

## Creating Pedagogical Agents as Social Models in an Online Learning Environment *MathGirls*

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**Abstract:** This paper introduces the learning environment *MathGirls* for high school girls learning fundamentals of algebra. Grounded in social cognitive theories of learning, MathGirls utilizes pedagogical agents to create a girl-friendly virtual learning environment. The design constituents of pedagogical agents are reviewed. These constituents are likely to influence building agent/learner relations. The agent design and system architecture of the MathGirls environment are developed to integrate some of the design constituents. Empirical findings from MathGirls deployment in classrooms support the efficacy of the presence of pedagogical agents in shaping affective and cognitive characteristics of the learner. The paper concludes with the discussions of future recommendations for the effective design of and research in pedagogical agent systems.

**Keywords.** pedagogical agents, learning companions, social interaction, online learning, motivation, math learning

### 1. Pedagogical Agents can Create Social Contexts for Learning

#### 1.1 Pedagogical Agents

Research has shown that one-to-one tutoring is the most effective and productive educational strategy for reaching individual learners. Bloom [1] defined the two-sigma principle, which stated that “students who receive one-to-one instruction perform two standard deviations better than students who receive traditional classroom instruction.” In other words, the average student who had private tutoring performed as well as the top two percent of those receiving traditional instruction.

However, it may not be affordable for individual learners to have their own tutor [2]. Given the advance in computing technology, we can design efficient learning environments to provide adaptive and individualized aids to a large number of users [9], though how well these environments duplicate one-on-one human tutoring remains an open question. In attempting to address the needs of individual learners, researchers in educational technology have developed adaptive learning environments, that is to say, learning environments that adjust to individual traits and needs of the learner. Although some of these environments, such as intelligent tutoring systems, can adapt to a student’s skill level, they still lack an important factor: the capability of interacting

with learners as human teachers do. Khawaja [3] claimed that intelligent tutoring systems are not “practical enough to be used in the real world,” even though they have been implemented successfully in occasion. The conventional tutoring systems lack rich the social context that might be essential for motivation and learning [4, 5].

To address this limitation, we may adapt software agents to serve as embodied agents in learning environments. A software agent is defined as a “soft robot” that inhabits the computer world [2], and the main reason behind its existence is to simplify and facilitate distributed computing as well as to overcome the limitations of current approaches to user interfaces [4]. According to Kay [2], a user delegates to software agents to perform a certain goal or task taking into consideration the user’s preferences, habits and interests. Table 1 enumerates some characteristics of software agents suggested by Etzioni and Weld [6]:

Table 1. Desirable characteristics of software agents.

Characteristic	Definitions
Adaptivity	The ability to learn and to adjust to the environment
Agency	The ability to understand the user’s needs and goals
Autonomy	The ability to select an appropriate task and make decisions without human intervention
Collaborative behavior	The ability to work in coordination with other agents to achieve a given goal
Inferential capability	The ability to deduce from previous situations and generalize to new ones
Communication ability	The ability to communicate with humans in a high-level language

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Characteristic	Definitions
Personality	The ability to act human or show such human attributes as emotions, gestures, reactions...
Reactivity	The ability to read a changing environment and react to it appropriately

Pedagogical agents derived from software agents can be embedded in educational systems to serve as human-like interface agents. They desirably share the characteristics listed in Table 1 with the broad domain of software or system agents. Kim and Baylor [7] define a pedagogical agent as an animated character that facilitates learning in computer-based environments. Johnson [8] claimed that pedagogical agents can lead to higher learner motivation and engagement through their ability to broaden the communication channels between humans and computer systems. They are characterized by their ability to understand an individual's needs, transforming these needs into their task goals and acting to accomplish these goals. Anthropomorphized pedagogical agents can add social richness to the computer-based learning environment, simulating such human instructional roles as expert, tutor, or learning companion. Pedagogical agents functioning as learning companions have gained attention in the field of educational technology, simulating human/peer interaction in conventional settings. A learning companion looks and acts like a peer and can function as more or less knowledgeable than the learner [9]. A knowledgeable learning companion can serve an advanced peer; a less knowledgeable companion is designed to learn along with the learner.

