A Social-Cognitive Framework for Pedagogical Agents as Learning Companions

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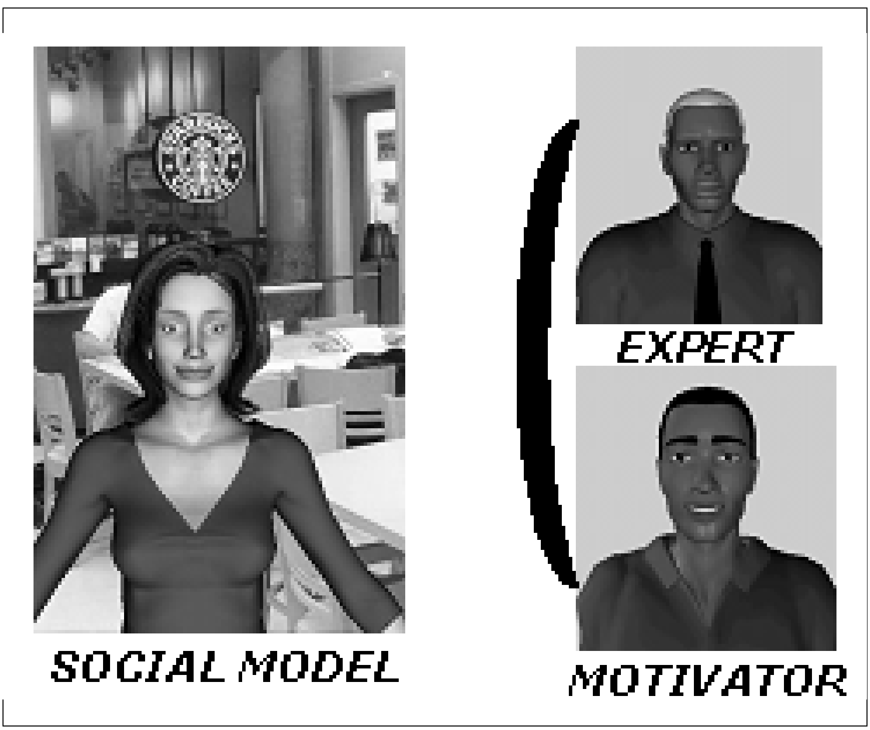
Teaching and learning are highly social activities. Seminal psychologists such as Vygotsky, Piaget, and Bandura have theorized that social interaction is a key mechanism in the process of learning and development. In particular, the benefits of peer interaction for learning and motivation in classrooms have been broadly demonstrated through empirical studies. Hence, it would be valuable if computer-based environments could support a mechanism for a peer interaction. Though no claim of peer equivalence is made, pedagogical agents as learning companions (PALs)—animated digital characters functioning to simulate human-peer-like interaction—might provide an opportunity to simulate such social interaction in computer-based learning. In this article we ground the instructional potential of PALs in several social-cognitive theories, including distributed cognition, social interaction, and Bandura's social-cognitive theory. We discuss how specific concepts of the theories might support various instructional functions of PALs, acknowledging concepts that PALs cannot address. Based on the theoretical perspectives, we suggest key constituents for designing PALs that in human-peer interactions have proven significant. Finally, we review the current status of PAL research with respect to these constituents and suggest where further empirical research is necessary.

Keywords: pedagogical agents, learning companions, social interaction, computer-based learning environment, advanced technology for learning

☐ Advances in computer and communication technology are providing opportunities to augment human cognition, interaction, and even social relations. In particular, pedagogical agents can be designed to simulate social interaction that may facilitate learners to engage in the learning task and consequently to enhance learning in computer-based environments. Pedagogical agents are animated life-like characters (Johnson, Richel, & Lester, 2000) embedded in instructional applications. What makes pedagogical agents unique from conventional computer-based environments is their ability to simulate social interaction. In pedagogical-agent–based environments, a learner grasps instructional content while interacting with one or more pedagogical agents programmed to provide information and/or encouragement, to share menial tasks, or to collaborate with the learner. Some studies indicated the positive instructional impact of pedagogical agents on cognitive and motivational outcomes (Atkinson, 2002; Kim, 2004, 2005b; Moreno, Mayer, Spires, & Lester, 2001). Figure 1 displays the motivator-expert combination of agents that jointly enhanced learning (Baylor & Kim, 2003) and Nina, an agent that served as a social model to influence student attitudes toward engineering (Baylor & Plant, 2005).

Figure 1 □ Nina and Motivator—Expert agents.



Pedagogical agents may help overcome some constraints of and expand functionalities of conventional computer-based environments. Traditionally, computer-based learning environments (e.g., intelligent tutoring systems) have been tailored to meet a student's individual needs, supporting each learner independently when the environments were well designed (Aimeur & Frasson, 1996; Anderson, Corbett, Koedinger, & Pelletier, 1995; Gertner & VanLehn, 2000; Graesser, VanLehn, Rose, Jordan, & Harter, 2001). However, those learning environments typically failed to provide situated social interaction, which is regarded as a significant influence on both learning and motivation (Lave & Wenger, 2001; Palincsar & Brown, 1984; Powell, Aeby, & Carpenter-Aeby, 2003; Vygotsky, Cole, John-Steiner, Scribner, & Souberman, 1978; Wertsch, Minick, & Arns, 1984). With the advances of technology, pedagogical agents can be designed to support the social-cognitive aspect of learning in computer-based environments, playing well-defined instructional roles, following specified social conventions, and even responding to learners with apparent empathy (Hays-Roth & Doyle, 1998). As Reeves and Nass (1996) concluded from more than 10 years of studies, people may apply the same social rules and expectations to computers as they do to humans in the real world. Thus, the simulated social presence of pedagogical agents in computing environments may provide learners with a sense of companionship and so make working in the computer-based environment relevant and/or meaningful (Biswas, Schwartz, & Bransford, 2001).

