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Toward Creating Computer-Based Math Learning Favoring High-School Females

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ABSTRACT

Research indicates that teenage females prefer to work and perform better at the learning environment that supports frequent interactions and allows them to build relationships with others. This paper will introduce a computer-based algebra-learning environment *MathGirls* equipped with pedagogical agents (digital life-like characters) that simulate real-world social interactions and relations. The goal of MathGirls is to help young women of high-school age build positive attitudes toward and self-efficacy in math learning through this simulated social context. To investigate the efficacy of MathGirls, a classroom experiment was conducted with 83 high-school females. The experiment examined the effects of agent attributes (female teacher-like, male teacher-like, female peer-like, and male peer-like) and learner ethnicity (Caucasian vs. minorities). The results indicated that minority females' math attitudes were significantly higher after working with the female-teacher-like agent than with the other agents. Second, Caucasian females' math attitudes were significantly higher after working with the male agents, whereas minority females' math attitudes were significantly higher after working with the female agents. Third, both groups of the female students perceived the peer-like agents to be significantly more affable than the teacher-like agents. Fourth, Caucasian females performed significantly higher after working with the teacher-like agents, whereas minority females performed higher with the peer-like agents. From the results, the author conjectures that the concept of attribute similarity (the similarity in personal characteristics of a role model and a learner) seems to have applied more to minority females. In contrast, the projection of real-world social stereotypes seems to have applied

more to Caucasian females. Overall, the findings support the instructional utility of agent attributes to address the needs of diverse groups of young female learners.

INTRODUCTION

Gender differences in academic interest and cognitive and interaction style are well documented (Arroyo, Murray, Woolf, & Beal, 2003; Evans, Schweingruber, & Stevenson, 2002; Hakkarainen & Palonen, 2003; Slotte, Lonka, & Lindblom-Ylänne, 2001). In particular, the gender differences in motivation to learn science, technology, engineering, and math (STEM) have become more salient with recent concern about workforce imbalances in the fields of science and engineering. Young women's lack of motivation to learn STEM subjects has been mainly attributed to the social influence of family, friends, and teachers, which impose gender-related social stereotypes and expectations on young women. Ultimately, that is a societal issue that might not be immediately resolved.

As an alternative, a team of multidisciplinary researchers created a computer-based math learning environment (MathGirls), funded by the National Science Foundation (HRD-0522634) equipped with digital simulated friends and teachers (called *pedagogical agents*), with the speculation that the virtual environment might be able to simulate social relationships in the real world and help high-school females improve their attitudes toward and self-efficacy in math learning. Traditionally, various technologies have been utilized to promote K-12 math learning – e.g., Cognitive Tutors by Carnegie Mellon University (Anderson, Corbett, Koedinger, & Pelletier, 1995) and Virtual Manipulatives (<http://enlvm.usu.edu/ma/nav/doc/intro.jsp>) by groups of researchers funded by the National Science Foundation. Unlike those existing interventions, the uniqueness of the current learning environment (MathGirls) is highlighted with its attempts to address the affective aspect of math learning; a major goal of MathGirls is to

build high-school females' positive math attitudes and confidence through the virtual social modeling with pedagogical agents and, eventually, to motivate the females to take elective math-related courses and pursue careers in STEM in the long term.

This paper introduces an experimental study that examined the efficacy of the MathGirls environment, whether the persuasive messages presented by the pedagogical agents to build positive math attitudes would contribute to the improvement of high-school females' positive math attitudes, math self-efficacy, and math learning. In particular, given the concept of attribute similarities – the similarities of personal characteristics between a social model and a learner in the real world (Bandura, 1997; Schunk, 1987), the study focused on the investigation of the impact of the pedagogical agents' attributes defined by agent age and gender among Caucasian and minority high-school females. Detailed descriptions of the study follow.

THEORETICAL BACKGROUNDS

Females' Lack of Motivation toward STEM

Many young females tend to hold beliefs that interfere with their learning of STEM and limit their pursuit of careers in those fields. They often identify STEM areas as associated with men, believe STEM aptitude to be a fixed ability (Heyman, Martyna, & Bhatia, 2002), perceive scientists and engineers as “geeks” (Muller, 2002), and doubt their own ability to succeed in science and engineering (Seymour & Hewitt, 1997). These beliefs are attributable mainly to the social and cultural influences of family, friends, and teachers (Clewett & Campbell, 2002; Sandler, Silverberg, & Hall, 1996; Wood, 2002), which include low expectations for girls in STEM, less attention and intellectual

encouragement to girls than boys in STEM classes, expectations that girls will be polite rather than active in class, and lack of role models (fewer females in STEM areas).

Those social influences lead females to have low confidence in and negative attitudes toward STEM learning and eventually pursuing careers in STEM. Studies indicate that girls' performances are often equal to or even better than those of boys in math and science during elementary school years (Baker, 2002; Brownlow, Jacobi, & Rogers, 2000). Through less-than-favorable educational experiences in traditional classrooms, young females are frequently imbued with gender-related stereotypes and develop negative beliefs about their potential to learn STEM (Sandler et al., 1996).

To counter these influences, organizations (e.g., NSF and Society of Women Engineers) have initiated various mentoring programs to match female scientists and engineers with young females and to guide their career choices. Female-friendly websites have been developed to familiarize young females with learning math/science concepts. As such, female-friendly STEM-related interventions should be warranted in order to proactively invite females who, because of stereotypic expectations, are not interested in learning STEM. In other words, females need to be exposed to the environments that will encourage them to overcome ungrounded social stereotypes and to build constructive views of their confidence and competence in STEM.