## 1.2 Effective Design of Pedagogical Agents

To use pedagogical agents effectively in a learning environment, we need to know critical design factors that would affect the efficacy of that environment. Developmental and social psychologists such as Vygotsky, Piaget, and Bandura [10] [11] [12] have theorized that social interaction is a key mechanism in the process of learning and development. Accordingly, pedagogical agents interacting socially with the learner might encourage the learner to engage in the learning task and thus, make the learning environment meaningful and relevant. An important goal of pedagogical agents might be, then, to provide social context for learning, building relations with the learner through social interaction [13]. Referring to social cognitive theories, Kim and Baylor [7] suggest seven design constituents of pedagogical agents (see Table 2): competency, interaction type, gender, affect, ethnicity, multiplicity, and feedback.

To date, some constituents have been studied more or less than the others; still all the constituents are wide open for empirical research. The learning environment *MathGirls* in the following sections was designed to implement some of the design so as to provide social

context for high school girls learning fundamentals of algebra.

Table 2. Design constituents for pedagogical agents.

Constituents	Agent Roles (or Functions)
Competency	Advanced agents: <ul style="list-style-type: none"> <li>• Provide information to advance a learner's knowledge</li> <li>• Provide scaffolding to extend a learner's cognitive range.</li> </ul> Equally capable agents: <ul style="list-style-type: none"> <li>• Bring new ideas to provoke cognitive conflict.</li> <li>• Learn contents along with the learner.</li> <li>• Share power equally to facilitate interaction.</li> </ul>
Interaction type	Responsive agents: <ul style="list-style-type: none"> <li>• Remain less visible or activated, appearing only at learner's request.</li> </ul> Proactive agents: <ul style="list-style-type: none"> <li>• Actively interact with learners to create social contexts for learning</li> </ul>
Gender	Same-gender vs. opposite-gender agents may result in differing modeling effects that will affect motivation and learning.
Affect	Affective agents: <ul style="list-style-type: none"> <li>• Express natural and believable emotions</li> <li>• Recognize the learner's affect</li> <li>• Respond with empathy to the learner's affect.</li> </ul>
Ethnicity	Same-ethnicity vs. opposite-ethnicity agents may result in differing modeling effects that will affect motivation and learning.
Multiplicity	Single agents: <ul style="list-style-type: none"> <li>• Play as a tutor or tutee</li> <li>• Co-learning partner</li> </ul> Multiple agents: <ul style="list-style-type: none"> <li>• Create dynamic social environments</li> <li>• Pool specific knowledge and skills</li> </ul>
Feedback	Informational agents: <ul style="list-style-type: none"> <li>• Provide corrective feedback on the learner's performance</li> <li>• Vary feedback: immediate vs. delayed</li> </ul> Motivational/Persuasive agents: <ul style="list-style-type: none"> <li>• Feed forward to keep the learner moving on</li> </ul>

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## 2. MathGirls: Utilizing Pedagogical Agents to Motivate High School Girls

The learning environment *MathGirls* adopts pedagogical agents to address the social/cognitive dimension of learning in computing environments. The disciplines of science, technology, engineering, and mathematics (STEM) have seen a lack of female involvement [14] [15]. Disproportionately fewer females than males participate in STEM fields. One reason is that social influence (i.e., gender-related stereotypes or role expectations and lack of role models in STEM areas) limits girls' pursuits in those fields [16] [17]. Also, the STEM curriculum content seems to be biased toward male interests [18]. Both claims may call for proactive solutions to enhance females' less-than-desirable perceptions about STEM and to increase their participation in the areas. To meet this end, the project *MathGirls* was initiated. Yet in its present stage of development the environment continues to be improved through research activities. When completed, the MathGirls environment will be open to public, so that any high school students can benefit from the environment in classrooms or at home.

### 2.1 Curriculum and Agent Messages

MathGirls, developed by CREATE ([www.create.usu.edu](http://www.create.usu.edu)), is an online learning environment, which provides high-school students guided by a pedagogical agent the opportunity to learn fundamentals of algebra. Following the US national standards, the curriculum content consists of four lessons covering four topic areas: Real Numbers (Lesson 1), Combining Like Terms (Lesson 2), Factoring (Lesson 3), and Graphing Linear Equations (Lesson 4). Each lesson comprises one web-based module taking about one class period (50 minutes). The lessons are further divided into four or five sections. Figure 1 presents an example screen of MathGirls.

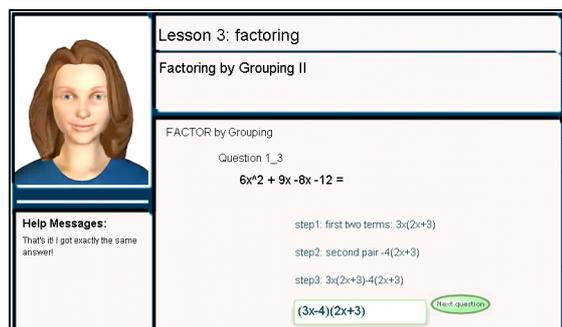


Fig. 1. A sample screen of MathGirls.