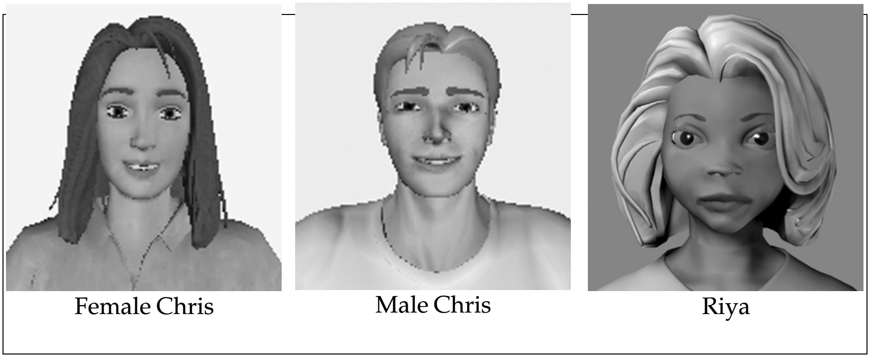
In general, it is recommended that a pedagogical agent should have a human-like persona to better simulate social contexts and to promote learner-agent interaction (Erickson, 1997; Koda & Maes, 1996; Laurel, 1990; Lester et al., 1997; Mulken, Andre, & Muller, 1998; Takeuchi & Naito, 1995; Walker, Sproull, & Subramani, 1994). Likewise, pedagogical agents as simulated beings are frequently designed to represent different human instructional roles, such as *expert* (Johnson et al., 2000), *tutor* (Graesser, Moreno, & Marineau, 2003), *mentor* (Baylor & Kim, 2005), and *learning companion* (Chan & Baskin, 1990; Dillenbourg & Self, 1992; Goodman, Soller, Linton, & Gaimari, 1998; Hietala & Niemirepo, 1998a; Kim, 2003b; Uresti, 2000). For example, the agents, Steve and Adele, developed by Johnson and colleagues (2000), represent experts for naval engineering and medical diagnosis. These agents observe learner performance to provide adaptive feedback and demonstrate expertise in the domain. Similarly, AutoTutor (Graesser et al., 2003) is designed to engage learners in a dialogue to highlight their misconceptions and to encourage deeper reasoning. Baylor and Kim (2005) effectively simulated agents as an expert, a motivator, and a mentor serving distinct instructional functions: the expert provided the learner with relevant information in a professional manner; the motivator provided verbal persuasion and encouragement, emphasizing affective affiliation with the learner; and the mentor incorporated both qualities to simulate an ideal instructor. In contrast to those agent roles, pedagogical agents as learning companions (PALs) adopt a peer metaphor, where the agent's function is to learn *with* the learner and act as a simulated peer. The following section discusses the potential benefits of employing the peer metaphor for designing pedagogical agents.

PALs

The value of human-peer interaction for learning and motivation has been emphasized at least since Bell and Lancaster initiated the systematic implementation of peer-mediated learning in the late 18th century (Chiplin-Williams, 1997). A number of peer-mediated interventions implemented in small- or large-scale studies demonstrate empirical evidence that peer partners are often more effective than adult partners for learning and motivation in various subject areas and across age groups (Griffin & Griffin, 1998; King, 1998; Rowell, 2002; Topping et al., 1997; Yarrow & Topping, 2001).

The benefit of peer interaction is also supported by theories of social cognition and learning. According to Bandura (1997), a great deal of psychological modeling occurs when learners observe behaviors of their everyday associates. When learners are exposed differentially to skilled human peers or to adults performing the same cognitive skills, they derive a stronger sense of personal efficacy from the peers. Further, social interaction with equally able peers fosters cognitive restructuring and promotes cognitive growth (Piaget, 1995), in that intellectual development, thinking, and affect are closely tied with the cooperation of equal partners (Matusov & Hayes, 2000) and peer interaction can provide a free and open forum to facilitate a more active and productive exchange of ideas (Driscoll, 2000). Clearly, interactions with actual peers are the ideal. However, human-peer–based interventions are not always feasible or successful in implementation, for logistical and political reasons, for example, matching optimal peers, coordinating schedules, and avoiding off-task distractions (Kim, 2004; King, 1998). Though they are clearly not equivalent to human peers, PALs—computerized virtual peers—may be able to simulate peer interaction in computer-based environments, as demonstrated in some studies (Biswas et al., 2001; Brophy, Biswas, Katzlberger, Bransford, & Schwartz, 1999; Ryokai, Vaucelle, & Cassell, 2003). Figure 2 shows examples of such PALs used in previous studies (Kim, 2004, 2005b): male and female Chris for college students and Riya for elementary school girls. Although the current technology cannot now—and likely will never—duplicate all aspects of human peer interaction in PAL-learner interaction, it is

Figure 2 □ Examples of pedagogical agents as learning companions (PALs).



worth noting that the learners in the studies reacted socially to the PALs and perceived the PALs as being more functional and more intelligent than they actually were.

From a researcher's point of view, PALs can also be used as a methodological tool to study human-peer interaction because instructional designers can easily manipulate PAL characteristics and functions to serve instructional goals at times when human peers are not available. That approach is not new in the fields of social psychology and communication. Researchers in those areas have already begun to employ virtual environments with digital characters to study social interaction in the real world (Bailenson & Yee, in press; Blascovich et al., 2002). They use computer capabilities to archive detailed records of all verbal and nonverbal behavior of users and to regulate the frequency, thoroughness, and intensity of the behavior of the virtual characters. Similarly, the flexibility in manipulating PAL characteristics may allow instructional designers and educational researchers to use the PAL as a mechanism for theory development. For instance, to support learning in context, PALs could be designed as peer tutors or peer tutees with varying levels of competency (Chan & Chou, 1997; Kim, 2003a). The gender or ethnicity of PALs can be matched with that of learner to facilitate collaboration, resulting in enhanced modeling effects (Baylor & Kim, 2004; Cooper & Weaver, 2003). Or the number of PALs can be adjusted to optimize collaboration (Hietala & Niemirepo, 1998b; White, Shimoda, & Fredericksen, 2000).

