

An embodied agent helps anxious students in mathematics learning

Yanghee Kim¹ · Jeffrey Thayne¹ · Quan Wei²

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Abstract Mathematics anxiety is known to be detrimental to mathematics learning. This study explored if an embodied agent could be used to help alleviate student anxiety in classrooms. To examine this potential, agent-guided algebra lessons were developed, in which an animated agent was equipped with prescriptive instructional guidance and anxiety treating messages. The lessons were deployed in regular mathematics classrooms, one lesson per day over a week, with 138 boys and girls in the 9th grade in the United States. After taking the weeklong agent-based lessons, students decreased in their mathematics anxiety ($p = .042$) and increased in mathematics learning ($p = .001$), regardless of the presence or absence of the agents' anxiety messages. The presence of the agents' messages only seemed to make a difference for high-anxiety students. This finding suggests that an embodied agent could provide affective support for students with special needs.

Keywords Embodied agents · Mathematics anxiety · Advanced learning technologies · Interactive learning environments · Pedagogical agents

Over the last three decades, some researchers in mathematics education have deliberated about affective factors that might interfere with students' learning of mathematics.

✉ Yanghee Kim
yanghee.kim@usu.edu

Jeffrey Thayne
jeffrey.thayne@gmail.com

Quan Wei
quan.wei@wne.edu

¹ Department of Instructional Technology and Learning Sciences, Utah State University, 2830 Old Main Hill, Logan, UT 84321, USA

² College of Pharmacy, Western New England University, 1215 Wilbraham Road, Springfield, MA 01119, USA

Mathematics anxiety is one such factor that has been well examined. Mathematics anxiety has a detrimental effect on mathematics-related affect and performance (Hembree 1990; Morsanyi et al. 2014). Studies have also revealed mixed results on a gender difference in mathematics anxiety (Ashcraft 2002; Devine et al. 2012). Some researchers argue that girls in general have a higher level of mathematics anxiety than boys (Osborne 2001), but others argue for no actual difference between boys and girls (Goetz et al. 2013).

Understanding anxiety and its effects on mathematics students is important because there is a positive relationship between students' sense emotional security and students' success in school across grade levels (Reyes et al. 2012). Nonetheless, there has been very little research on anxiety management in a classroom setting, and as a result, many students who have high mathematics anxiety seem to receive little help in classrooms. Due to this lack of school support, some students from affluent families might resort primarily to one-on-one clinics but those without means to hire a private tutor may be left to simply struggle on their own (Dugas and Robichaud 2006; Foss and Hadfield 1993; Hembree 1990; Wadlington et al. 1992). It is important for all students—regardless of socioeconomic status, gender, or race—to have the best possible chance for success, and this study has explored the use of an advanced technology, an embodied agent (an animated, on-screen character acting as a tutor), as a supplemental tool in supporting students both cognitively and emotionally. An agent can be designed to simulate an effective in-person clinical approach and help anxious students to cope with anxiety while learning mathematical concepts. In this paper, we present the development of an agent-based anxiety treatment and the empirical evidence for its impact that was collected through a classroom-based experiment with 9th grade boys and girls.

Theoretical background

Mathematics anxiety

Mathematics anxiety is generally defined as unpleasant feelings of tension or fear when doing mathematics (Ashcraft 2002; Ma and Xu 2004). The classic anxiety study identifies two components of mathematics anxiety: emotional and cognitive (Liebert and Morris 1967). The emotional component explains nervousness, tension, fear, and discomfort, which are manifested by physiological signals and feelings (Adams 2001; Morris et al. 1981). The cognitive component involves an individual's concerns about their performance, self-doubt, and lack of confidence, and this cognitive aspect of anxiety is known to interfere with mathematics performance more than the emotional component (Morris et al. 1981). On the whole, there is a negative relationship between mathematics anxiety and mathematics achievement and mathematics-related activities (Leppavirta 2011; Ma and Xu 2004). Students with high mathematics anxiety typically receive lower scores in mathematics, compared to those with low mathematics anxiety (Cates and Rhymer 2003; Hembree 1990; Ma 1999). Highly anxious students seem to build a negative view of doing mathematics and avoid taking mathematics-related courses (Goetz et al. 2013).

After an examination of national data from a senior cohort, Osborne (2001) reports that gender difference in mathematics anxiety partly explains gender difference in mathematics achievement. In recent studies, more girls than boys report that they experience anxiety and discomfort while learning mathematics (Devine et al. 2012; Frenzel et al. 2007; Geist 2010). Even when some girls' performances are equal to or better than boys during early

school years, the girls show less positive affect in mathematics (e.g., low interest and weak confidence) than boys as they advance to upper grades (Baker 2002; Brownlow et al. 2000; Lindberg et al. 2010). In contrast, in a study conducted with German students, Goetz et al. (2013) claim that although girls report more mathematics anxiety on generalized assessments, they do not actually experience more anxiety than do boys in mathematics classes and examinations. Göetz et al. argue that general questionnaires might reflect girls' inaccurate beliefs about their mathematics ability, leading to their inaccurate evaluations of their anxiety.

