learning math. To varying degrees, students' attitude towards math could be either positive or negative.

Students' attitude towards math has long been assumed to impact their math learning and achievement. Based on their meta-analysis of 113 studies, Ma and Kishor (1997) showed that attitude towards math is significantly related to, and possibly a cause of, math achievement.

Positive attitude tends to be associated with higher achievement (House, 1995; Evans, 2007), whereas negative attitude tends to be related to poor performance (Mayes, Chase, & Walker, 2008). These findings are not surprising considering the different ways positive and negative attitude could impact students' learning. For example, students who believe that mathematics is useful and worth learning, who are motivated and enjoy working on math tasks, and who are confident about their own math abilities are more likely to have higher levels of math engagement and, consequently, have higher achievement. On the other hand, students with negative attitude towards math may lack confidence in their own abilities and may resist math-related learning activities, which can lead to low engagement and poor performance.

A negative mathematics attitude that has received much research attention is *math anxiety*, a feeling of tension and anxiety that interferes with students' ability to solve math problems (Dowker, Cheriton, Horton, & Mark, 2019). Research shows that higher levels of math anxiety are associated with less enjoyment and motivation and poorer test performance among high school students (Hembree, 1990; Ma & Kishor, 1997). This could be due to students with high math anxiety avoiding math-related activities (e.g., not doing home assignment or practice questions), thus, having fewer opportunities to hone their math skills (Ashcraft, 2002). The negative relationship between math anxiety and achievement could also be the result of students becoming mentally preoccupied with their anxiety, which uses up available cognitive resources that would otherwise be deployed to solve math problems (Eysenck, 1992). Indeed, in a study by Cargnelutti and colleagues (2017) that examined 161 Grade 2 students, the authors found that math anxiety had a direct negative impact on math test performance that was independent of students' cognitive abilities, and that math anxiety impeded students' cognitive functioning which in turn predicted poor performance. In addition, research shows that the negative

relationship between math anxiety and performance is a two-way street: poor performance in mathematics could also increase anxiety (Ganley & Lubienski, 2016; Maloney & Beilock, 2012; Maloney, Ansari, & Fugelsang, 2011).

This bidirectional relationship with math performance also holds true for general attitude towards math. Despite the long-held belief that students' attitude towards math determines their performance on math test, recent research demonstrates a reciprocal relationship between the two. In a longitudinal study conducted by Ma and Xu (2004), the authors followed 3,116 students from grades 7 to 12. These students were recruited from 52 public middle and high schools across the United States. Each year the students wrote an achievement test which assessed basic skills, algebra, geometry, and quantitative literacy. They then completed a questionnaire that measured their attitude towards math — that is, opinions on whether math is useful in daily problems, whether math helps with a person's logic, and whether math will be used extensively later on in adulthood. Using six waves of data the authors sought to understand the causal ordering between attitude and achievement. Employing structural equation modeling techniques, the authors found cross-lagged effects such that prior achievement in mathematics positively predicted later attitude towards math and prior attitude toward math also positively predicted later math achievement. Moreover, they found stronger effects from achievement to attitude than from attitude to achievement, suggesting how well students perform in test could shape their subsequent attitude towards learning mathematics. This reciprocal relationship between attitude and math achievement affords an opportunity for intervention that utilizes positive reinforcement strategies. Students with negative attitude toward math may experience a positive attitudinal shift by having repeated success in solving math problems that match their abilities. This change in attitude could, in turn, boost future math achievement.

Until recently, researchers and educators alike thought that negative attitude towards math was not commonly present among students in the early years of elementary school. They theorized that students often developed negative attitude in middle and high school as a result of encountering increasingly complex and challenging mathematical problems (Maloney & Beilock, 2012). For example, Ma and Kishor's meta-analysis (1997) showed that, across the more than 100 studies they reviewed, the relationship between attitude towards math and math achievement was generally stronger for upper elementary (5th and 6th) grades than for lower elementary (1st to 4th) grades. However, recent research findings paint a different picture. For example, using iPad video diaries as a methodological tool to record students' opinion toward mathematics, Larkin and Jorgensen (2015) found that 3rd Grade students expressed negative attitude towards math and used strong emotive language that was similar to the language 6th Grade students used (e.g., "I hate maths… Why do we have to do maths"). Ramirez and colleagues (2013) showed in their study of 154 1st and 2nd Grade students that even in early elementary school, some students experienced nervousness when it came to math-related situations. Such early negative experience could over time reinforce students' negative attitude towards math. Moreover, math anxiety impairs the performance of students who had better working memory. In another study, Young and colleagues (2012) analyzed functional brain-imaging data from 46 children between the ages of seven and nine and found that, when performing math calculations, children with higher levels of math anxiety showed hyperactivity in the region of the brain responsible for processing negative emotions, known as the right amygdala. At the same time, their dorsolateral prefrontal cortex and posterior parietal lobe, which support the functioning of working memory and numerical processing, showed reduced activity. These findings suggest that even young children in the early years of elementary school