Although the popularity of PAL applications in computing environments has been increasing both in academia and in business, there is limited empirical research regarding their efficacy. Furthermore, the theoretical foundation for the application and design of PALs has not yet been built. Hence, the remainder of this article will ground the instructional application of PALs in a social-cognitive framework, will discuss critical constituents for designing PALs, and will review the current status of findings from PAL research with respect to these constituents.

A SOCIAL-COGNITIVE FRAMEWORK

Social-cognitive theories emphasize that teaching and learning are highly social activities and that interactions with teachers, peers, and instructional materials influence the cognitive and affective development of learners. When individuals perform intellectual activities, they dynamically interact with other participants, tools, and contexts, which could support improved performance and/or frame individual cognition and intellect. Therefore, interventions failing to address the social-cognitive dimension of learning and intelligence might not accomplish their goals (Perkins, 2001). It is warranted, then, that computer-based environments should be designed to afford this social-cognitive dimension. This section examines how social-cognitive perspectives might serve as a theoretical framework for and a guide to the optimal design of PALs. Three social-cognitive theories are reviewed here: (a) distributed cognition, (b) social interaction as addressed in the work of Piaget and Vygotsky, and (c) Bandura's social-cognitive theory. Given the three theoretical perspectives, the varying instructional functions of PALs are suggested in light of each.

Distributed Cognition

Human cognition is distributed among individuals and across tools and symbols in a society (Hewitt & Scardamalia, 1998; King, 1998; Pea, 2001; Perkins, 2001; Salomon, 1988, 1989, 1990, 2001; Salomon & Almog, 1998). Traditionally, it is presumed that cognition exists inside an individual's mind and that the cognitive process occurs internally. Recently, however, a number of researchers have suggested that the human mind rarely works in solo; instead, it is shaped in social contexts while the individual is communicating within physical and social surroundings. In their daily surroundings it is not difficult to see that such artifacts as letters on a keyboard, a shopping list, graphs and diagrams, and calculators help individuals better perform cognitive activities and expand their cognitive capabilities. One's cognition also evolves through discourse with others. In effective conversation, one makes a statement based on the previous utterance of one's interlocutor.

According to this line of thought, PALs could be designed to share learners' cognition and flexibly function as artifacts (*cognitive tools*) or collaborating partners (*social tools*). PALs as cognitive tools could scaffold learner performance, where PALs were equipped with knowledge and skills that learners would not have, or could perform simple and mechanical tasks to preserve the cognitive capabilities of the learner for higher mental activities. PALs could learn with the learner and/or take turns generating ideas. The presence of PALs on the screen and their responsiveness to the learner's behavior could also provide social contexts (PALs as social tools), in which learners could build social relations with the PALs (Ruttkay & Pelachaud, 2004; Suzuki, Takechi, Ishii, & Okada, 2003). In either or both ways, PALs could play a role of coworking partners, building intellectual partnership for enhanced learning in computer-based environments.

Researchers in distributed cognition, however, vary in their interpretations—some focusing more on individuals and others on contexts. According to Perkins (2001), individuals and their surroundings are compound systems of thinking and learning (*person-plus*). But there is still higher-order knowledge, in individuals' minds, that cannot be distributed. Thus, for Perkins, there is an asymmetry in distributed cognition and, possibly, in the relationship between a learner and a PAL. In this perspective, a learner could be expected to play a more active role in performing learning tasks than would a PAL. However, others, for example, Lave and Wenger (2001), argued that cognition spreads over minds, artifacts, social processes, and cultural factors, comprising an interdependent and inseparable system of cognition (sociocultural cognition). Learning and thinking take place during communication with others in a social context. The dynamic nature of the cognitive process is emphasized. In this perspective, a PAL could be viewed as creating a more interactive social environment and making learning part of a social process (Biswas et al., 2001). The perspective one takes determines the composition of learner-PAL relationships. That is, the perspective centering on person-plus argues for an intervention emphasizing the learner's actions and responsibility. A PAL could be activat

Lastly, Salomon (1990) argued for two types of cognitive effects that children could attain in computer-mediated learning. *Effects of technology* are the cognitive skills resulting from the use of technology. PALs can be equipped with information and designed to demonstrate skills so that a learner can master the information and those skills at the end of the lesson. On the other hand, working at computers, learners employ unique mental operations that they could not carry out otherwise. *Effects with technology* are cognitive changes derived from working with computer software itself. Similarly, interaction with a PAL could have a unique impact on the learner's cognition, subsequently producing a unique intellectual partnership between them. Table 1 illustrates the key concepts of distributed cognition and the functions of PALs suggested by the concepts.

Table 1 ☐ Concepts of distributed cognition and functions of pedagogical agents as learning companions (PALs).

Concepts	*Functions of PALs*
Person-plus cognition	Remain less visible or activated only on learners' requests.
Sociocultural cognition	Actively interact with learners to create social contexts for learning.
Effect of technology	Facilitate the acquisition of knowledge and skills.
Effect with technology	Function as intellectual partners to collaborate and make learning a social process

Social Interaction

Learning is a social process. Intellectual development is achieved when learners are involved in learning activities in which they interact with others (Vygotsky et al., 1978). Learners come to understand phenomena through negotiating meanings with people in the environment, and they achieve goals through interacting, both explicitly and implicitly, with the instructor, peers, materials, and atmosphere embedded in the context. Unlike traditional computer-based learning, which seemingly was limited to knowledge and skill acquisition, PALs as simulated peers could simulate a type of social interaction, making computer-based learning more meaningful. The theoretical concepts illustrated below stress the importance of social interaction for intellectual development, from which we draw implications for designing PALs that are educationally effective and appealing.