Although the cause of mathematics anxiety is still unclear, some researchers believe that poor teaching is one source of the anxiety (Preis and Biggs 2001) and argue that the instructor's willingness to help anxious students is crucial for reducing mathematics anxiety in classrooms (Steele and Arth 1998; Wadlington et al. 1992). It is likely that anxious learners would benefit from a patient, understanding instructor, but they might not have access to such support; even the best teachers can struggle to meet the needs of every student in every class period. To fill this gap, the authors explored the potential of an embodied agent tutor as a supplemental tool.

Embodied agents in computer-based learning

Embodied agents are animated, digital characters embedded in computer-based learning to assist learners. Depending on its functionality and behaviors, a character may also be called a pedagogical agent (Johnson et al. 2000), a virtual peer (Ryokai et al. 2003), or an embodied conversational agent (Nass et al. 2005). Over the last two decades, researchers from various disciplines have examined the impact of embodied agents on learners' affect and learning gains (Atkinson 2002; Baylor and Kim 2005; Dunsworth and Atkinson 2007; Kim and Wei 2011; Moreno et al. 2001; Wang et al. 2008). Overall, there is a consensus that agent presence enables computer-based learning to be more social and natural and, consequently, could promote learners' positive affect and motivation toward the learning task (Gulz 2004; Heidig and Clarebout 2011; Krämer and Bente 2010). For instance, after working with an agent, adolescent students evaluated their learning experience as more enjoyable and more engaging (Lester et al. 2001; Mulken et al. 1998) and perceived the learning environment as easy to use (Moundridou and Virvou 2002). Additionally, when they worked with an agent, elementary-school children expressed a desire to use the environment again (Robertson et al. 2004). Middle-school students also demonstrated higher interest in the material and higher motivation to continue with the learning task (Moreno and Mayer 2000) when they worked with an agent.

More recently, researchers in agent technology have further attempted fostering an agent's affective roles for increasing students' positive emotions while learning (Graesser et al. 2008; Kim and Lim 2013; Krämer et al. 2013). We expected that a human-like agent might be able to help anxious learners to overcome their mathematics learning anxiety. It was not clear prior to this study whether an agent's carefully-designed instructional guidance would be sufficient to assist anxious students, given the social and motivational nature of an embodied agent (Baylor 2011), or whether the addition of the agent's messages to reduce anxiety reducing would be necessary.

Purpose of the study

The purpose of the study was to examine the effectiveness of an agent's anxiety reducing messages on learners' mathematics anxiety and their mathematics learning. In the agent-

guided algebra lessons that were implemented in natural classrooms, a tutor agent was designed to help students to manage their anxiety through both instructional guidance and anxiety reducing messages.

Research questions

Three sets of research questions on mathematics anxiety and learning guided the study. The first set of questions asked about the effects of an agent's anxiety messages and learner gender: (1a) Do the anxiety messages and learner gender affect learners' mathematics anxiety? (1b) Do the anxiety messages and learner gender affect learners' mathematics learning? Learner gender was included as a factor because gender difference has been a popular issue in mathematics anxiety research. The second set of questions asked about the effects of the agent's messages and learners' prior anxiety levels: (2a) Do the anxiety messages and learners' prior anxiety levels affect their mathematics anxiety? (2b) Do the anxiety messages and learners' prior anxiety levels affect their mathematics learning? Prior mathematics anxiety was included as a factor with the consideration that the effectiveness of anxiety treatment might differ among the learners who have different degrees of mathematics anxiety. The third set of questions asked about the effects of the agent's messages and learner gender for high-anxiety students: (3a) Do the anxiety messages and learner gender affect highly anxious learners? (3b) Do the anxiety messages and learner gender affect highly anxious learners' mathematics learning?

Method

Participants

Participants were 9th grade boys and girls enrolled in Algebra I in a high school located in a mountain-west state of the USA. One hundred sixty-one students started the first lesson, among which twenty-three students missed at least one lesson because of tardiness or absence. A total of one hundred and thirty-eight students were included in the data analysis. In the participating school district, students were allowed to take Algebra I from the 7th grade and required to complete the course by the 9th grade. The study was implemented as regular class activities using the portable lab in the school (34 laptop computers designated to mathematics classes). The average age of the students was 15.91 ($SD = 0.95$). Sixty-four students (46.4 %) were male, and seventy-four students (53.6 %) were female. Prior to participation, parental consent was obtained.