Upon log-in, students are led to a lesson. They first listen to a pedagogical agent introducing the topic and explaining key concepts. Then the students are asked to practice algebra problem-solving, receiving context-specific feedback from the agent.

The agent has two roles: to build high-school girls' confidence and positive attitudes towards learning math and to assist their learning. Three types of agent scripts are included: informational, motivational, and persuasive.

*Informational messages* are content-related, including instructions – brief overviews of key concepts that the students have learned – and feedback on the students' performance. *Motivational messages* are praise and encouragement regarding the students' performance. For example, when a student's answer is correct, the agent says "Good job" or "Great, I'm proud of you"; when the student's answer is incorrect, the agent says "Everybody makes mistakes" or "you're almost there; one more thing you need to consider is..." *Persuasive messages* are the statements about the benefits and advantages of doing well in math and of pursuing careers in the area.

### 2.2 Agent Development

Three design constituents were integrated: agent age (teacher-like and peer-like), gender (male and female), and ethnicity (Caucasian and Hispanic). During system development, graphic designers produced several draft paintings in each type, later presented to high school students to choose favorable agent images for the intended types. From the students' choices, 3D agent images were developed using Poser 6 [19] and exported to Mimic Pro [20]. Mimic Pro provides an advanced environment for creating lip synchronization and editing facial expressions and head movements sequences.

Given the superior impact of human voices over synthesized ones, the agents' scripts were recorded by voice actors matched with the agents' age, gender, and ethnicity. The agents' talking styles and accents were matched with their appearances as well. For example, to develop the Hispanic peer-like male agent, the voice of Hispanic boy with a Hispanic accent was recorded. The images and recorded voices were integrated within Mimic Pro for lip synchronization. Facial expressions, eye-blinking, and head movements were also added to make the agents more natural. The characters were brought back to Poser 6 and refined with some more realistic effects, e.g., lighting and posing. Finally, the animated characters were rendered in Poser to produce AVI files, which were later batch-compressed to Flash files, using Sorenson Squeeze for web casting. Figure 2 shows the agent development process in sequence.

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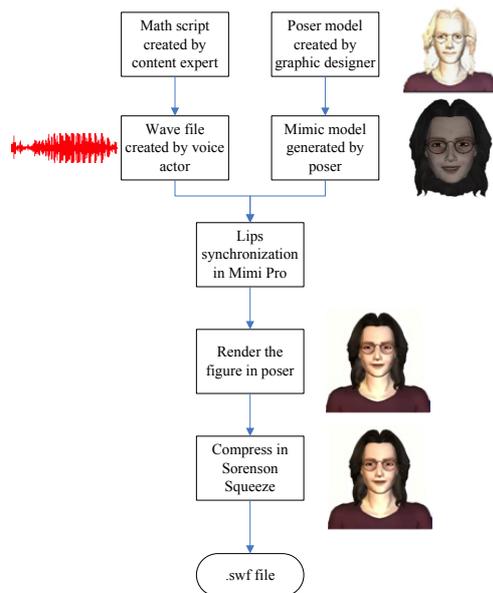


Fig. 2. Agent character development process.

## 2.3 System Development

### 2.3.1 Three-Tier Architecture of MathGirls

The application system was designed based on a three-tier architecture 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. Based on this requirement, MathGirls adopted a three-layer topology.

Macromedia Flash was chosen as a suitable platform for designing colorful and interactive interfaces. Flash coding controlled the application flow, for example, when a student should move to the next instructional screen or when an agent should pop up and interact with the student. To use this application the student needed only an Internet browser with Flash Player.

ColdFusion, the middle layer in this topology, was used for connecting Flash frames to dynamic instruction content. ColdFusion coding offered a tight interaction with the database. It read educational resources such as instructions, math problems, and attitude questions, meanwhile, recording onto the database all pertinent information, such as a student's name, grade, agent type, and performances.

MySQL was used as the back end database server. Curriculum developers were easily able to use any standard database browser, e.g., SQLyog or MySQL, to update relevant instructional content. Meanwhile, graphic designers could produce as many agent videos as necessary and upload to the ColdFusion server using any standard FTP client software. Figure 3 depicts the three-layer topology.