Cognitive Conflict and Equal Power Relations

Neo-Piagetian psychologists have argued that Piaget's theory is "fundamentally social" (Bickhard, 2004; Carpendale & Muller, 2004). In Piaget's theory, cooperation and free discussion play an essential role in acquiring and constructing knowledge because they establish the most favorable conditions for counteracting an individual's egocentrism. In particular, Piaget acknowledged the value of peer interaction in terms of equal power relations and cognitive conflicts (Tudge & Winterhoff, 1993). He argued that high-level development in thinking and affect is not possible without the cooperation of equal partners (Matusov & Hayes, 2000). This is because equal power relations among peers allow learners to actively take different perspectives. By examining the perspectives of peers, learners can progress to and reflect on their own ideas and coordinate actions and perspectives to resolve contradictions among the different perspectives, which Piaget referred to as *sociocognitive conflict*. Clearly, PAL-learner interaction is equivalent towith human-peer interaction. Even so, PALs designed not necessarily to command advanced knowledge but to bring forth different perspectives could serve to instigate learners' cognitive conflict in computer-based environments. This kind of use of equally or less competent peers has been subject to experimentation in both classrooms and tutoring systems, where students learned by teaching their peers or the system (Chan, 1996; Gartner, Kohler, & Riessman, 1971; Goodlad & Hirst, 1989).

The Zone of Proximal Development and Scaffolding

Vygotsky's (Vygotsky et al., 1978) concept of the zone of proximal development (ZPD) is at the center of learning and developmental processes. ZPD, the distance between a learner's actual development and his or her potential development assisted by others, defines developmental functions that have not yet matured but are in the process of maturation. In collaboration with more capable others, learners can grow intellectually beyond the current limit of their capabilities. Along this line, a PAL might be designed to be in a higher intellectual stage than that of the learner, to provide a scaffolding to advance the learner's knowledge. Effectively designed PALs could simulate the five characteristics of scaffolding suggested by Greenfield (1984): (a) serving to provide supports; (b) functioning as tools by sharing learning tasks; (c) extending the cognitive ranges of learners; (d) allowing the learners to accomplish tasks not possible otherwise; and (e) being used selectively to aid the learners when needed.

Empathetic Relations

Affective experience is a natural process of learning (Damasio, 1994; Forgas, 2001). When interacting with environments, a learner may experience a variety of emotional states, such as interest, curiosity, excitement, confusion, frustration, and discouragement (Kort, Reilly, & Picard, 2001), all of which might influence learning and motivation. For instance, Bower and Forgas (2001) found that emotions and moods had an impact on social memories and their reconstruction: when learners' moods in learning tasks were matched with their moods in retrieval, the amount of retrieved information was significantly increased (*mood congruency*). Ellis, Ottaway, Varner, Becker, and Moore (1997) showed that the affective states of college students influenced their text comprehension. Meyer and Turner (2002) reported that students of a negatively affective instructor experienced negative affect and handicapped themselves significantly more than did students of a positively affective instructor.

Given the implications from the classroom-based emotion research, a PAL could be designed to address a learner's emotional states and subsequently build empathetic relations with the learner (Dautenhahn, Bond, Canamero, & Edmonds, 2002). More specifically, a PAL could express its own emotions and respond to learners' emotions in order to elicit a learner's positive emotions and to diminish negative emotions in learning contexts (Picard, 1997). Also, an important mechanism of emotional development of children through adolescence is socialization by peers (Asher, Parker, & Walker, 1996). Friends are likely to disclose to each other the emotional understandings and experiences they may hide from others (e.g., adults), helping each other acquire emotional competencies. Simulating a human peer, a PAL can be equipped with a variety of emotional expressions and reactions designed to help a learner's emotional development (Denham & Kochanoff, 2002). The inclusion of affect has been shown to make the PAL more believable and natural (Bates, 1994) and, subsequently, may help establish social bonds between the learner and the PAL. Table 2 summarizes the key concepts of social interaction and different functions of PALs suggested by the concepts.

Social-Cognitive Theory

Social cognitive theory (Bandura, 1986, 1989, 1999, 2001, 2002) uses the concept of human agency to explain human functioning in the world. (*Agency* or *being an agent* in the theory means that people intentionally make things happen by their action. Hence, *agent* should be distinguished from its use in pedagogical agents or PALs.) Social cognitive theory recognizes three modes of human

Table 2 ☐ Concepts of social interaction and functions of pedagogical agents as learning companions (PALs).

Concepts	*Functions*
Cognitive conflict Equal power relations	Co-learning virtual peers Bring new ideas to provoke cognitive conflict. Learn contents along with the learner. Share equal power relations to facilitate interaction.
ZPD Scaffolding	Advanced virtual peers Provide information to advance a learner's knowledge. Provide scaffolding to extend a learner's cognitive range.
Empathetic relations	Affective virtual peers Express emotions to be natural and believable. Respond with empathy to a learner's emotions.

agency: (a) personal, (b) proxy, and (c) collective. These modes can be related to learning concepts frequently referred toin educational research: personal agency to learner control; proxy agency to social modeling; and collective agency to collaboration.