Material: agent-based anxiety treatment

Curricular content

The agent-based lessons consisted of four online self-instructional modules, each module taking one class hour. The curriculum covered four topics in fundamentals of algebra: signed number arithmetic, combining like terms and distribution, factoring, and graphing linear equations using slope and y-intercept. Each lesson consisted of 4–5 sections dealing with component concepts, and each section consisted of two learning phases of Review and Problem Practice. In Review, the agent presented a brief review of the concepts and

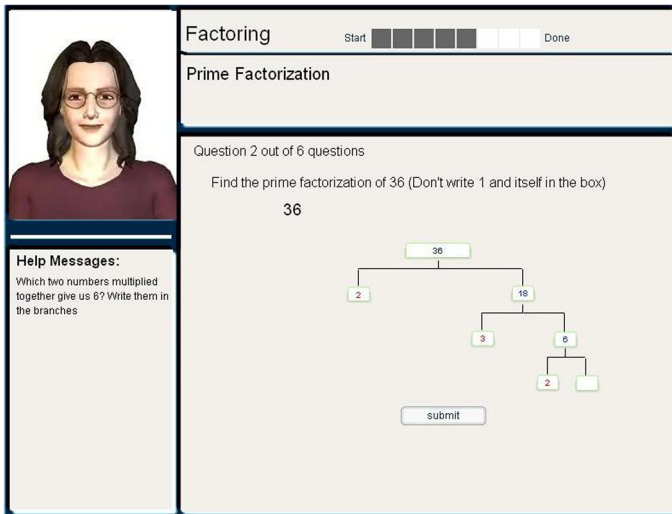


Fig. 1 A screen sample of agent-based lessons

examples, which the students had already learned from their teacher. In Problem Practice, the students practiced solving problems guided by the agent who provided informational feedback on their performance. Figure 1 presents screen excerpts of the agent-based lessons. During the problem solving practice, the students were encouraged to use scratch paper and pencils to reach the solution and choose their answers from one out of four possible choices. The lessons were prescriptive, and the agent's feedback was responsive according to predefined error types.

Agent instructional guidance

All participating students received an agent's instructional guidance. The agent *Chris* was designed to be a female teacher capable of explaining the concepts proficiently. The female gender was chosen based on literature that a female agent was more popular among both male and female 9th graders (Kim 2009; Kim and Wei 2011). A human teacher voice was recorded for Chris. Figure 2 overviews the design of interactions between Chris and the learner. Chris used two distinct instructional strategies to help anxious students, well-organized instruction and immediate, corrective feedback. Well-organized, guided instruction is likely to assist learners with understanding mathematical concepts more effectively than less organized, discovery-oriented approaches (Haak et al. 2011; Kirschner et al. 2006; Norwood 1994; Preis and Biggs 2001). In the current study, Chris presented the concepts from simple to complex and the problems from easy to difficult in a hierarchical order. Also, previous research indicated that corrective feedback had a significant positive impact on reducing mathematics anxiety (Aksu and Saygi 1988) and that assisting students to conceptualize *why* an answer was correct (more than simply providing the correct answer) helped them develop a deeper understanding and promoted their motivation to learn (Corbalan et al. 2009; Hattie and Timperley 2007; McKendree 1990). Immediate feedback during problem practice was more effective for retention of information than delayed feedback (Dihoff et al. 2004). So Chris provided immediate, corrective feedback as the students progressed. The algebra teachers in the participating school helped identify

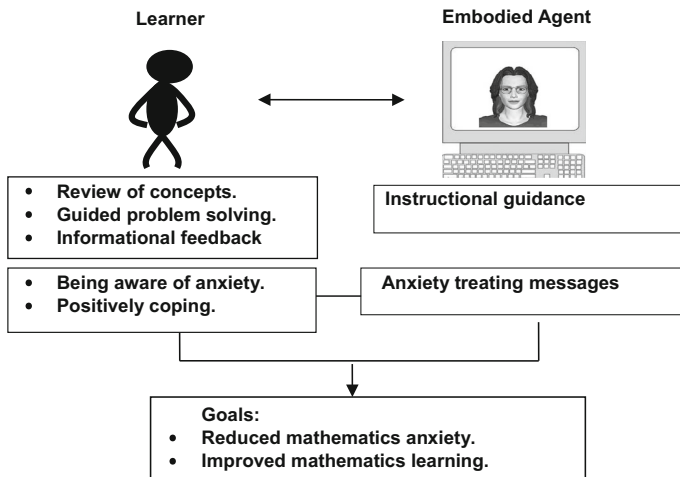


Fig. 2 Agent/learner interaction diagram

the common error types observed in classrooms and write the error-specific feedback messages later implemented by Chris.