Ultimately, the females' unfavorable educational experiences might be a societal issue, involving parents, teachers, and friends, whose stereotypic views seem unlikely to change immediately. However, with the advances of computing technology, a female-friendly virtual environment that simulates social interaction can be instantiated. This

environment may counter the undesirable social influences in the real world and foster social interaction favoring the young females who learn STEM.

Girls' Preference for Social Interaction in Learning

In classrooms, females tend to be more aware of social influences than males. Sandler and colleagues (1996) argued that girls' participation in class is more affected by teacher behavior than that of boys. A developmental theorist Gilligan (1993) contends that girls more than boys value relationships and connections with others and construct their identities as a result of the interpersonal relationships they have created and maintained. Lightbody and Siann (1996) show that female students are more likely than boys to interact by cooperating and synthesizing and to feel more comfortable in making connections and negotiating closeness in relationships. In the study, the female students also reported liking friends, interactions, and relationships, whereas the boys reported liking sports and school clubs. However, according to Jones and Dindia (2004), in classroom practices, girls seem to have fewer opportunities than boys to interact with their teachers. The researchers conducted a meta-analysis of 32 empirical studies to examine patterns of gender differences in teacher-initiated teacher/student interactions. They found a tendency for teachers to initiate more overall interactions with male students than with female students. This phenomenon contradicts females' preferences for interactive learning experiences. Given that STEM areas have fewer role models for females, the phenomenon may influence females to feel isolated in STEM classrooms and, eventually, limit their motivation toward STEM learning. It is highly plausible that females can be more successful in STEM learning environments that afford social context in which they can interact and build relations. For instance, for women successful in

mathematics-related careers, social influences such as encouragement and support from family members and teachers are found to be the foundation on which these women build their academic confidence to overcome obstacles in their progression through male-dominated academic programs (Zeldin & Pajares, 2000).

Females' inclinations toward interactions and relationships in conventional settings are consistently demonstrated in computer-based environments. They are more sensitive than boys to help messages (Arroyo et al., 2003) and perform better with highly interactive hints than with non-interactive and low-intrusive hints (Arroyo, Beck, Woolf, Beal, & Schultz, 2000). Cooper and Weaver (2003) argue that female prefer instructional programs to be more like learning tools, helping them through direct and frequent verbal feedback. Littleton and colleagues (1998) reason that one of the difficulties females have with learning from many instructional programs is that generally warrior-like characters in such programs are not appealing to them. Their lack of identification with the characters may cause girls to experience greater computer anxiety, lack of interest, and poorer performance. Along this line, female college students significantly more positively respond to a digital human-like character (i.e. a pedagogical agent) embedded in an instructional program than did males (Baylor & Kim, 2003).

Pedagogical Agents as Persuaders

Pedagogical agents (PAs) are animated life-like characters (Johnson, Rickel, & Lester, 2000) included in computer-based educational interventions. In a PA-based environment, a learner grasps instructional content while interacting with one or more PAs designed to provide information and/or encouragement, to share menial tasks, or to collaborate with the learner. What would make PA's unique from conventional computer-

based environments would be the PA's capability to simulate social interaction. Being human-like, PA's are often designed to simulate human instructional roles such as expert, tutor, instructor, or peer (See Figure 2 on page 13). No matter what role it may play, a PA can present persuasive messages to less motivated learners to engage in the learning task. Several studies have revealed the positive impact of pedagogical agents on cognitive and motivational outcomes in computer-based learning (Atkinson, 2002; Kim, 2004b; Moreno, Mayer, Spires, & Lester, 2001).

Research on human/computer interaction identifies that people respond to computers in fundamentally social ways. People, young or old and educated or not, often apply the same social expectations and rules to computers as they do to humans in the real world. For instance, gender differences in the real world are projected to computing environments (Lee, 2003). Educated computer users apply politeness norms, notions of "self" and "other," and gender stereotypes when interacting with computers (Reeves & Nass, 1996). This tendency seems to be stronger among inexperienced computer users, who tend to attribute more validity to computer-generated and computer-presented information than is warranted (Harmon, 1996). As a result, information from computers often gains special authoritative status. Also, Burgoon and colleagues (2000) found that computers were more attractive task partners and more influential to decision making than human partners. In that study, credibility of the information increased as more modalities became available. Similarly, the messages from PA's can be viewed at least as valid, credible, and persuasive to high-school females as those from their parents or teachers. In other words, it is very likely that PA's may persuade the females to build positive attitudes toward and confidence in learning STEM.

Attribute Similarities and Virtual Role Models

The concept of attribute similarities (Bandura, 1997) refers to the similarities of personal characteristics between a social model and a learner such as age, gender, ethnicity, or competency. Attribute similarities, as a determinant of successful modeling in the real world, significantly influences learners' self-efficacy beliefs in learning tasks. That is, the more similar models are to learners, the greater is the probability that actions by the models are perceived by the learners as socially appropriate and therefore more frequently produced by the learners. Schunk and Hanson (1985) found that observing a peer model led to higher self-efficacy for learning, posttest self-efficacy, and achievement than did observing a teacher model or observing no model at all. Therefore, to build positive attitudes and self-efficacy of high-school females learning STEM, it would be ideal to match the females with a best role model having similar attributes as the learner's own. However, this might not always be possible in the real world, especially for minority females. Alternatively, computer-based learning can include PA's to play the simulated social role (Kim & Baylor, 2007). Previous studies indicated that female college students showed preferences for and positive perceptions of the social presence of PA's as their learning partners when they performed a learning task (Baylor & Kim, 2003; Kim, 2004a, 2004b, 2005). In the studies, the match or mismatch of the personal attributes of PA's and learners was a relevant factor that influenced learner motivation to work with the agents. However, it was unknown, before the current study, if these trends would be consistently found among high-school females in STEM learning contexts. That is, will high-school females' task-specific attitudes, self-efficacy, and

learning be influenced by the personal attributes of the agents embedded in the learning environment?