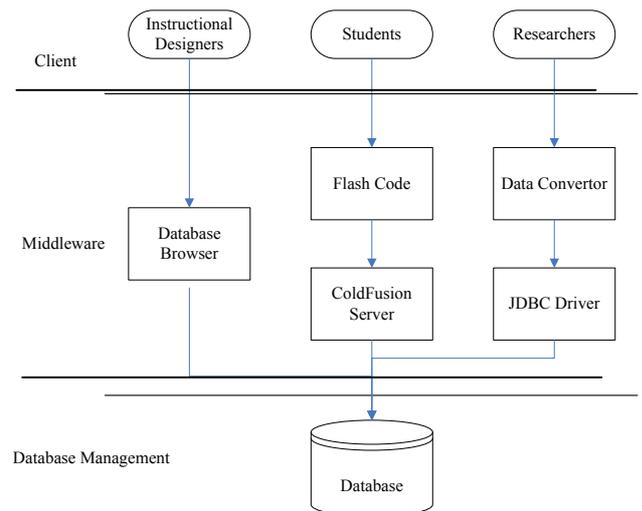


Fig. 3. Three-Tier architecture of MathGirls.

### 2.3.2 Database Design

To conform to Boyce-Codd normal form [21], students' data were stored in three different database tables, holding demographic information, agent information, and math performance and survey separately. To make data analysis handy, records in the database were converted by a data-converting module, with the help of MySQL JDBC driver [22]. Thus, records from different database tables could be retrieved and written onto the same row of an Excel document.

### 2.3.3 String Parser Design

In MathGirls, math problems are presented in an open-ended format. This required that the system recognize equivalent variations of a student's input. For instance,  $x(x+3)+4(x+3)$ ,  $4(3+x)+(x+3)$ , and  $(x+3)x+4(x+3)$  should be all treated in the same way although their format is different. Since it was impossible to keep all possible students' responses in the database, the system used a parser module, written in Java Beans, to evaluate whether the student's input matched any specific entry kept in the database. To develop feedback for open-ended questions, possible wrong answers commonly occurring in classrooms were identified by math teachers and later categorized by error types. Thus, the basic mechanism of the module is as follows: two strings (one provided by the student, the other from the database) are split into conjuncts and disjuncts. Then those two strings are compacted and compared, returning a true value if they bear the same mathematical meaning, a false value otherwise.

## 2.4 Agent Competency

A study conducted by Kim and Baylor [9] revealed a positive influence of low-competent peer-like agents on college students' self-efficacy beliefs in learning. In the study, freshmen and sophomore males and females showed significant higher self-efficacy in the task of instructional design after working with a low-competent peer agent than after working with a high-competent one. The agents in the study were pre-scripted and not adaptive.

In a real situation, however, it is natural that the learner's ability should change as he/she interacts with other participants. Advanced system functionality is required to achieve such type of interaction.

In MathGirls, agent competency is dynamic, adopting the concept of a learning companion who would build content knowledge as a student makes progress. The current level of companion competency is determined by the status of the student's problem-solving capability. The student's input of a correct answer contributes to the increase of the companion's competency level; continuous error-making decreases the companion's competency. Next, the companion's current level of competency determines what type of feedback the companion should provide. Each math problem is designed to determine competency level, the amount of knowledge the student should have mastered in order to solve that particular problem. Since the companion's competency reflects the student's math capability, when the student's capability doesn't meet the predefined difficulty level of a math problem, the system presents a companion with lower competency; otherwise a companion of higher competency shows up. The flow chart in Figure 4 presents the flow of agent competency.

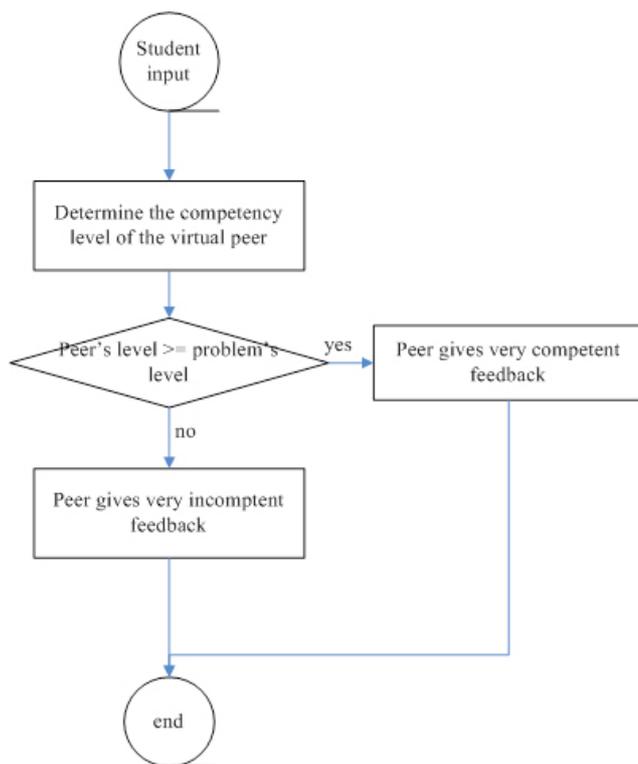


Fig. 4. Competency design.