experience negative feelings and emotions toward mathematics which negatively impact their math learning and achievement.

Where does negative attitude towards mathematics come from? Surveying elementary school students, Mitchell (1999) found that these students struggle to understand the relevance of math in their lives, hence, a lack of motivation to learn math. Mitchell also found that students did not associate math activities in class with enjoyment and perceived math as boring. It becomes apparent that students' need intervention in the early years of elementary school to enhance their motivation and engagement before negative attitude towards math further develops and matures over time. This is especially clear in light of the possibility that students would become more discouraged after they encounter more difficult math problems in later years. Intervention activities targeting students' attitude towards mathematics should be made enjoyable for the students and foster a sense of confidence in their own abilities. Equally important, through continued engagement in this type of activities, educators should instill within students the belief that their math abilities and achievement are not fixed and do not rely solely on intelligence, but can be improved through continuously devoting effort to learning.

Educational Games Promote Positive Attitude Towards Math

Various intervention strategies have been designed to promote students' positive attitude towards mathematics. These interventions differ from the traditional teacher-centered classroom instruction delivery by incorporating innovative activities to make learning fun and engaging. For instance, Csíkos and colleagues (2012) used drawings to help develop mathematical word problem-solving abilities among a group of 3rd Grade students. They found that, compared to students in the control group, those in the treatment group reported stronger belief in using visual

aides to enhance their math learning. Rukavina and colleagues (2012) incorporated math and science workshops into classrooms of students of 10 to 14 years of age. These workshops were designed to match the curriculum while encouraging classroom engagement and meaningful involvement with real-world problems. The authors found that the workshops promoted positive attitude towards math and science in the students. In another study, Şengul and Dereli (2013) examined how using cartoons to help a group of 7th Grade students learn integers affected their attitude towards mathematics. After six weeks of intervention, the students reported greater enjoyment learning with the cartoons as well as increased interest in math lessons.

In recent years there has been a strong push to integrate technological innovation — especially digital technologies — into mathematics education in an effort to promote positive attitude towards math. For example, in a study that compared the effectiveness of computer-assisted instruction to traditional teaching in mathematics education for 4th Grade students, the researchers found that students who received the computer-assisted instruction reported a more favorable attitude towards math than students who received traditional instruction (Pilli & Aksu, 2013). In another study, 6th and 7th Grade students used mathematics apps on a tablet device to explore their physical environment as a way to understand geometry concepts such as area, perimeter, and angle. These students reported the use of digital device as more fun and engaging than their usual mathematics class (Fabian, Topping, & Barron, 2018).

Among the different digital technologies that have been used in classrooms, computer-based educational games have great potential to promote positive attitude towards math and enhance engagement and motivation for younger students. This is because younger students are biased towards "games." In general, they are more likely to hold a positive attitude towards computer and video games as a means of entertainment, which leads them to perceive computer-based

educational games as more enjoyable than traditional instruction and assignments. Consequently, students become greatly motivated to learn and practice math problems through educational games. Indeed, research shows that both younger and older students perceive educational games as more fun, engaging, and satisfying to work on than traditional learning methods, and report more favorable attitudes towards mathematics as a result (Castellar, All, de Marez, & van Looy, 2015; Faber, Luyten, & Visscher, 2017; Mavridis, Katmada, & Tsiatsos, 2017; Ninaus, Moeller, McMullen, & Kiili, 2017). As Connolly and colleagues (2012) stated in their literature review, affective and motivational outcomes are among the most frequent effects of interacting with educational video games.