The purpose of this study, therefore, was to identify the impact of agent attributes on high-school females' math attitudes, math self-efficacy, perceptions of agent affability, and learning. Also, learner ethnicity was included as a variable, given a previous study that identified learner ethnicity as an influential factor for learners' perceptions of and motivation to work with pedagogical agents (Baylor & Kim, 2004).

Research Questions and Hypotheses

The study was guided by four specific research questions:

- 1) Will the attributes (age and gender) of pedagogical agents influence Caucasian and minority high-school females' attitudes toward learning math in a pedagogical-agent-based learning environment?
- 2) Will the attributes of pedagogical agents influence the females' self-efficacy in learning math in a pedagogical-agent-based learning environment?
- 3) Will the attributes of pedagogical agents influence the females' perceptions of agent affability?
- 4) Will the attributes of pedagogical agents influence the females' learning outcomes?

First, Baylor and Kim (2004) found that African-American college students reacted more sensitively to their agent's attributes than Caucasian students did. Thus, it was expected that learner ethnicity would interact with agent attributes. More specifically, minority females' task-related attitudes would vary according to the agent attributes (H1). Second, research on social modeling suggests that attribute similarities lead learners to judge modeled behaviors as appropriate for them. In a previous study,

college students of both genders showed higher self-efficacy in the task of instructional planning after they worked with female-instructor agents, even though they had positive attitudes toward male agents (Baylor & Kim, 2003). Thus, it was expected that female agents would have a positive impact on high-school females' self-efficacy in learning math (H2) and also that female agents would have a positive impact on the females' perceptions of agent affability (H3). Last, research on pedagogical agents has not provided sufficient evidence for their impact on learning outcomes. Thus, it was expected that agent attributes would not influence learning (H4).

METHOD

Participants

Participants were 83 female 9th graders in required introductory algebra classes in two high schools located in a mountain-west state of the USA. The participants were chosen for two reasons. First, in the collaborating school district, ninth graders must take introductory algebra (Algebra I or Applied Algebra), regardless of their interests. This meant that the ninth grade participants would represent a population that included females who did not have strong achievements in or motivation toward math learning. Second, the females in the 9th grade were typically assumed to be imbued with social stereotypic expectations, but at an age where those social forces might be counteracted in the interest of positive attitudes toward and beliefs about science and math (Dunham, 1990). Access to the participants was achieved by including four math teachers who volunteered to participate in the study. The ethnic compositions of the participants as self-reported were Caucasian (58.3%), Hispanic (22.8%), African-American (3.9%), Asian (3.3%), and others (11.7%). The average age of the participants was 15.51 ($SD =$

1.14). For analysis, only 67 females were included, due to participant attrition and the removal of outliers and invalid records: 36 (53.7%) females were Caucasian and 31 females (46.3%) were minorities that included 20 Hispanic, 5 Asian, 2 African-American, and 4 others.

Materials: MathGirls

Curriculum. “Fundamentals in Algebra” was the curriculum. Following the Principles and Standards of the National Council of the Teachers of Mathematics (NCTM, 2000), the curriculum content, developed in collaboration with participating teachers, dealt with fundamentals in two areas of introductory algebra, each area providing one lesson. Lesson I covered the use of real numbers - addition, subtraction, multiplication, division, and order of operations. Lesson II dealt with combining like terms and with the applications of distributive property. Each lesson took one-class period and included four to five subsections that consisted of two phases: Reviews and Problem Practice. The lessons were to be used as supplemental materials for the classes, where the students, with the assistance of a pedagogical agent, practiced problem-solving individually after taking conventional lessons from their teachers. Figure 1 presents example screens of the learning environment MathGirls. The login screen was intended to invite the females’ attention by presenting the program logo conspicuously; in the problem practice, the female-peer-like agent is presenting corrective feedback to the student’s wrong answer. The students were able to read her comments below the image.

[Insert Figure 1 about here]

Agent messages. Three types of agent messages were developed: informational, motivational, and persuasive. The informational messages were content-related, including

reviews--the brief overviews of what the students had learned from their teachers--and feedback on students' performances. When a student made a mistake, the agent provided error-specific explanations to guide her to the right problem-solving path, which helped construct knowledge step by step. Motivational messages were words of praise or encouragement. When a student had the correct answer, the agent said "Good job" or "Great, I'm proud of you"; when the student had a wrong answer, the agent said "Everybody makes mistakes" or "You're getting there. One more thing you need to consider is..." Persuasive messages were statements about the benefits or advantages of learning math and pursuing careers in STEM. At the beginning of each section, the agent proactively made statements to positively influence the females' perceptions of and attitudes toward math. The messages were presented at the beginning of a new section, without the learner's request.

Agents design. Four 3D images of PA's, representing male and female teachers in their forties and male and female teenagers of about 15, were designed using Poser 6 (<http://www.e-frontier.com>). Given the superior impact of human voices to synthesized ones, the agent messages were prerecorded by four voice actors matched with the agent's age and gender. The agent images and the recorded voices were integrated within Mimic Pro for lip synchronization. Facial expressions, blinking, and head movements were added to make the agents look more natural. Then the 3D animated agents were rendered in Poser to produce AVI files, which were later batch-compressed to Flash files, using Sorenson Squeeze to be cast via the web. Figure 2 shows the four agents used in MathGirls.