Agent messages to reduce anxiety

The agent's anxiety messages were designed to encourage the student to be aware of their mathematics anxiety, cope with uncertainty, and face challenges (Dugas and Robichaud 2006; Foss and Hadfield 1993). Chris adopted a well-known cognitive-behavioral approach developed by Dugas and Robichaud (2006), which included, (1) helping the person be aware of his/her anxiety, (2) developing a greater tolerance for uncertainty, and (3) encouraging him/her to cope with problematic situations rather than avoid them. Earlier, Foss and Hadfield (1993) recommended a similar approach to treat mathematics anxiety in one-on-one settings: (1) helping the student to identify their fears and the source of the fears, and (2) suggesting coping skills to build confidence. Each time a student was about to progress to the next section in a lesson, an anxiety question was presented, and the student had to answer the question in order to move on. Four to five anxiety questions were asked depending on the number of subsections in the lesson: one question in a multiple-choice format with four choices and the rest in a Yes/No format. The agent's responses to the choices were pre-scripted, and given the limited choices that students had, the authors did not view the agent's responses as adaptive. For example, Chris asked a learner, "When you solve mathematics problems, what do you usually do?" If the student chose the answer out of four alternatives, "Spending a long time in reading a mathematics problem before solving it because I am not sure that the way I use to solve the problem was right", then the agent responded "Well, you may not feel confident about your work while solving the problem. Everyone's life is filled with uncertainty. However, with time and practice, you will find that worry will go away." If a student chose the answer "I always feel confident", the agent told the student to keep up with good work.

Independent variables

There were three independent variables: anxiety reducing messages, learner gender, and the learner's prior anxiety. Anxiety messages had two levels of Presence vs. Absence. In the message presence condition, the agent presented both instructional guidance and anxiety messages. The agent's anxiety messages were presented in between sections (four to five sections per lesson) when the student progressed to a new concept. In the absence condition, the agent presented only instructional guidance. These two conditions were identical in all other aspects (e.g., information, problem solving practice, and feedback) and differed only in the anxiety messages. Learners' interaction logs showed no statistical difference in instructional time between the two conditions.

Learner gender was identified by self-report. At login, students were asked to indicate their gender (two levels, Male vs. Female). Also, prior to the study, student mathematics anxiety was measured. The scores were categorized into four levels: Low ($M = 17.38$, $SD = 1.28$), Medium-low ($M = 23.91$, $SD = 2.38$), Medium-high ($M = 32.83$, $SD = 3.02$), High ($M = 48.56$, $SD = 10.46$). According to the distribution of their mathematics anxiety scores ($Mdn = 29$, $IQR = 18$), the scores that were in the lowest quartile were categorized as low ($n = 34$); the scores that were in the highest quartile were categorized as high ($n = 34$); and the scores that were in the second and third quartiles were categorized as medium-low and medium-high, respectively ($n = 35$, for both groups).

Measures

Mathematics anxiety

The 16-item Learning Mathematics Anxiety scale, a subscale of Revised Mathematics Anxiety Rating Scale (RMARS), was used to measure learner anxiety in mathematics learning before and after intervention (Plake and Parker 1982). RMARS is targeted secondary school students and has been broadly used by researchers (Akin and Kurbanoglu 2011; Ashcraft 2002; Devine et al. 2012; Leppavirta 2011) and cited by more than one hundred studies since its development. The items used a five-point Likert scale ranging from 1 "not at all" to 5 "very much." Students were asked to indicate how anxious they were with activities, such as (1) Looking through the pages on a mathematics text, (2) Reading a formula, (3) Working on an abstract mathematical problem, and so forth. Inter-item reliability evaluated by Coefficient α was .91 in the pretest and .94 in the posttest.

Mathematics learning

Students' mathematics learning was measured with a pretest and an immediate posttest in each lesson. To ensure content validity of the test items, the items were developed concurrently when the lesson content was developed, so that the assessments matched what was expected to learn. Also, face validity was established through careful examination of the items by the researchers and collaborating mathematics teachers. Students were asked to solve a set of short-answer problems in a pretest (6 questions in Lessons 1 through 3, 10 questions in Lesson 4); at the end of the lesson, they were asked to solve another set of equivalent questions that tested their understanding of matching concepts but were only

different superficially. For example, in the lesson on Distributing Like Terms, students were asked to solve distributing $3(2a + 3b)$ in the pretest and distributing $2(4x + 5y)$ in the posttest. The Pearson correlation between pretest and posttest was $r = .79$, which indicated a high correlation. Students were allowed to use a scratch paper and a pencil. The items were scored for correctness, and no partial credit was awarded. The pre and posttests were implemented without agent presence.

Procedures

With the assistance of the algebra teachers, the research team implemented the four lessons using laptops in classrooms over a one-week period, one lesson per day with no lesson on Wednesday. On Day 1, the students were given a brief introduction to the lesson and the interfaces. Then, they were asked to put on the headset. They accessed the lesson web site and typed in their demographic information to log in. At login, they were randomly assigned to either the control group or the experimental condition. They took a mathematics anxiety pretest and a mathematics understanding pretest; following that, they continued to work on Lesson 1 guided by the tutor Chris (taking approximately 35–45 min with individual variations). Then they took a mathematics learning posttest. On Days 2–3, students started with a pretest covering the lesson topic, continued to work on the lesson, and took a posttest. On Day 4, they took a pretest, studied the lesson, and took a mathematics learning posttest and a mathematics anxiety posttest.