## 2.4 Research Findings

In the process of developing MathGirls, the authors have been investigating the impact of the design constituents of the agents on high-school girls' social judgments of the agents' personas, the girls' attitudes towards math learning, and their self-efficacy beliefs in math learning. In general, the findings supported the instructional efficacy of the agents serving as role models for the high school girls in the studies.

### 2.4.1 Agent Age and Gender

An experiment was conducted to examine the impact of agent age (teacher-like vs. peer-like) and agent gender (male vs. female) on students' choice of an agent and their attitude, self-efficacy, and learning [23]. The participants were 83 girls in required algebra classes in two high schools in the US. The findings are summarized as follows:

- (i) A total of 80% of the high-school girls in the study chose *female* agents as their learning partners.
- (ii) The students perceived the *peer-like* agents to be significantly more affable than the teacher-like agents.
- (iii) All the students who worked with an agent, regardless of agent age and gender, significantly increased their positive math attitudes and their math self-efficacy from pretest to posttest whereas the students who received text messages without an agent did not show any significant increase.
- (iv) Regardless of agent conditions, the students showed significant increases, from pretest to posttest, in their learning.

### 2.4.2 Agent Ethnicity

In another study, the interaction impact of agent/student ethnicity was investigated using four agents: Caucasian versus Hispanic and male versus female [24]. Participants were 132 high school girls from the same region as in the agent age and gender study. The approximate ethnic composition of the participants, as self-reported, was Caucasian (36.7%), Hispanic (38.7%), and others (24.6%). For data analysis, only the Caucasian and Hispanic students were included.

- (i) 80% of the Caucasian female students chose the Caucasian agent whereas 95% of Hispanic female students chose the Hispanic peer agent.
- (ii) All the girls significantly increased their math self-efficacy from pretest to posttest after working with an agent. The degree of the increase, however, significantly varied by agent ethnicity, where the girls who worked with the Hispanic agent showed a higher increase than did the girls with the Caucasian agent.
- (iii) Regardless of the agent conditions, the students showed significant increase in their learning from pretest to posttest.

Overall, empirical studies supported the efficacy of the MathGirls environment for learner affect and cognition.

## 2.5 Limitations

Despite the positive impact of the MathGirls environment, the authors recognize some limitations. First of all, the effective computer-based environment should provide adaptive and individualized aids to a variety of learners [9]. The math problems and instructional sequence in MathGirls are both predetermined, unable to adapt to each students' needs. In the future, the adaptability of the system will be improved, adjusting the difficulty of math

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problems according to a student's ability level. This way the environment can challenge advanced students with difficult problems and, at the same time, care for slow students.

Second, the agents in MathGirls have only the heads and shoulders, to highlight vivid facial expressions. However, it is possible for the agents to be viewed merely as talking heads. To make the agents more natural and human-like, the MathGirls team would like to develop full-body agents or, at least, agents with full upper bodies, like Adele, developed at CARTE [25], able to show hand gestures.

### 3. Future Directions

#### 3.1 Emotional Agents

Research on human emotion indicates that students in classrooms place value on having teachers with positive affect [26]. Kim and colleagues [27] show that college students perceive a pedagogical agent that expresses positive emotions as more engaging and facilitating to their learning. Also, the emotions of an agent are considered critical to believability and naturalness [28]. Equipped with emotional capabilities, a pedagogical agent might be able to appear socially intelligent and to build empathetic relations with a learner.

In the coming year, MathGirls is extended to integrate affective functions to elicit learners' positive affect for learning. That is, an agent will express its emotions to build affective relations with the learner, which might help create a friendlier learning environment for the target audience.