[Insert Figure 2 about here]

System design. The MathGirls system was designed to accommodate four principal users: a) the students, who needed an engaging, interactive web-based experience; b) the instructional designers, who needed an easy way to create new lessons with agent videos; c) the researchers, who needed comprehensive data collection and experiment implementation; and d) the system developers, who needed a friendly programming environment for updating codes.

The developers, on the back end, connected Flash movies to dynamic instructional content with ColdFusion. The back-end relational database stored instructional texts, questions, feedback, graphics, agent videos, students' choice of agent, and students' answers to the questions. By keeping all content in the database tables, the instructional designers could update lessons and agent information using a database browser. Once the schema was set up and the basic code was written, only a few modifications were necessary to implement a new lesson. The students could start working on the lessons immediately after they logged into the system, using an Internet browser. During implementation in schools, the front-end automatically captured all responses with time stamps.

Independent Variables

There were two independent variables in the study: agent attributes and learner ethnicity. Agent attributes, the treatment variable, had four levels of female-peer-like vs. male-peer-like vs. female-teacher-like vs. male-teacher-like. Agent attributes, defined by agent age and gender, were operationalized by image and voice. The four agents had been morphed from a base image and designed to fit to the respective roles, and four human voices matched with the roles were recorded. Thus, the four agents were identical in their

messages, gestures, and facial expressions and different only in their images and voices (See Figure 2).

Learner ethnicity was included as a factor, with the consideration that females' reactions to virtual social beings might be influenced by their social cultural backgrounds (Baylor & Kim, 2003). Learner ethnicity was identified by self-report. For analysis, learner ethnicity had two levels of Caucasian (36) vs. minorities (31 including 20 Hispanic, 5 Asian, 2 African-American, and 4 others).

Dependent Measures

Math attitudes. Fishbein and Ajzen (1975) define attitude as “a learned predisposition to respond in a consistently favorable or unfavorable manner with respect to a given object (p. 6). In this study, math attitudes toward learning math referred to the degree of learners' favorableness toward learning math (L. W. Anderson & Bourke, 2000). A questionnaire of 10 items was developed, derived from the Mathematics Attitude Survey (Ethington & Wolfe, 1988) and Attitudes Toward Mathematics Inventory (Tapia & Marsh, 2004). Math attitudes were measured before and after the intervention. The items were scaled from 1 (*Strongly disagree*) to 7 (*Strongly agree*). Item reliability evaluated with coefficient α was .89 in the pretest and .82 in the posttest. For analysis, the mean scores of the items were calculated.

Math self-efficacy. In general, self-efficacy beliefs are defined as an individual's judgment about his or her competency in performing a particular task (Bandura, 1986, 1997; Weiner, 1992). The direction of self-efficacy is best captured by “*I can* vs. *I can't*” (Weiner, 1992) or “*How sure are you ~?*” (Bandura & Schunk, 1981; Pajares, 1996). In this study, mathematics self-efficacy referred to learners' belief about their competency

in learning math. A questionnaire of six items was developed according to Bandura's guidelines (2001) and scaled from 1 (*Strongly disagree*) to 7 (*Strongly agree*). The participants were asked to indicate their confidence for achieving outcomes in mathematics before and after the intervention. Item reliability evaluated with coefficient α was .87 in the pretest and .87 in the posttest. For analysis, the mean scores of the items were calculated.

Agent affability. The Merriam-Webster Online Dictionary defines the word "affable" as "characterized by ease and friendliness." The affability of a pedagogical agent (PA) considered important in helping learners build social relations and trust with the PA (Kim, 2004b). A questionnaire of nine items was developed, derived from the Agent Persona Instrument (Baylor & Ryu, 2003). The items were scaled from 1 (*Strongly disagree*) to 7 (*Strongly agree*). Item reliability evaluated with coefficient α was .90. For analysis, the mean scores of the items were calculated.

Learning. Learning was measured by the learners' performances in pre- and posttests, with each having 10 questions. The mean scores were calculated for analysis.

Procedure

The study was implemented in collaboration with the math teachers in participating schools, using their regular algebra classes for two consecutive days, one lesson (approx. 50 minutes) each day. The current study implemented Lesson 1 (Using Real Numbers) and Lesson 2 (Combining Like Terms). The MathGirls environment was self-inclusive, in that the participants completed pretests, learning tasks, and posttests within the lesson modules. In the lessons, the agents proactively presented informational,

motivational, and persuasive messages without the students' requests. This way, students across the experimental conditions received the same amount of information.

The overall procedures were as follows:

- a) The implementer gave the students a brief introduction to the activity and taught them how to use the interfaces; students then put on headsets so that they could concentrate on their own tasks without distraction;
- b) Students accessed the MathGirls web site and entered demographic information to log in. Upon the log-in, the students were randomly assigned to the experimental conditions by system programming;
- c) They took pretests (self-efficacy, attitudes, and algebra tests);
- d) They performed the tasks (solving problems in fundamentals of algebra with the agent's guidance) for an average of 40 minutes; and
- e) They took posttests (self-efficacy, attitudes, agent affability, and algebra tests).

Design and Analysis

The study employed a 2×4 factorial design, in which the variables included agent attributes (female-peer-like vs. male-peer-like vs. female-teacher-like vs. male-teacher-like) and learner ethnicity (Caucasian vs. minorities). To test Hypothesis 1 (H1) and 4 (H4), two-way ANCOVA with agent attributes (4) and learner ethnicity (2) was used, with a pretest set as a covariate. To test Hypothesis 2 (H2) and 3 (H3) focusing on agent gender, the treatment conditions were re-grouped by agent gender, two-way ANCOVA was used with agent gender (2) and agent ethnicity (2), with a pretest set as a covariate.

