The Effects of a Pedagogical Agent for Informal Science Education on Learner Behaviors and Self-efficacy

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Abstract. We describe Coach Mike, an animated pedagogical agent for informal computer science education, and report findings from two experiments that provide initial evidence for the efficacy of the system. In the first study, we found that Coach Mike's presence led to 20% longer holding times, increased acceptance of programming challenges, and reduced misuse of the exhibit, but had limited cumulative impact on attitudes, awareness, and knowledge beyond what the host exhibit already achieved. In the second study, we compared two different versions of Coach Mike and found that the use of enthusiasm and self-regulatory feedback led to greater self-efficacy for programming.

Keywords: pedagogical agents, intelligent tutoring systems, informal science education, computer science education, enthusiasm, self-efficacy.

1 Introduction

After over two decades of research, the design, use, and impacts of animated pedagogical agents continue to be topics of much debate for educational technology researchers. Because learning with and from others is a fundamentally social activity, the arguments for using pedagogical agents are compelling: embodied conversational agents allow for a wider range of communicative behaviors, such as nonverbal behaviors, displays of empathy, and more [1]. Further, most research on pedagogical agents has occurred in pursuit of formal learning goals. In this paper, we focus on the use of a pedagogical agent in an informal learning context where self-directed learning is the norm and noncognitive outcomes carry greater importance.

1.1 Cognitive and Social Effects of Pedagogical Agents

Evidence supporting the use of pedagogical agents to promote learning is mixed. Some studies suggest that they can enhance learning and recall [2], while others report

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equivalent learning between conditions that provide learning support with and without an agent [3]. Further, many studies on pedagogical agents lack adequate controls to rule out competing explanations, such as whether learning is due to the *internal* properties of the agent (i.e., pedagogical behaviors) or *external* properties, such as appearance and gestures[4, 5].

Despite mixed findings on learning, the ability of pedagogical agents to achieve social and emotional outcomes is well-established. For example, researchers have determined that some pedagogical agents enhance attitudes and emotions associated with learning [6], increase motivation [7], promote interest and self-efficacy [8], as well as lead to a variety of additional social and emotional outcomes [9].

All of this suggests that it is important to investigate the role pedagogical agents might play in promoting desirable noncognitive outcomes related to learning. And such a focus would not be without empirical merit: seminal work on early-intervention programs by economist James Heckman has shown that promoting noncognitive skills such as perseverance, self-control, grit, motivation, and others have long-term societal benefits [10]. At this time, however, it is not clear how the strengths of pedagogical agents align with broad goals such as Heckman's. Thus, one aim of our work is to begin to disentangle these complex challenges and work towards an understanding of how best to use pedagogical agents for learning.

1.2 Using Pedagogical Agents in Informal Learning Environments

Cognitive and noncognitive skills are both important to consider in informal learning environments such as museums, science centers, and zoos. Such spaces are *designed* to promote understanding, conversations, and positive attitudes about their content. Although knowledge gain is an important goal for informal science educators, it is always accompanied by other important outcomes such as attitude, awareness, interest, and self-efficacy [11]. Choice plays a key role in all phases of a visitor's experience: they decide *what* to see, *when* to engage, and *how* long to stay. In other words, learners have a high degree of control over most aspects of their own learning. This means if an experience is not judged to be of value or sufficiently interesting, the learner will simply disengage and seek another activity.

What does this imply for the design of an intelligent tutoring system or pedagogical agent for informal learning? At the very least, it means that such systems need to go beyond simply focuses on knowledge outcomes. They must take seriously goals such as convincing a visitor to engage, promoting curiosity and interest, and ensuring that a visitor has a positive learning experience. In other words, pedagogical agents for informal learning need to not only act as coach (or teacher), but also as *advocate* (or salesperson). Historically, intelligent tutoring systems rarely address these issues. It is worth noting, however, that the community has radically embraced techniques from affective computing to improve the quality of learning experiences and encourage productive emotional self-regulatory behaviors [12].