Design and analysis

The research questions were answered using a pre and posttest experimental design. Our interest was to see if there would be any changes in mathematics anxiety and/or in learning gains from pretest to posttest following the intervention. A two-way repeated measures ANOVA was conducted for research questions 1a (on anxiety) and 1b (on learning), including two factors of treatment (message presence vs. absence) and gender (boys vs. girls). For research question 2a on anxiety, a two-way ANOVA was conducted to examine the effect of treatment and learner prior anxiety levels (high vs. mid vs. low). For research question 2b on learning, a two-way repeated measures ANOVA was conducted, including two factors of treatment and prior anxiety levels. Research questions 3a (on anxiety) and 3b (on learning) dealt only with high-anxiety students; a two-way repeated measures ANOVA was conducted including two factors of treatment and gender. The significance level was set at $\alpha < .05$ for all analyses.

Results

Question 1: The effect of agent anxiety messages and learner gender

(1a) Do the anxiety messages and learner gender affect learners' mathematics anxiety?

A two-way repeated measures ANOVA was conducted to test the effect of anxiety messages and learner gender on the anxiety of all participants, with anxiety messages and gender as between-subjects factors and time as a within-subjects factor. The repeated

ANOVA revealed that there was a significant main effect of time on mathematics anxiety, $F(1, 125) = 4.205$, $MSE = 31.65$, $p = .042$. Students' anxiety decreased significantly from pretest to posttest after working at the weeklong agent-based lessons. The effect size of this difference, however, was small, as calculated by *Cohen's d*, $d = 0.140$. There was no significant main effect of agent anxiety messages on anxiety, $F(1, 125) = 1.504$, $MSE = 31.65$, $p = .222$, $\eta^2 = .001$. There was no significant main effect of learner gender, $F(1, 125) = 0.120$, $MSE = 31.65$, $p = .730$, $\eta^2 = .000$. There was no significant interaction between treatment and learner gender, $F(1, 125) = 0.322$, $MSE = 31.65$, $p = .572$, $\eta^2 = .000$.

(1b) Do the anxiety messages and learner gender affect learners' mathematics learning?

A two-way repeated measures ANOVA was conducted to test the effect of anxiety messages and learner gender on the learning of all participants. The repeated ANOVA revealed that there was a significant main effect of time on mathematics learning of all participants, $F(1, 134) = 136.091$, $MSE = 6.338$, $p < .001$. Students' learning increased significantly from pretest to posttest after working at the agent-based lessons. The effect size of this difference was medium, as calculated by *Cohen's d*, $d = .623$. There was no significant main effect of anxiety messages on learning, $F(1, 134) = .180$, $MSE = 6.338$, $p = .673$, $\eta^2 = .000$. There was no significant main effect of gender, $F(1, 134) = 0.013$, $MSE = 6.338$, $p = .910$, $\eta^2 = .000$. There was no significant interaction effect of treatment and learner gender although the value was close to statistically significant, $F(1, 134) = 3.114$, $MSE = 6.338$, $p = .080$, $\eta^2 = .002$. Table 1 presents the means (*M*) and standard deviations (*SD*) of mathematics anxiety and mathematics learning scores by time, anxiety messages (treatment), and learner gender.

Question 2: The effects of agent anxiety messages and learner prior anxiety

(2a) Do the anxiety messages and learners' prior anxiety levels affect their mathematics anxiety?

A two-way ANOVA was conducted to test the effect of anxiety messages and learner prior anxiety levels on post-test mathematics anxiety of all participants. The two-way ANOVA

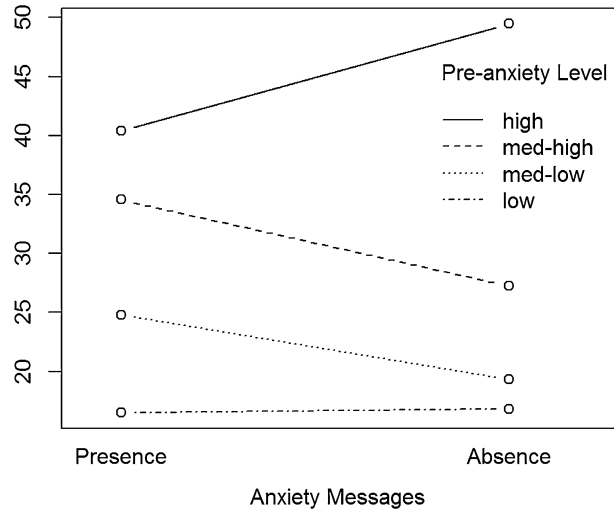
Table 1 M's and SD's of anxiety and learning by time, treatment, and gender for all participants