RESULTS

Math Attitudes

The results revealed a significant interaction effect of agent attributes and learner ethnicity for math attitudes, $F(3, 58) = 4.18, p < .01, \eta^2 = .18$. Given the interaction effect, further analysis was conducted to examine the simple main effects of interaction, i.e., detailed interaction patterns among the levels of each variable. First, two one-way ANCOVA's were conducted with agent attributes as a factor, one with Caucasian females and the other with minority females. The results indicated that with minority females, agent attributes had a significant main effect, $F(3, 26) = 3.14, p < .05, \eta^2 = .27$. Minority females who worked with a female-teacher agent showed significantly higher attitudes toward learning math in MathGirls than minority females who worked with the other agents. With the Caucasian females, there was no significant main effect of agent attributes. Figure 3 presents this result.

[Insert Figure 3 about here]

Second, agent attributes included two sub-factors: agent age and agent gender. To examine the simple main effects of the interaction between the sub-factors and learner ethnicity, the four treatment conditions of agent attributes were re-grouped into two groups, two groups by agent age and also two groups by agent gender. Each two-group was tested with learner ethnicity. That is, two 2-way ANCOVA's were conducted, one for the factors of agent age (teacher-like vs. peer-like) and learner ethnicity and the other for the two factors of agent gender (male vs. female) and learner ethnicity. The results indicated a significant interaction effect of agent gender and learner ethnicity, $F(1, 62) = 4.34, p < .05, \eta^2 = .065$. Caucasian females showed significantly higher attitudes toward

learning math in MathGirls after working with the male agents, whereas minority females showed higher attitudes after working with the female agents. Figure 4 is the graphic representation of this difference. Given the results, the hypothesis (H1) that minority females' math attitudes would vary according to the agents' attributes was supported.

[Insert Figure 4 about here]

Math Self-Efficacy

The results indicated no significant main or interaction effects of agent attributes and learner ethnicity for math self-efficacy, $F(1, 58) = 1.81, p = .18$. The results did not support the hypothesis (H2) that female agents would have a positive impact on self-efficacy in learning math. However, some distinct trends were noteworthy between Caucasian vs. minority females. Caucasian females' self-efficacy was higher after working with the male agents ($M = 31.9, SD = 6.04$) than after working with the female agents ($M = 28.95, SD = 7.39$), whereas minority females' self-efficacy was higher after working with the female agents ($M = 29.02, SD = 6.59$) than after working with the male agents ($M = 27.84, SD = 8.70$). This trend was not sufficiently strong enough to indicate a statistical significance.

Agent Affability

The results indicated no significant main or interaction effects of agent gender and learner ethnicity for the high-school females' perceptions of agent affability. The hypothesis (H3) that female agents would have a positive impact on the perceptions of agent affability was not supported by the results. However, there was a significant main effect from agent age, $F(1, 63) = 4.83, p < .05, \eta^2 = .07$. Both Caucasian and minority

females perceived the peer-like agents ($M = 45.57$, $SD = 8.92$) to be more affable than the teacher-like agents ($M = 40.05$, $SD = 10.94$).

Learning

The results revealed a significant interaction effect of agent attributes and learner ethnicity for learning, $F(3, 58) = 2.72$, $p < .05$, $\eta^2 = .12$. Given the interaction effect, further analysis was conducted to examine the simple main effects of interaction. First, two one-way ANCOVA's were conducted with agent attributes as a factor, with Caucasian females and with minority females separately. The results indicated no significant effects. Second, agent attributes included two sub-factors: agent age and agent gender. To examine the simple main effects of the sub-factors, the four treatment conditions were re-grouped by agent age and by agent gender. Two 2-way ANCOVA's were conducted, one for the factors of agent age (teacher-like vs. peer-like) by learner ethnicity and the other for the factors of agent gender (male vs. female) by learner ethnicity. The results indicated a significant interaction effect between agent age and learner ethnicity, $F(1, 62) = 6.81$, $p < .05$, $\eta^2 = .10$. Minority females performed significantly higher after working with the peer-like agents than with the teacher-like agents, whereas Caucasian females performed significantly higher after working with the teacher-like agents than with the peer-like agents. Figure 5 is the graphic representation of this difference.

[Insert Figure 5 about here]

In summary, the results showed that minority females' math attitudes at MathGirls were significantly higher after working with the female-teacher-like agent. Next, Caucasian females' math attitudes were significantly higher after working with the male

agents; in contrast, minority females' math attitudes were significantly higher after working with the female agents. Second, math self-efficacy was affected by neither agent attributes nor learner ethnicity. Third, the students perceived the peer-like agents to be significantly more affable than the teacher-like agents. Fourth, for learning, minority females performed higher in the peer-like agent conditions, whereas the Caucasian counterparts performed significantly higher in the teacher-like agent conditions.

DISCUSSION

Grounded in human social modeling and human/computer interaction research, this study examined the potential of pedagogical agents that simulate social roles for high school females in computer-based math learning. The experiment investigated the effects of agent attributes on math attitudes, math self-efficacy beliefs, the perceptions of agent affability, and math learning. Along the line, learner ethnicity was included as a factor, given the diversity of the participants. Overall, the results supported that pedagogical agents played distinct social roles. The findings are discussed in terms of the hypotheses.