Personal Agency: Learner Control

The concept of personal agency emphasizes learners' control over and self-regulation of their learning tasks. According to Bandura (2001), the essential capacity of humanness is to exercise control over the nature and quality of one's life. Through the exercise of personal agency, people can enhance their efficacy beliefs. With their own intention, learners may want to plan, select, motivate, regulate, and evaluate cognitive activities. Personal agency could also be consistently applied to computing environments. As in conventional computer-based environments indicating the positive motivational impact of learner control (Large, 1996), learners may increase self-efficacy beliefs when they initiate interaction and make decisions with less direction or control by PALs. To this end a PAL could be designed as a responsive partner, one that does not direct but rather responds to the learner's requests. This way the learner could exercise personal agency and, consequently, increase self-efficacy beliefs in the task. Of course, this presumed benefit of learner control appears to work with learner characteristics in traditional computer-based learning as well (Arnone, Grabowski, & Rynd, 1994; Large, 1996; Ross, Morrison, & O'dell, 1989); thus, a designer should include such learner characteristics as competency, age, learning styles, and so forth in determining the optimal design of PAL-learner interaction.

Proxy Agency: Social Modeling

Proxy agency is socially mediated agency, which enables people to get resources or expertise of others to accomplish what they desire. People's appraisals of their own efficacy are influenced through vicarious experience mediated through social models (Bandura, 1997). Learners actively search for competent models and take advantage of time, efforts, and resources of social models that will transmit the knowledge, skills, and strategies they seek. Recently, human-computer interaction research has indicated the potential of virtual characters (e.g., pedagogical agents) functioning as social models. Learners have seemed to consider the characters to be social entities. For instance, college students applied politeness norms (Mayer, Johnson, Shaw, & Sandhu, 2005), notions of self and other, and gender stereotypes while interacting with computers (Reeves & Nass, 1996). Thus, a PAL that successfully performs the tasks may serve as a social model for enhanced motivation and learning in computer-based environments. Also, attribute similarity between learners and social models significantly influences modeling effects in traditional classrooms (Bandura, 1997; Schunk, 1987), so it seems plausible that the attributes or personal characteristics of a PAL might have an impact on learners in computing environments (Kim, 2005a).

Collective Agency: Collaboration

Collective agency is exercised through group action. Individuals do not live in isolation but rather are interdependent in a variety of social contexts. In their everyday lives, people typically achieve goals through collective efforts with others. People have to pool their knowledge, skills, and resources; provide mutual support; and work together to secure what they cannot accomplish on their own (Bandura, 2002). Collaborative learning may take its place with the concept of collective agency. Supporting collaboration through various mechanisms has been claimed in computer-based environments (Dillenbourg, Mendelsohn, & Schneider, 1994). Toward that goal, PALs could be designed to promote the exercise of collective agency. The number of PALs can be adjusted to meet the instructional needs of the moment. In a multiple-PAL environment, each PAL equipped with various domain-specific skills could share tasks by their expertise and thus collectively help a learner to achieve goals; also, the inclusion of multiple PALs could enhance the social richness of the environment. Table 3 summarizes the PAL functions with the concepts of social cognitive theory.

Table 3 □ Concepts of social cognitive theory and the roles of pedagogical agents as learning companions (PALs).

Concepts	*Roles*
Personal agency: Learner control	Responsive partners Allow learners' initiation and control over tasks. Respond to learners' direction and/or requests.
Proxy agency: Social modeling	Peer models Transmit knowledge and skills. Increase modeling effects by sharing similar attributes with the learner.
Collective agency: Collaboration .	Multiple collaborators Pool specific knowledge and skills Create dynamic social environments

Summary

Overall, this review of the seminal concepts from social cognitive theories is intended to provide a theoretical framework for designing the optimal functionalities of PALs. To summarize, distributed cognition may support intellectual partnership between a learner and a PAL. The concepts of social interaction could emphasize the intellectual and empathetic transactions between them. Social cognitive theory suggests multiple constructs of PALs, such as gender, ethnicity, and multiplicity (more than one PAL), which could render PALs as desirable social models. Each of these theories and concepts suggest a full spectrum of permutations in designing desirable characteristics of PALs. It should be acknowledged, of course, that the fruitful applications of PALs can evolve only with the advancement of agent technology and will be ensured by the empirical evidence of instructional impacts accumulated with time. In the following section, the design constituents of a PAL are discussed along with the research findings to date.

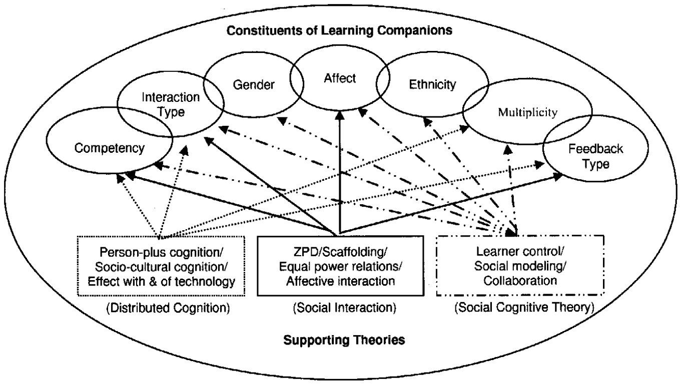
CONSTITUENTS OF PALS

Based on the review of the social-cognitive perspectives, seven design constituents of instructional PALs are proposed: (a) competency, (b) interaction type, (c) gender, (d) affect, (e) ethnicity, (f) multiplicity, and (g) feedback. Of these constituents, distributed cognition suggests PAL competency, interaction type, multiplicity, and feedback as relevant; the concepts of social interaction suggest PAL competency, interaction type, affect, and feedback; and the concepts of Bandura's social cognitive theory suggest PAL competency, interaction type, gender, affect, ethnicity, and multiplicity. Figure 3 presents the graphical representation of the constituents and the supporting concepts. The seven constituents are intended not as definitive but as suggestive for subsequent research on PALs. Detailed discussions of each constituent and any related research follow.