Several virtual agents have successfully been deployed in museums, such as the relational agent *Tinker* [13], the conversational guide *Max* [14], and the "Twins," Ada and Grace [15] (who are also at MOS). In each case, these pedagogical agents act as the centerpieces of their exhibits and play a role of guide or teacher. Because they are not designed to support a specific problem solving task, their use of intelligent tutoring techniques is limited. In this paper we consider the use of a pedagogical agent, *Coach Mike*, that uses intelligent tutoring techniques to help visitors acquire basic programming skills in an informal learning setting.

2 Robot Park and Coach Mike

Informal learning experiences are generally more effective when a staff member (or other expert) is available to help visitors, either by answering questions or demonstrating how to interact with exhibits. Staffed spaces have been shown to produce longer *holding times* and improve learning outcomes [16]. We sought to determine if a pedagogical agent would be able to emulate some of the skills and impacts of human guides. In this section, we briefly describe the exhibit that acted as the context for our research and the pedagogical agent, Coach Mike.

Fig. 1. Robot Park at the Boston Museum of Science. Visitors program a robot using a tangible interface (right) and receive support from a pedagogical agent.

2.1 Robot Park

Located in Cahner's Computer Place at the Museum of Science (MoS), Boston, *Robot Park* is an interactive exhibit where visitors can control an iRobot Create^{TM} robot by assembling jigsaw-like blocks into chains of robot commands. It opened in October of 2007, was used by approximately 20,000 people in its first year [17]. The exhibit was redesigned in 2010 to incorporate a pedagogical agent (figure 1). Each physical block corresponds to a robot action. This set of blocks includes basic movement actions, such as LEFT, FORWARD, and SPIN, while others allow for sound and play, like BEEP, GROWL and SHAKE. Visitors can place blocks on a "tester" which will execute the command immediately or press a "run" button to compile and execute multi-step programs. To create a program, visitors need to attach one or more command blocks to a START block. A push of the run button (1) triggers a camera above to take a snapshot of the work area, (2) recognition of the program steps using fiducial markers on the blocks, and (3) transmission of the steps, sequentially, to the robot. The snapshot is displayed on the screen and each block is highlighted while being executed by the robot (i.e., it steps through the program).

Museum staff members often help visitors by demonstrating these steps and recommending challenges. One of the most common involves writing a program to move the robot touch a target (the metal structure just under the monitor in figure 1). If the robot's magnetic arm touches the target, the Robot Park sign lights up and makes noises. Other challenges, such as turning the robot around or in specific patterns can be found in a small booklet available at the exhibit.

The primary purpose of Robot Park is to give visitors an opportunity to learn programming basics in a fun and engaging context. Ideally, visitors will engage in goal-directed behaviors that involve planning, discussing, writing and debugging programs. According to museum staff, visitors tend to overuse the tester, so they tend to encourage visitors to write full programs instead. Initial studies on Robot Park focused on the benefits of its tangible interface showing that when compared with a point-and-click, graphical interface, using the blocks produced longer holding times, more sophisticated programs, deeper conversations between visitors, and more gender-balanced interest [17].

2.2 Coach Mike

Coach Mike was designed to emulate many of the tactics used by MoS staff. He greets visitors when they arrive and indicates his willingness to help. If visitors start using the exhibit, he will act primarily as a cheerleader by complimenting the programs, encouraging exploration, and reacting to the activities of the robot. At any time, visitors can push "Mike's button" to get his attention, which will trigger his help based on the context. He encourages visitors to do this. For example, upon arrival, he says "Mike is the name and robot programming is my game. Push the button with my picture on it and I'll show you how to get started." Later on, a button press will be an invitation to accept one of his programming challenges, such as to program the robot to move in a square. A constraint base is used to assess progress and provide feedback on three challenge problems. In addition to support for challenge problems, he also spends time explaining how the exhibit works, talking about debugging, and explaining the function of specific programming commands (see [18] for details).