The first hypothesis stated that minority females' math attitudes would vary according to agent attributes (age and gender). The results supported the hypothesis, revealing that the minority females' attitudes toward learning math were most positive after working with the female-teacher-like agent than after working with the other three agents, whereas Caucasian females were not similarly affected. This trend was replicated in a previous study that African-American college students' reactions to the attributes of their agents were significantly more sensitive than the Caucasian counterparts (Baylor & Kim, 2003). Also regarding agent gender, minority females' math attitudes were significantly more positive after working with the female agents than after working with

the male agents, whereas Caucasian females showed more positive attitudes after working with the male agents. From those results, the effect of attribute similarities applied only to the minority females: that is, the minority females' math attitudes were more positive after working with the female agents. On the other hand, the similarity effect did not apply to Caucasian females; rather, the male agents were superior to the female agents for Caucasian females' math attitudes. This phenomenon has been consistently found in previous studies and can be interpreted in terms of the transference of gender-related stereotypes in human relationships (Carli, 2001) to virtual artificial relationships. In Kim and colleagues' study (2007), male and female college students who were dominantly Caucasian reported a male agent to be significantly more human-like, engaging, and facilitating to learning. Likewise, Moreno and colleagues (2002) showed that male and female undergraduates applied gender stereotypes to animated tutor agents and that their stereotypic expectations affected learning. Earlier, in the studies on gender differences in power and their effect on social influence in the real world, Carli (1999; 2001) found that men are generally perceived to possess higher levels of expert and legitimate power than women are; simply speaking, men are more influential than women. This gender-biased power relationship seemed to be applied to the digital agents, especially by Caucasian females in the current study. This finding seems to bring more questions: Are they more deeply imbued with gender stereotypes, compared to the minority counterparts? And will they need more persistent and proactive interventions to counteract the stereotypes? Subsequent research may further investigate these issues. Overall, both groups of girls significantly improved their math attitudes in a positive direction from pretest to posttest ($p < .05$).

The second and third hypotheses that expected the positive impact of female agents on self-efficacy and perceptions of agent affability were not supported by the results. However, the students perceived the peer-like agents as significantly more affable than the teacher-like agents, confirming the attribute-similarity effect applied to the virtual environment. The fact that the similarity effect applied only to the perceptions of the agents, but not to self-efficacy beliefs might be attributable to the relatively short intervention periods. In the long term, subsequent research is recommended to confirm this finding.

The last hypothesis stated that agent attributes would not influence learning. However, learning was differentiated, depending on the agent attributes. Caucasian females performed better after working with the teacher-like agents, whereas minority females performed better after working with the peer-like agents. Again, the effect of attribute similarities applied only to the minority females.

This finding invites further inquiry about the reasons for the differential effect of attribute similarities on Caucasian and minority females. This inquiry might be about agent/learner relations, but also can be extended to human relations in traditional settings. Researchers in social psychology and communication employ virtual environments with digital characters to study social interaction in the real world (Bailenson & Yee, 2005; Blascovich et al., 2002). In this sense, pedagogical agents can be used as a methodological tool to study human social interaction since instructional designers can easily manipulate agent attributes and functions to serve instructional goals at times when human partners are not available (Kim & Baylor, 2006). That is, the flexibility in manipulating an agent's personal characteristics may allow STEM researchers to use the

agent as a mechanism for developing theories of social dynamics in STEM teaching and learning.

There were some limitations in this study: First, the duration of the study was only two days. It should be determined whether the immediate results endure over time. Second, the minority females were a composite of those from seemingly diverse backgrounds. It was considered that sub-grouping by more specific ethnicities would have a detrimental effect on the statistical rigor, due to the resulting small cell sizes. The results, thus, should be cautiously generalized to any specific minority group. Third, the variations in the four voice actors were not controlled, which might be a confounding factor (Nass & Brave, 2005). These limitations may guide future research, which could be extended to examine long-term effects, focus on specific minority groups, and control for confounding voice effects. In short, much still remains to be learned.

In conclusion, unlike the traditional computer-based math learning, MathGirls was developed to provide social richness for girls learning math at computers. It was expected that, through virtual social relations with pedagogical agents, high-school females, who otherwise lack motivation, might be better motivated toward math learning. With empirical evidence, this study confirmed that the virtual relations between the females and agents played a role for improving affective and cognitive outcomes. In line with the trends in human/computer interaction, the females perceived digital pedagogical agents socially. Given the limitations of the study, however, the findings should be judiciously generalized. Also, further investigation is warranted to better explain the distinct patterns of Caucasian and minority interactions with agents.

REFERENCES

- Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, K. (1995). Cognitive tutors: Lessons learned. *The Journal of the Learning Science*, 4(2), 167-207.
- Anderson, L. W., & Bourke, S. F. (Eds.). (2000). *Assessing affective characteristics in the schools* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.
- Arroyo, I., Beck, J. E., Woolf, B. P., Beal, C. R., & Schultz, K. (2000). Macroadapting animalwatch to gender and cognitive differences with respect to hint interactivity and symbolism. In *Intelligent Tutoring Systems, Proceedings* (Vol. 1839, pp. 574-583).
- Arroyo, I., Murray, T., Woolf, B. P., & Beal, C. R. (2003). *Further results on gender and cognitive differences in help effectiveness*. Paper presented at the International Conference of Artificial Intelligence in Education, Sydney, Australia.
- Atkinson, R. K. (2002). Optimizing learning from examples using animated pedagogical agents. *Journal of Educational Psychology*, 94(2), 416-427.
- Bailenson, J. N., & Yee, N. (2005). Digital Chameleons: Automatic assimilation of nonverbal gestures in immersive virtual environments. *Psychological science*, 16, 814-819.
- Baker, D. (2002). Good intentions: An experiment in middle school single-sex science and mathematics classrooms with high minority enrollment. *Journal of Women and Minorities in Science and Engineering*, 8, 1-23.
- Bandura, A. (1986). *Social foundations of thought and action: A social-cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: W. H. Freeman.
- Bandura, A. (2001, March, 2001). Guide for constructing self-efficacy scales. Retrieved December 25, 2004, from <http://www.emory.edu/EDUCATION/mfp/bgd.html>
- Bandura, A., & Schunk, D. H. (1981). Cultivating competence, self-efficacy, and intrinsic interest through proximal self-motivation. *Journal of Personality and Social Psychology*, 41, 586-598.