Competency

PALs can be designed to achieve different levels of competency depending on the theoretical perspective. A PAL could be designed to demonstrate knowledge and skills maximizing the effect of technology (Salomon, 1990) or to advance the learner's knowledge in the zone of proximal development. Likewise, the concept of proxy agency (social modeling) supports PAL competency that is high, but not too high, to serve as a desirable social model for learning. As Bandura (2001) warned, a highly competent model could some-

Figure 3 □ Constituents of pedagogical agents as learning companions



times impede the cultivation of personal competencies because the learner might unduly rely on the model's competency. Also, from a Piagetian perspective, a PAL designed to have low-to-moderate ability could simulate an equal partner to instigate the learner's cognitive conflict.

Among the constituents, PAL competency has gained attention frequently in research on both learning companions (Hietala & Niemirepo, 1998a; Kim & Baylor, 2006) and intelligent systems without anthropomorphism (Chan & Chou, 1997; Palthepu, Greer, & McCalla, 1991; Ur & VanLehn, 1995; Uresti, 2000; Uresti & Boulay, 2004). For instance, Kim and Baylor (2006) examined the desirable levels of PAL competency for college students learning introductory instructional design. The study showed that highly competent PALs increased both male and female student applications of acquired knowledge whereas low competent PALs increased student self-efficacy beliefs in the domain. In the study, PAL interaction was not intelligent but pre-scripted, which could indicate that the PAL-learner interaction was somewhat limited. Similarly, Hietala and Niemirepo (1998a) examined how intelligent pedagogical agents called EduAgents, strong or weak in the domain of math, facilitated or frustrated male and female 6th graders. They found that when the task was demanding, strong students (high IQ) more frequently asked for the strong agents' suggestions, whereas weak students (low IQ) asked more for weak agents' suggestions. This difference was not shown when the task was easy. Given the technological or methodological limitations of the studies, those findings may be too premature to generalize and should be interpreted as preliminary. It is also noted, however, that learners' showing increased self-efficacy after working with weak agents has been replicated consistently in other studies (Baylor & Kim, 2004, 2005). The educational use of this observation is worth exploring. Subsequent research is warranted to confirm the findings of the studies and to identify whether the optimal levels of PAL competency would interact with learner competency. Also, it would be desirable, as in any other educational interventions, for the long-term–based evidence to be established.

Interaction Type

The type of interaction between a PAL and a learner can be examined from two angles: (a) the control of interaction and (b) the content of interaction. Regarding interaction control, person-plus cognition (Perkins, 2001) suggested that learners should be active initiators in their cognitive activities. Similarly, the concept of personal agency (learner control), which emphasizes the value of self-monitoring, self-examination, and self-reflection, supports a learner's voluntary initiation of interactions with a PAL. In contrast, in light of sociocultural cognition (Lave & Wenger, 2001), a PAL could simulate an active partner initiating interactions to promote the sense of social context. Kim and Baylor (2006) examined the effects of PAL interaction type (proactive vs. responsive) with 72 male and female college students learning instructional planning. The results indicated that students who worked with a PAL that proactively provided information achieved higher recall than students who worked with a PAL that responded only to a learner's requests. A detailed look revealed that students in the responsive PAL condition used the PAL's information less than might be desired. The study also showed that the proactive PAL tended to have a more positive impact on academically strong students whereas the responsive PAL tended to have a more positive impact on academically weak students.

Regarding the content of interaction, a PAL can utilize a variety of discourse functions, such as suggestion, argument, confirmation, and questioning to scaffold learners in the zone of proximal development. Goodman and his colleagues (1998) suggested a learning triangle that illustrates the types of interaction exchanges between a learner and a partner: clarify, critique, explain, question, evaluate, articulate, reinforce, and justify. How to delineate these exchanges in PAL-learner interactions effectively needs to be determined. Related to the content of interaction, Craig, Gholson, Ventura, Graesser, and Group (2000) examined the effect of learning companion dialogue versus monologue with 48 college students in a domain of computer literacy. Results showed that students who overheard the dialogue in which a virtual tutee asked a virtual tutor questions wrote significantly more propositions in free recall and asked significantly more questions in the transfer task than did students who overheard a monologue. Also, students who overheard the dialogue showed deeper-level reasoning. Research on the content of PAL-learner interaction seems wide open and could require multidisciplinary efforts. Instructional designers may be guided by the implications from classroom research, social psychology, and communication theories as well as human-computer interaction. Further, the design of PAL-learner interaction could be a function of technological advancement. That is, the naturalness of PAL-learner interaction appears to be critical for efficacy.

Gender

Issues of gender difference, of importance in cognitive and interaction styles, are especially salient in educational computing, a salience often attributed to male-oriented software (Cooper & Weaver, 2003). Littleton, Light, Joiner, Messer, and Barnes (1998) reasoned that one of the difficulties girls have with learning from instructional software could be that characters (warrior-like in general) in those programs are not appealing to girls. This lack of identification with the characters may cause the girls to experience greater computer anxiety, lower interest, and poorer performance. PALs with friendly demeanors could help to reduce such anxiety and to increase motivation in computer-based learning environments. In addition, according to Bandura (1997), similarities of personal characteristics between a social model and a learner (*attribute similarity*) often are predictive of the learner's efficacy beliefs and influence the success of social modeling. This principle may be applied to design PALs in computing environments, given the consistency between human-computer interaction and human-to-human interaction (Reeves & Nass, 1996).

Interestingly, the gender of PAL—of all the variables treated here—tends best to reflect human relationships in the real world. Kim and colleagues examined in several studies the effects of PAL gender on college students' social judgments, motivation, and learning. Both male and female college students perceived the persona of a male PAL more positively than that of a female PAL (Kim & Baylor, 2005a); recalled more after they worked with a male PAL than with a female PAL (Kim & Baylor, 2005b); and showed higher motivation toward and more favorable perceptions of male instructor agents over female agents (Baylor & Kim, 2003, 2004). Those agents, differing only in gender, were morphed from one image and equipped with identical scripts, gestures, and emotions. Likewise, the study conducted by Moreno and colleagues (2002) showed that male and female undergraduates applied gender stereotypes to animated tutor agents and that their stereotypic expectations affected learning. Stereotypic expectations of males and females in human relationships (Carli, 2001) seem to be consistently applied to PAL-learner relationships. However, given that gender awareness may differ across developmental stages, the application of the stereotypic bias to PAL-learner relations may vary according to learner age levels. Nonetheless, the remedial solutions to overcome the gender-related bias applied to computing environments will be worth pursuing. The motivation for overcoming this bias would be social, not instructional.