Gender	Anxiety messages	Anxiety ^a				Learning			
		Pretest		Posttest		Pretest		Posttest	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Male (<i>n</i> = 59)	Presence (<i>n</i> = 31)	29.58	12.16	28.84	13.32	16.97	6.20	21.18	6.52
	Absence (<i>n</i> = 28)	28.61	11.41	26.93	13.01	17.54	5.95	20.42	6.21
Female (<i>n</i> = 70)	Presence (<i>n</i> = 28)	28.54	8.31	28.11	10.90	16.50	5.12	19.70	5.61
	Absence (<i>n</i> = 42)	30.00	12.01	27.02	11.02	15.82	5.53	19.84	5.70
	Total**	29.28	11.10	27.67	11.91	16.63	5.68	20.26	5.96

** $p < .01$

^a Anxiety score ranges 16–80, Learning score ranges 0–28

Fig. 3 An interaction trend of agent messages and learner prior anxiety



revealed that there was a significant interaction effect between anxiety messages and prior anxiety levels, $F(3, 120) = 5.717$, $MSE = 75.309$, $p = .001$, $\eta^2 = .050$. However, this data set failed the homogeneity of variances assumption, so the result should be cautiously interpreted. Figure 3 presents this interaction trend graphically. By a visual inspection, high-anxiety students tended to demonstrate lower anxiety in the presence of the agent's anxiety messages than in the absence of the messages whereas the mid-range anxiety groups tended to demonstrate the opposite trend. We ran a Tukey's post hoc analysis. The results revealed that the high-anxiety group neared statistical significance ($p < .07$) whereas the other groups did not.

(2b) Do the anxiety messages and learners' prior anxiety levels affect their mathematics learning?

A two-way repeated ANOVA was conducted to test the effects of anxiety messages and learner prior anxiety levels on learning of all students. The results revealed that there was no significant main effect of prior anxiety on learning, $F(3, 128) = 0.868$, $MSE = 6.427$, $p = .459$, $\eta^2 = .002$. There was also no significant interaction effect of treatment and prior anxiety, $F(3, 128) = .197$, $MSE = 6.427$, $p = .899$, $\eta^2 = .000$. Table 2 presents the means (M) and standard deviations (SD) of mathematics anxiety and mathematics learning scores by time, anxiety messages (treatment), and learner anxiety levels.

Question 3: The effect of anxiety messages and learner gender for high-anxiety learners

(3a) Do the messages and learner gender affect highly anxious learners' mathematics anxiety?

A two-way repeated ANOVA was conducted to test the effect of anxiety messages and learner gender only for highly anxious students. The results revealed that there was a

Table 2 M's and SD's of mathematics anxiety by time, treatment, and prior anxiety levels

Prior anxiety	Anxiety messages	Anxiety ^a				Learning			
		Pretest		Posttest		Pretest		Posttest	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
High (<i>n</i> = 32)	Presence (<i>n</i> = 13)	46.31	5.59	40.38	10.99	15.27	5.64	18.40	6.20
	Absence (<i>n</i> = 19)	49.95	12.54	49.47	15.66	16.21	6.20	18.63	6.34
	<i>Total</i>	<i>48.47</i>	<i>10.33</i>	<i>45.78</i>	<i>14.34</i>	<i>15.79</i>	<i>5.88</i>	<i>18.53</i>	<i>6.18</i>
Medium-high (<i>n</i> = 33)	Presence (<i>n</i> = 16)	32.69	3.09	34.56	11.43	17.88	5.90	22.06	5.79
	Absence (<i>n</i> = 17)	32.71	3.06	28.84	4.98	17.47	4.98	21.21	6.06
	<i>Total</i>	<i>32.70</i>	<i>3.03</i>	<i>30.79</i>	<i>9.35</i>	<i>17.66</i>	<i>5.34</i>	<i>21.60</i>	<i>5.87</i>
Medium-low (<i>n</i> = 33)	Presence (<i>n</i> = 15)	24.67	2.50	24.80	7.31	17.44	5.67	21.38	6.52
	Absence (<i>n</i> = 18)	23.39	2.19	19.33	2.93	15.12	6.54	19.00	6.51
	<i>Total</i>	<i>23.97</i>	<i>2.39</i>	<i>21.82</i>	<i>5.97</i>	<i>16.17</i>	<i>6.18</i>	<i>20.09</i>	<i>6.53</i>
Low (<i>n</i> = 30)	Presence (<i>n</i> = 14)	17.36	1.22	16.50	0.94	16.31	5.68	19.94	5.81
	Absence (<i>n</i> = 16)	17.38	1.41	16.81	1.56	18.50	4.12	22.69	2.55
	<i>Total</i>	<i>17.37</i>	<i>1.30</i>	<i>16.67</i>	<i>1.30</i>	<i>17.41</i>	<i>5.00</i>	<i>21.31</i>	<i>4.63</i>

^a Anxiety score ranges: 16–80, Learning score ranges 0–28

significant main effect of time on anxiety, $F(1, 25) = 6.344$, $MSE = 33.245$, $p = .019$, $\eta^2 = .031$. Consistent with observations in Question 1 and Question 2, anxiety of the highly anxious group decreased from pretest to posttest after the weeklong agent-guided lessons. The effect size was small, as measured by Cohen's d , $d = .317$. There was neither significant main effect of anxiety messages, $F(1, 25) = 0.064$, $MSE = 33.245$, $p = .802$, $\eta^2 = .000$, nor learner gender on the anxiety of high-anxiety students, $F(1,25) = 1.320$, $MSE = 33.245$, $p = .262$, $\eta^2 = .007$. There was no significant interaction effect of anxiety messages and learner gender, $F(1,25) = 0.958$, $MSE = 33.245$, $p = .337$, $\eta^2 = .005$.