- Baylor, A. L., & Kim, Y. (2003). *The role of gender and ethnicity in pedagogical agent perception*. Paper presented at the E-Learn, the Annual Conference of Association for the Advancement of Computing in Education., Phoenix, AZ.
- Baylor, A. L., & Kim, Y. (2004). *Pedagogical agent design: The impact of agent realism, gender, ethnicity, and instructional role*. Paper presented at the Intelligent Tutoring Systems, Maceió, Alagoas, Brazil.
- Baylor, A. L., & Ryu, J. (2003). *The API (Agent Persona Instrument) for assessing pedagogical agent persona*. Paper presented at the International Conference of Ed-Media, Honolulu, Hawaii.
- Blascovich, J., Loomis, J., Beall, A., Swinth, K., Hoyt, C., & Bailenson, J. N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry*, 13, 103-124.
- Brownlow, S., Jacobi, T., & Rogers, M. (2000). Science anxiety as a function of gender and experience. *Sex Roles*, 42, 119-131.
- Burgoon, J. K., Bonito, J. A., Bengtsson, B., Cederberg, C., Lundeberg, M., & Allspach, L. (2000). Interactivity in human-computer interaction: a study of credibility, understanding, and influence. *Computers in Human Behavior*, 16, 553-574.
- Carli, L. L. (1999). Gender, interpersonal power, and social influence. *Journal of Social Issues*, 55(1), 81-99.
- Carli, L. L. (2001). Gender and social influence. *Journal of Social Issues*, 57(4), 725-741.
- Clewell, B. C., & Campbell, P. B. (2002). Taking stock: Where we've been, where we are, where we're going. *Journal of Women and Minorities in Science and Engineering*, 8, 255-584.
- Cooper, J., & Weaver, K. D. (2003). *Gender and Computers: Understanding the Digital Divide*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Dunham, P. H. (1990). Procedures to increase the entry of women in mathematics-related careers (Publication no. ED324195). Retrieved December 7, 2006
<http://ericae.net/edo/ED324195.HTM>
- Ethington, C. A., & Wolfe, L. M. (1988). Women's selection of quantitative undergraduate fields of study: Direct and indirect influences. *American Educational Research Journal*, 25, 157-175.

- Evans, E. M., Schweingruber, H., & Stevenson, H. W. (2002). Gender differences in interest and knowledge acquisition: The United States, Taiwan, and Japan. *Sex Roles*, 47(3-4), 153-167.
- Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention, and behavior: An introduction to theory and research*. Reading, MA: Addison-Wesley.
- Gilligan, C. (1993). *In a different voice: Psychological theory and women's development*. Cambridge, MA: Harvard University Press.
- Hakkarainen, K., & Palonen, T. (2003). Patterns of female and male students' participation in peer interaction in computer-supported learning. *Computers & Education*, 40, 327-342.
- Harmon, S. W. (1996). Novice use of a dimensional scale for the evaluation of the hypermedia user interface: caveat emptor. *Computers in Human Behavior*, 11, 429-437.
- Heyman, G. D., Martyna, B., & Bhatia, S. (2002). Gender and achievement-related beliefs among engineering students. *Journal of Women and Minorities in Science and Engineering*, 8(1).
- Johnson, W. L., Rickel, J. W., & Lester, J. C. (2000). Animated pedagogical agents: face-to-face interaction in interactive learning environments. *International Journal of Artificial Intelligence in Education*, 11, 47-78.
- Jones, S. M., & Dindia, K. (2004). A Meta-analytic perspective on sex equity in the classroom. *Review of Educational Research*, 74(4), 443-471.
- Kim, Y. (2004a). *Learners' expectations on the desirable characteristics of learning companions*. Paper presented at the the Annual Conference of American Educational Research Association, San Diego, CA.
- Kim, Y. (2004b). *Pedagogical agents as learning companions: The effects of agent affect and gender on learning, interest, self-efficacy, and agent persona*. Unpublished doctoral dissertation, Florida State University, Tallahassee, FL.
- Kim, Y. (2005). *Pedagogical agents as learning companions: Building social relations with learners*. Paper presented at the 12th International Conference on Artificial Intelligence in Education, Amsterdam, The Netherlands.

- Kim, Y., & Baylor, A. L. (2006). A social-cognitive framework for designing pedagogical agents as learning companions. *Educational Technology Research & Development*, 54(06), 569-596.
- Kim, Y., & Baylor, A. L. (2007). Pedagogical agents as social models to influence learner attitudes. *Educational Technology*, 47 (01), 23-28.
- Kim, Y., Baylor, A. L., & Shen, E. (2007). Pedagogical agents as learning companions: The impact of agent gender and affect. *Journal of Computer-Assisted Learning* 23 (03), 220-234.
- Lee, E. (2003). Effects of gender of the computer on informational social influence: the moderating role of task type. *International Journal of Human-Computer Studies*, 58, 347-361.
- Lightbody, P., Siann, G., Stocks, R., & Walsh, D. (1996). Motivation and attribution at secondary school: The role of gender. *Educational Studies*, 22(1), 13-25.
- Littleton, K., Light, P., Joiner, R., Messer, D., & Barnes, P. (1998). Gender, task scenarios and children's computer-based problem solving. *Educational Psychology*, 18, 327-340.
- Moreno, K. N., Person, N. K., Adcock, A. B., Eck, R. N. V., Jackson, G. T., & Marineau, J. C. (2002). *Etiquette and Efficacy in Animated pedagogical agents: the role of stereotypes*. Paper presented at the AAAI Symposium on Personalized Agents, Cape Cod, MA.
- Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction*, 19(2), 177-213.
- Muller, C. (2002). *The under-representation of women in engineering and related sciences: Pursuing two complementary paths to parity*. Paper presented at the Paper presented at the National Academies' Government University Industry Research Roundtable Pan-Organizational Summit on the U.S. Science and Engineering Workforce.
- Nass, C., & Brave, S. (2005). *Wired for Speech*. Cambridge, MA: The MIT Press.