Affect

Given the integral nature of affect and cognition (Damasio, 1994), affective interaction between users and computers has recently been of particular interest in the fields of human-computer interaction and educational computing. For instance, when a program deliberately frustrated users playing games, the users persisted longer in the program than did the users in the control group (Scheirer, Fernandez, Klein, & Picard, 2002). College students perceived pedagogical agents as more interesting and engaging when the agents expressed affect (Elliott, Rickel, & Lester, 1999; Okonkwo, 2003). As Saarni (2001) argued, emotional development of individuals is often attributed to immediate contexts and relationships. It sounds plausible that a PAL designed to express positive emotions about the task might be used to stimulate a learner's positive affect (Picard, 1997).

In general, PAL affect is defined in terms of PAL capabilities of expressing their own affect and recognizing and responding to a learner's affect (Hudlicka, 2003; Picard, 1997). For affect recognition, researchers in the MIT Media Lab have developed systems to recognize a learner's affect, using hardware technology such as a pressure-sensitive mouse, a BlueTooth® wireless skin conductivity sensor, a TekScan® pressure sensor on a chair, a stereo head-tracking system, and Blue Eyes® infrared-sensitive camera (Burleson, Picard, Perlin, & Lippincott, 2004). It is reported that these technologies demonstrate approximately 80% accuracy in detecting discrete emotions, such as happy versus sad or angry versus calm. At present, capturing users' complex emotions seems challenging. Although the capability of responding to a learner's affect awaits the necessary technology, affective expression has already been nearby. Using software tools, designers can build realistic 3-D images with subtle emotional expressions without much difficulty.

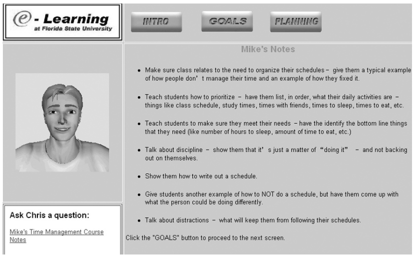
Each aspect of the PAL affective capabilities requires different technologies and resources to varying degrees; thus, their efficacy can be examined separately prior to the integrative efficacy. Kim (2004) examined the impact of PAL affective expressions and responses separately in two controlled experiments. For affective expression, based on the findings from human emotion research, she examined whether the positive or negative moods of a PAL would differently influence a learner's affective and cognitive characteristics. The participants were 142 male and female college students learning introductory instructional designing. The results showed that students who worked with a PAL that expressed a positive mood perceived the PAL as significantly more facilitating to learning, more engaging, and more intelligent than did students working with a PAL that expressed a negative mood. The students with the positive PAL also rated their motivation to keep working with the PAL significantly higher than did those with the negative PAL. Figure 4 presents male and female PALs, both named Chris, in the positive- and negative-affect conditions. In another experiment examining the impact of affective response, learners were asked to express their emotional states by clicking an emoticon presented on the screen; a PAL responded verbally with empathy or did not respond at all. Students showed significantly more interest and higher self-efficacy in the task when the PAL empathetically responded to their affect than when the PAL did not. In general, the positive impact of empathetic agents on learner motivation is steadily supported, but such an impact on learning is not reported frequently.

Ethnicity

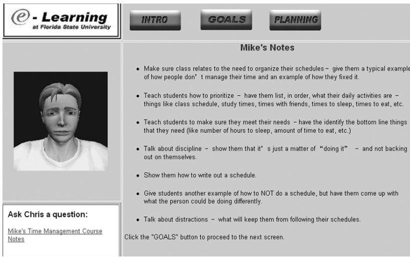
With respect to the concept of attribute similarity (Bandura, 1997), models of the same ethnicity seem to be viewed as more credible and to instill stronger efficacy beliefs and behavioral intentions than models of other ethnicities. In a computer-mediated communication, college students who had similar-ethnicity partners presented more persuasive arguments and also elicited more conformity to the partners' opinions and perceived their partners as more attractive and trustworthy than those who had different-ethnicity partners (Lee & Nass, 1998). Given the implications, PAL ethnicity can be manipulated to match or mismatch with learner ethnicity to serve instructional purposes.

Research focusing on learner-PAL ethnicity is rare, but some studies examined the ethnicity of pedagogical agents in general. Baylor and Kim (2004) found that college students (Caucasian and African-American) who worked with agents of the same ethnicity as their own perceived the agents as more credible, more engaging, and more affable than did students who worked with agents of different ethnicity. This tendency appeared more strongly among African-American students than among Caucasian students. In contrast, the ethnicity of pedagogical agents did not influence students' stereotypic expectations and learning in a study conducted by Moreno and colleagues (2002). The implication of these studies for PALs may or may not be consistent, given the distinctive role of PALs as simulated peers.

Figure 4 ☐ Chris in positive and negative affect.



Chris in the positive mood.



Chris in the negative mood.

Multiplicity

When learners are exposed to multiple social models, they may produce stronger beliefs in their ability to learn (Bandura, 1997). Bandura argued that diversified models of widely different characteristics are superior to a single model. To apply this principle, a PAL-based environment may include multiple PALs with varying perspectives or domain-specific skills. For instance, in a computer-based inquiry learning environment, SCI-WISE, White and colleagues (2000) provided young learners at the elementary level with multiple peer-like advisers, such as a planner, an inventor, and a collaborator, so as to facilitate collaborative inquiry and reflective learning. Hietala and Niemirepo (1998a, 1998b) also implemented two male and two female learning companions with varying competencies to facilitate collaboration with 6th graders learning math. The learners were able to choose a learning companion to work with, and their selections were closely related to the learners' academic competencies.