(3b) Do the messages and learner gender affect highly anxious learners' mathematics learning?

Lastly, a two-way repeated measures ANOVA was conducted to test the effect of anxiety messages and student gender for high-anxiety students' learning. There was a significant main effect of time on learning, $F(1, 28) = 15.373$, $MSE = 7.398$, $p < .001$. Learning of the highly anxious group increased significantly from pretest to posttest. The effect size was medium, as calculated using Cohen's d , $d = .489$. There was no significant main effect of anxiety messages on learning, $F(1, 28) = .053$, $MSE = 7.398$, $p = .473$, $\eta^2 = .002$. There was also no significant main effect of gender on learning, $F(1, 28) = .360$, $MSE = 7.398$, $p = .553$, $\eta^2 = .002$. There was no significant interaction effect of anxiety messages and gender on learning, $F(1, 28) = .031$, $MSE = 7.398$, $p = .860$, $\eta^2 = .000$. Table 3 presents the means (M) and standard deviations (SD) of mathematics anxiety and mathematics learning scores by time, anxiety messages (treatment), and gender for high-anxiety students.

Table 3 M's and SD's of anxiety by time, treatment, and gender for high-anxiety students

Gender	Anxiety messages	Anxiety ^a				Learning			
		Pretest		Posttest		Pretest		Posttest	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Male (<i>n</i> = 15)	Presence (<i>n</i> = 7)	46.00	4.28	45.00	6.71	15.33	6.78	18.33	7.30
	Absence (<i>n</i> = 8)	53.75	16.25	50.50	19.37	20.43	4.47	22.14	4.18
Female (<i>n</i> = 14)	Presence (<i>n</i> = 5)	46.00	7.91	38.40	9.76	13.80	2.28	17.40	4.34
	Absence (<i>n</i> = 9)	47.33	9.50	43.56	6.37	14.82	4.73	17.64	5.78
	<i>Total</i>	48.55*	10.75*	44.93*	12.07*	16.03***	5.43***	18.78***	5.81***

* $p < .05$, *** $p < .001$

^a Anxiety score ranges 16–80, Learning score ranges 0–28

Discussion

Embodied agents can provide social and affective affordances in a variety of situations, and there is a growing body of research that attests to agents' effectiveness in developing students' positive affect and motivation to participate in learning tasks. (Baylor and Kim 2005; Kim 2013; Kim and Lim 2013; Kim and Wei 2011; Moreno and Mayer 2000). Also, there is a consensus that mathematics anxiety is detrimental to learners' interest and ability in mathematics. Given the rarity of anxiety management in mathematics classrooms, the current study explored whether an embodied agent might be designed to help manage mathematics-related anxiety while guiding students' learning of mathematical concepts. The authors developed embodied-agent-based lessons equipped with anxiety-reducing messages adopted from popular clinical therapies as well as instructional guidance. The initial classroom experiments described in this paper did not result in strong evidence of the effectiveness of the agent's anxiety messages for all students. Rather, this trial revealed the efficacy of the agent-guided lessons that incorporated the solid instructional strategies. It seems that this finding underpins our initial effort to use embodied agent technology as a supplemental tool to manage learner anxiety in mathematics classrooms, therefore inviting continued efforts to refine the design of agent-based anxiety management.

Agent anxiety treatment

The statistical results did not confirm the benefit of the agent's anxiety reduction messages for all participants. Overall, the students decreased their anxiety from pretest to posttest significantly after the weeklong agent-guided lessons, regardless of the presence or absence of the messages. The authors conjectured that the anxiety-management strategies were actually already embedded in the agents' instructional guidance. That is, following the literature on instructional strategies, the agent presented the concepts and problems from simple to complex step-by-step in a highly organized manner and also provided immediate, explanatory feedback that was tailored to typical learner errors. Also, learning from the agent who guided the participants personally and patiently through the lesson might have

created a favorable, instructional context. Therefore, additional anxiety messages might only be necessary for students with high anxiety. This phenomenon was somewhat analogous to a previous study reporting that only the students with prior negative attitudes improved their attitudes toward mathematics learning significantly after working in agent-based learning (Kim 2009). The current study showed that high-anxiety students benefited most from the agent's anxiety messages.