- NCTM. (2000, November 15, 2006). Principles and standards for school mathematics.
from <http://standards.nctm.org/document/chapter3/index.htm>
- Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research*, 66(4), 543-578.
- Reeves, B., & Nass, C. (1996). *The Media Equation: How people treat computers, television, and new media like real people and places*. Cambridge, MA: Cambridge University Press.
- Sandler, B. R., Silverberg, L. A., & Hall, R. M. (1996). *The chilly classroom climate: A guide to improve the education of women*. Washington DC: National Association for Women in Education.
- Schunk, D. H. (1987). Peer models and children's behavioral change. *Review of Educational Research*, 57(2), 149-174.
- Schunk, D. H., & Hanson, A. R. (1985). Peer models: influence on children's self-efficacy and achievement. *Journal of Educational Psychology*, 77(3), 313-322.
- Seymour, E., & Hewitt, N. M. (1997). *Talk about leaving: Why undergraduates leave the sciences*. Boulder, CO: Westview Press.
- Slotte, V., Lonka, K., & Lindblom-Ylänne, S. (2001). Study-strategy use in learning from text. Does gender make any difference? *Instructional Science*, 29(3), 255-272.
- Tapia, M., & Marsh, G. E. (2004). An instrument to measure mathematics attitudes. Retrieved December 24, 2004, from <http://www.rapidintellect.com/AEQweb/cho253441.htm>
- Weiner, B. (1992). Motivation. In M. Alkin (Ed.), *Encyclopedia of educational research* (4th ed., pp. 860-865). New York: Macmillan.
- Wood, S. L. (2002). Perspectives of best practices for learning gender-inclusive science: Influences of extracurricular science for gifted girls and electrical engineering for women. *Journal of Women and Minorities in Science and Engineering*, 8(1).
- Zeldin, A. L., & Pajares, F. (2000). Against the odds: Self-efficacy beliefs of women in mathematical, scientific, and technological careers. *American Educational Research Journal*, 37, 215-246.

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Figure 1. Screen excerpts of MathGirls.



Figure 2. Images of four agents in MathGirls

Female peer



Male peer



Female teacher



Male teacher



Figure 3. Minority girls' attitudes by agent attributes

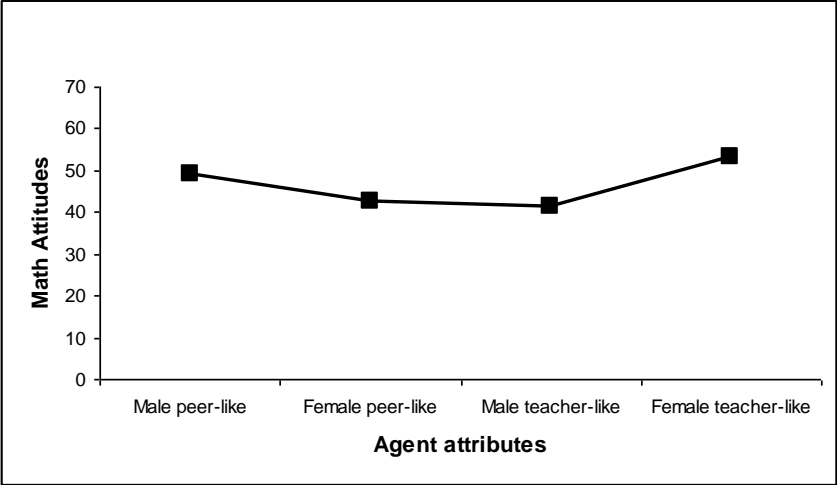


Figure 4. Interaction of agent gender & learner ethnicity for learner attitudes

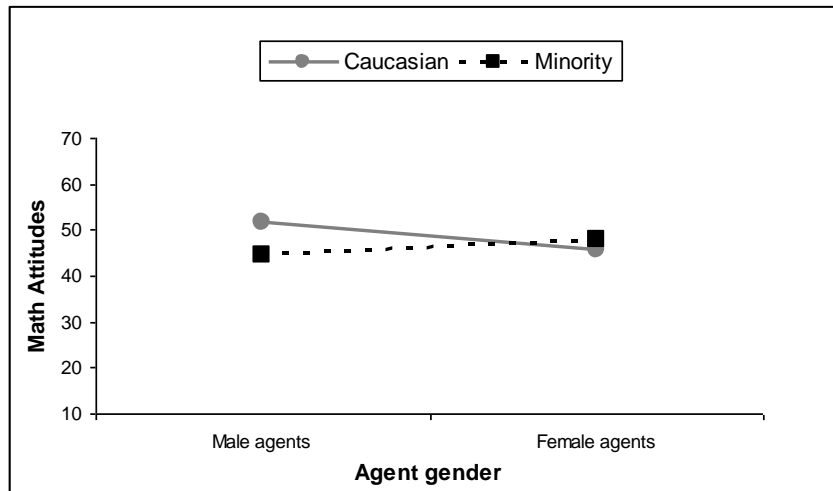


Figure 5. Interaction of agent gender & learner ethnicity for learner attitudes