For the enhanced efficacy of multiple PALs in an environment, there are some issues that should be examined in research: the optimal size of a PAL social group, the roles of PALs (e.g., peer tutee, tutor, trouble-maker, or helper), effective ways to coordinate multiple PALs to keep from confusion or even distraction, and the strategies to manage or control the behaviors of a PAL in accord with one another.

Feedback

Learners in the zone of proximal development may benefit from the effective use of feedback as a scaffolding strategy. The provision of clear informative feedback to a learner's performance facilitates cognitive growth in peer collaboration (Tudge, Winterhoff, & Hogan, 1996). Also, verbally persuading learners that they can master skills encourages them to exert greater efforts and sustain them (Bandura, 1997). Schunk and Lilly (1984) showed that the different types of performance feedback had differential effects on learner self-efficacy.

In computer-based environments, learners often lack skills in the effective use of help messages (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003), so PAL feedback should be designed to ensure their effectiveness. In general, PAL feedback relating to PAL interaction type has been least studied among the suggested design constituents. To design PAL feedback effectively, multiple factors could be considered simultaneously, such as feedback type (informative vs. motivational), scope (general vs. context specific), timing (immediate vs. delayed), learner characteristics (e.g., metacognitive skills, motivational levels, and learning styles), and learning goals and contexts.

In summary, the social-cognitive framework for PAL design led to drawing the seven design constituents of PALs. Readers will notice that the extent of understanding of and the technology for each constituent differ. Some constituents have been investigated more frequently and can be more easily implemented than other constituents. Also, suggestions for the optimal design of a constituent are sometimes contradictory, necessitating subsequent research to gradually resolve the differences. Table 4 summarizes the discussions of the PAL constituents.

CONCLUSION

As stated earlier, this article is not an argument for replacing human peers with PALs. Rather, we attempted to base the instructional application and design of PALs in a social-cognitive framework so as to address social-cognitive dimensions of learning in computing environments. The ideal form of instruction could well be human tutoring (Bloom, 1984), where a learner can benefit from individualized cognitive guidance through dynamic social interaction. But given the challenges of providing such an ideal environment, computer-based learning should aspire to simulate that environment. Some computer-based tutoring systems have reported success in providing individualized cognitive guidance to a learner (Koedinger & Anderson, 1997), but their impact has always been—as is to be expected—much weaker than that of human tutoring. What has been missing in these computer-based systems? Perhaps learners miss empathetic social encouragements and caring. Given the findings from human-computer interaction, PALs simulating human instructional roles may prove a useful tool for creating social environments in computer-based learning. Although researchers understand the limitation of

Table 4 ☐ Pedagogical agents as learning companions (PAL) design constituents and current findings.

Constituents	*Research Variables*	*Intended or actual Outcomes*	*Studies*
Competency	Low-competent PAL High-competent PAL • Strong students with high-competent PALs • Weak students with low-competent PALs	Enhanced learner self-efficacy Enhanced application of learning Enhanced collaboration	Kim & Baylor, 2006 Hietaka & Niemirepo, 1998a
Interaction type	Proactive PAL over responsive PAL PALs dialog over monolog	Enhanced recall Enhanced recall and deeper reasoning	Kim & Baylor, 2006 Craig et al., 2000
Gender	Male PAL over female PAL	Positive perceptions of the PAL persona Enhanced recall	Kim & Baylor, 2005a Kim & Baylor 2005b
Affect	Affect recognition Affective expression: positive affect over negative affect Affective response: Empathetic over nonempathetic to learners' affect	Expected to build empathetic relationships with learners Positive social judgements; Enhanced motivation Enhanced interest and self-efficacy	Burleson & Picard, 2004 Kim, 2004 Kim, 2004
Ethnicity	Lack of research		
Multiplicity	Three PALs differing by expertise (as Planner, Inventor, Collaborator) Four PALs differing by gender and competency	To facilitate collaborative inquiry and reflective learning To facilitate collaboration	White, et al., 2000 Hietala & Niemirepo, 1998a, b
Feedback	Lack of research		

current technology, the use of PALs may help in shaping a new paradigm in computer-based learning, as implied by a decade ago.

To provide concrete guidance for researchers interested in PAL, we suggested seven design constituents of PALs drawn from social-cognitive perspectives. Yet these constituents are not comprehensive; the review of literature is rather modest. More important, it should be noted that research on PAL constituents has been very limited and that the studies reviewed in this article may sometimes bring more questions than answers. PALs is an emerging technology and may keep evolving with technological advancement and subsequent research. The findings from the research might produce more constituents and lead to increased sophistication of PAL design.

In spite of the potential usability of PAL-based environments, this article ends with some cautions. First, the naturalness of PAL behavior may be crucial to fostering social relations with learners. The current status of PAL technology is rather limited in creating desirable naturalness. In that regard, second, PALs may require intelligence (e.g., dynamic interaction and adaptive feedback) to substantiate their instructional potential. Currently, technology cannot fully feature *intelligent* PALs. Third, even without artificial intelligence, to design and develop PALs is technologically demanding. Although there are some ready-made agents available (e.g., Microsoft Agent® characters), it is usually necessary for researchers to develop their own PALs according to specific research variables. Fourth, research on PALs is inevitably multidisciplinary and may involve researchers in instructional design, cognitive psychology, human-computer interaction, artificial intelligence, social psychology, and communication. Although this can be advantageous in promoting more ecologically valid research, it can be a challenge to coordinate collaborative efforts among such diverse fields. The efforts are worth making. □

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