Computer-based educational games could also promote positive attitude towards mathematics through enhancing students' self-confidence in math. For example, some educational games feature immediate feedback to let students know the correctness of their answers right away and give them another opportunity to solve the problem if the first attempt was unsuccessful. Playing these games enables students to make progress at their own pace and provides them with a sense of autonomy to their learning (Cayton-Hodges, Feng, & Pan, 2015; Schenke, Rutherford, & Farkas, 2014; Ysseldyke & Bolt, 2007), which builds confidence for the students in their math abilities. Also, being able to know the correctness of an answer through immediate feedback removes a sense of uncertainty about one's understanding of a given concept. This is in contrast with the traditional homework assignments for which students must wait until the teacher finishes grading to know whether the answers were correct. Thus, playing computer-based educational games with immediate feedback may help reduce math anxiety for some students.

How Does This Relate to Prodigy Math Game?

Prodigy Education believes that learning math should be as fun as playing a video game. It has worked hard to deliver a digital game-based learning platform, Prodigy Math Game, that makes the most of children's preference for video games to engage them in math learning. In particular, the design of its interface and mechanism follows the four design principles for serious video games (i.e., games designed for a primary purpose other than pure entertainment, such as learning) in mathematics education (Chorianopoulos & Giannakos, 2014). The first principle is that a game should have engaging narratives to motivate students to play. This includes a captivating storyline and a hero. Prodigy Math Game presents a role-playing game (RPG) in which each student plays a young wizard who is tasked to find six magic wands and stop the uprising of a corporation of evil wizards. On their journey students must defeat monsters and bosses by correctly answering math questions that match their abilities. The overarching storyline of the game and the many quests available make up an engaging experience for students. In addition, as shown in Figure 1, the game displays bright graphics and lively animated characters that are appealing to students of this age group (i.e., 1st through 8th Grades).

Figure 1. Captured gameplay image of Prodigy Math Game.

The second principle of serious game design is to have game interactions and mechanisms that are familiar to students (Chorianopoulos & Giannakos, 2014). Prodigy Math Game's RPG format is similar to many of the popular video games that students may have played. In Prodigy Math Game students can raise their own magic pets and upgrade their gear by using rewards won through answering math questions. Students can also interact with both non-playing characters and other real players in the game. The turn-based combat system is also widely used in many RPG games. Familiarity with the game mechanisms and interface lets students navigate through the game with relative ease.

The third design principle of serious game for math education is to have trial-and-error gameplay (Chorianopoulos & Giannakos, 2014). This means that students receive immediate feedback on their answers, and, if the first attempt was unsuccessful, they would have another opportunity to solve the problem. This design offers a meaningful learning experience to students, allowing them to recognize and rectify their mistake when it is still fresh. In addition, having repeated success in solving math problems could positively reinforce students' attitude towards math.

The fourth design principle is to support a collaborative learning environment among students (Chorianopoulos & Giannakos, 2014). Collaboration could improve engagement as students have in-game interactions with their friends. Prodigy Math Game lets student send emojis to their friends and participate in player vs player (PvP) duels as they battle for math supremacy. These design features Prodigy Math Game adopts capitalize on elements that maximize student motivation and engagement. As one of its missions, Prodigy Math Game aspires to make learning math fun for students, fundamentally changing their attitude towards math.

Conclusion

For students to have positive learning experiences and outcomes, they need to be motivated to have the desire to actively engage in the learning process. To this end, students' attitude towards mathematics plays an important role in their math learning. Positive attitude is associated with higher achievement whereas negative attitude is associated with lower achievement. Students' attitude towards math is a manifestation of their beliefs in the value, enjoyment, self-confidence, motivation, and anxiety when it comes to learning math. Even in the early years of elementary school, students may already start to develop negative attitude towards mathematics. It is important to intervene in the early stages to prevent negative attitudes from being solidified. Computer-based educational games have the potential to serve as a successful intervention for promoting positive attitude towards math. This is because students are more likely to find computer-based games enjoyable and more likely to be motivated to engage. Computer-based educational games may also foster self-confidence and reduce math anxiety through features such as immediate feedback. As an organization rooted in innovation, Prodigy Education aspires to make learning math a fun experience for students through the engaging gameplay offered in its game-based math platform, Prodigy Math Game. Thus, it is worth the effort to search for the optimal classroom integration for digital game-based learning.

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