On the other hand, although the results were somewhat mixed for anxiety reduction, learning was constant regardless of the presence or absence of additional anxiety-reduction messages. All participants increased in their learning significantly after the agent-based lessons, and even the high-anxiety group's learning did not seem to be affected by the agents' messages or lack thereof. Similarly, some previous studies showed that agent effectiveness on learner affect was not always conducive to cognitive gains (Baylor and Kim 2005; Kim and Wei 2011). Perhaps this is because the consequence of any changes in psychological constructs might take longer to be realized, as represented in Fisher et al.'s study, which found changes in learner affect predicted performance improvement months later (Fisher et al. 2012). Likewise, the students who participated in this study, and particularly those with high anxiety, might show more significant emotional and cognitive gains related to their experience with embodied agents after a longer period of time..

Learner gender

Based on previous research presenting conflicting arguments on gender difference in mathematics anxiety, this study examined whether or not the agent's anxiety-reduction messages would influence girls and boys to a different degree. Our results did not reveal gender difference. Both boys' and girls' anxiety and learning were improved in a similar fashion after the agent-based lessons. This finding is in line with a recent study (Goetz et al. 2013) reporting that girls do not experience higher anxiety than boys do.

Also, it is noteworthy that the previous research presenting gender difference has examined student anxiety in classroom instruction (Geist 2010; Osborne 2001). Often, researchers have attributed gender difference in motivation toward STEM learning to the unfavorable classroom atmosphere for girls (Cheryan et al. 2009; Gallagher and Kaufman 2005; Sandler et al. 1996). However, such gender difference has not been observed in agent-based learning, or, at least, is less prominent. Rather, many agent studies have showed girls react more positively to an embodied agent than boys do (Arroyo et al. 2013; Baylor and Kim 2004; Kim and Lim 2013). In this study, the agent's individualized instruction might have induced favorable reactions from both genders, just as joyful facial expressions could elicit more positive affective responses (such as higher interest) regardless of learner gender (Ravaja and Kätsyri 2014). Hopefully, further research can demonstrate more clearly whether or not an embodied agent is able to supply an equitable context in learning mathematics.

Implications and recommendations

Overall, the results of the study were in line with a trend prevalent in agent literature, confirming the affective benefit of humanlike agents and the need for a marriage between agent social presence and solid curricular pedagogy. Different from many agent studies examining ways to improve positive affect (e.g., interest, engagement, and self-efficacy),

this study this study highlights the effect that agent-based learning can have on negative affect (e.g. anxiety).

The study had some limitations. The agent's anxiety messages were not truly personalized to each learner's needs: anxiety questions were asked with limited answer choices and agent responses pre-scripted by the choices. Also, as aforementioned, the weeklong intervention may have been too short to elicit all possible affective changes and consequential cognitive changes. Even when human therapists treat anxiety one on one, change is usually the result of a dedicated, long-term commitment. Additionally, there is no doubt that developing artificial beings that help reduce anxiety will be costly, demanding long-term resources. This study therefore could be viewed appropriately as a preliminary effort to try embodied agent technology to help anxious students in classrooms. Now that the study presented the initial evidence for agent effectiveness for high anxiety students, subsequent research might continue to refine agent-based anxiety treatment. First, agent treatment should become more adaptive to individuals' needs, taking advantage of advanced intelligent technology. Second, agent treatment might be deployed, at a minimum, for a few weeks or throughout an entire semester to genuinely understand the effectiveness of the treatment. Third, agent treatment might be tried out with a bigger subject pool, increasing the statistical power. On the other hand, in-depth qualitative data (e.g., interviews, observations, and survey responses) should complement the quantitative data to provide clearer information about the agent effectiveness on mathematical anxiety and learning.

To conclude, with the advance of technology, embodied agents might be able to provide personalized help for all learners. Many of today's adolescents have grown up with technologies as an integral part of their everyday life and are often called digital natives (Jones et al. 2010; Kennedy et al. 2010; Prensky 2001). In their use of the technologies, interacting with animated digital characters (e.g., avatars and agents) is becoming more ordinary (Turkle 2011). Embodied agent technology could be effectively used as a supplemental tool for the young learners who grapple with everyday learning challenges and also alleviate pressure on overloaded teachers in classrooms.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical approval The authors have complied with American Psychological Association ethical standards.

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Yanghee Kim, Ph.D. is an Associate Professor of Instructional Technology and Learning Sciences at Utah State University. Her research focuses on the design of embodied technologies (e.g., pedagogical agents and humanoid robots) to support learner affect in literacy and mathematics learning. She has expertise in design of interactive learning environments for culturally and linguistically diverse students and equity in STEM education.

Jeffrey Thayne is a Ph.D. candidate in the Department of Instructional Technology and Learning Sciences at Utah State University. His research focuses on how learning technologies help learners to understand the statistical concepts and increase opportunities for learners to care about what they are learning.

Quan Wei, Ph.D. is an Instructional Designer at Western New England University.