#### 3.2 Data Mining

In the past decade, the issue of data mining has interested researchers in educational technology. Data mining helps build new knowledge by gleaning information from students' action data. To obtain meaningful information, instructional developers utilize adaptive web-based educational systems [29] [30] [31]. Two typical uses are categorizing students [29] and mining association rules [31] [30]. In many instructional situations, it may not be possible to understand each learner in advance, so researchers set criteria for categorizing learners according to their navigation behaviors and their learning performances. Mining association rules study dynamic browsing structures and student performances to detect meaningful patterns. Both techniques can be useful in designing personalized pedagogical agents for individual learners. Using the data mining techniques, we can gather information about new students in order to provide an appropriate treatment in real time.

#### 3.3 Learner Characteristics

##### 3.3.1 Individual Differences

Many researchers have tried to assess individual differences in learning through a variety of interventions [32] [33]. One of the best known assessment interventions

is aptitude-treatment interactions (ATI) [34]. Aptitude refers to any characteristic of a person that affects his/her response to any given treatment. Fundamentally, ATI states that researchers in applied psychology should deal with treatments and persons simultaneously because instructional treatments may either facilitate or inhibit learning, according to the type of learner. Another emerged concept in individual differences is learning orientation [35] [36] [37]. Considering both cognitive and emotional factors, the concept distinguishes four types of learners: 1), transforming, 2), performing, 3), conforming, and 4), resistant. A transformer is "highly self-motivated ... [and] uses exploratory learning to transform to high personal standards ...[and] experiences frustration if restricted or given little learning autonomy" [36]. In contrast, a conformer "assumes little responsibility, manages learning as little as possible, is compliant, wants continual guidance, and expects reinforcement for achieving short-term goals" [36]. A performer is something in the middle. A resistant learner "sets personal goals that avoid meeting formal learning requirements or expectations" [36].

In classroom settings, expert teachers may attempt to take care of individual's learning styles, which often is possible only in small-group tutoring. Given the advances in computer technology, computer-based learning environments may offer equivalent care and support. The strength of e-learning might be the capability to provide individualized experiences, addressing learner difference [38]. If a pedagogical agent plays the role of a mediator broadening the communication channels between humans and computer systems [8], the agent should be more capable of understanding and accommodating an individual's needs. Equipped with such capability, a pedagogical agent system can be utilized more fruitfully. Research on the effectiveness of agent systems may extend to investigating the interaction between individual differences and agent systems.

##### 3.3.2 Possible Research Directions

Given the large variety of individual learner traits, it would be too challenging to customize an individual instructional treatment for each learner. But we can introduce some key learner traits, more frequently studied or highly related to pedagogical agent systems, as below:

- (i) Findings from the MathGirls project showed a consistent pattern that the girls identified as less sociable increased their math self-efficacy significantly whereas the girls identified as high sociable decreased their self-efficacy [39]. This trend leads to a new line of inquiry: Why was the trend so? How can we effectively differentiate the use of pedagogical agents for both high- and low-social girls? How can we create agent/learner interaction to be more natural?
- (ii) Some research [40] [41] investigated instructional design methods in terms of different media, e.g., on-screen text only vs. video only vs. both., along with learning styles, e.g., visualizer vs. verbalizer. For a pedagogical agent, should a system introduce redundant texts while the agent is talking? Would it

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make any difference in terms of learning styles?

- (iii) Learning orientation studies indicate that the same version of instruction may not interest both transformers and conformers. If so, when is the right time to use a proactive agent or a responsive one? What is the optimal length of agent message between presenting onscreen information?
- (iv) Different age groups might have different expectations on a virtual peer, cartoon-like or human-like, mentor or co-learner, for instance. To date, we do not understand which type is preferred by young learners and which by adult learners. It will be interesting to find out preferred agent appearances for learners of various ages.

### 3.4 Competition and Collaboration

An engaging element of computer games is competing with peers. One way to integrate this concept into agent systems is to design a virtual peer as a competitive co-learner or as a mediator when a learner competes with another learner via an instructional system. Imagine such a scenario: in a small study room, two learners are working together, sometimes competing with each other and sometimes collaborating. Once in a while, they may need to turn for help to somebody more advanced. In real life, this advanced other might not be available all the time. In computing environments, a pedagogical agent could play the role, accomplished by integrating the techniques used in multi-players gaming into pedagogical-agent-based systems.

In conclusion, the authors, grounded in social cognitive theories of learning, introduced MathGirls systems to illustrate the instructional use of pedagogical agents playing social roles to render social context to online learning environments. The empirical findings supported the instructional efficacy of pedagogical agents in creating virtual affable learning environments favoring high school girls. MathGirls, still in its infancy, will continue to be refined through empirical research.

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