Coach Mike was designed to be approachable and friendly, but also to generate excitement about programming. A creative decision to use a cartoon character was made early in the project because of the intended audience, 7 to 12 year olds. Determining Coach Mike's appearance was a long process, including surveys and voting by museum visitors and staff. Ultimately, a "Pixar-like", younger version of the original creator of Robot Park was the decisive choice of the museum visitors [18]. Further, Ada and Grace [15], Coach Mike's close neighbors, provide a contrast in terms of ethnicity and gender.

Fig. 2. Coach Mike, a pedagogical agent for computer science education

A variety of techniques were used to give personality to Coach Mike. For example, he can use "magic" to refer to commands – blocks appear and disappear as he refers to them (figure 2, middle). Several animations seek to convey enthusiasm and excitement: when the visitor uses the "growl" command, he will flex his muscles and say that it "makes the robot angry!" Congratulatory feedback is also available, including a fist-pump move (right side of figure 2).

In addition, many of Coach Mike's utterances are intended to be humorous and convey his interest in both the learner and the act of programming. A few examples illustrating Coach Mike's sense of humor are:

- "That was a great square! I think the robot is ready for square dancing!"
- "We've got a regular John Von Neumann on our hands here."
- "You are writing a lot of programs. I think the robot is getting tired! Just kidding, robots don't get tired."

A variety of utterances also encourage visitors to engage more deeply in the exhibit and to not give up. If the visitor is trying out different commands, Coach Mike might say "Keep exploring, I love it!" If a program doesn't correctly solve a challenge, he will sometimes preface his feedback with "Don't worry that program didn't work the first time. That happens to all of us."

3 Experiments with Coach Mike

Our experiments sought to (1) determine the impact of Coach Mike on visitor behaviors at Robot Park, and (2) identify the influence of different kinds of feedback on self-efficacy for computer programming.

3.1 Study 1: Robot Park with and without Coach Mike

Study 1 compared the exhibit with and without the agent (treatment and control, respectively). The control group used Robot Park as-is, with no guidance. Basic instructions were available on how to write programs, but no other support was provided. There were a total of 269 observations (i.e., visits to Robot Park by individuals or groups), 223 interviews, and 75 follow-up questionnaires (answered).

Holding Time. A comparison of stay times revealed that visitors stayed at Robot Park for an average of 4:51 in the treatment condition (N=145, SD=4:12) vs. 4:00 in the control (N=124, SD=2:44). We note that the higher standard deviation for holding times is typical for museum exhibit holding times. Thus, with Coach Mike active, visitors stayed at Robot Park for an average of 51 additional seconds. This difference was found to be statistically significant (t-test: T=2.003, N=269, p=.046).

Programming Behaviors. Analyses of executed programs revealed no significant differences between conditions in terms of the number of programs written or the lengths of programs written during a visit. Coach Mike did influence other visitor behaviors while at Robot Park, however. The likelihood that a visitor would attempt the "touch the target" problem was dependent on the condition ($\chi 2$= 4.858, N=269, p=0.028); treatment visitors were more likely to *attempt* the target challenge. Further, treatment visitors were more likely to *complete* the task ($\chi 2$= 4.553, N=269, p=0.033). A 95% confidence interval shows that between 1% and 24% more visitors will complete the target challenge if Coach Mike is engaged. Also, as time spent at the exhibit increased, the average length of programs written by visitors tended to decrease. This suggests that with Coach Mike, visitors likely spent more of the time revising and creating new programs rather than focusing entirely on program length.

In addition, visitors who attended Robot Park without Coach Mike engaged were more likely to misuse the exhibit, including using the block tester for the majority of movements (as opposed to creating programs), and pushing run without the start block or without creating a program ($\chi 2$ = 12.968, N=269, p=0.000). These specific behaviors reflect visitors' misunderstanding of how to use the exhibit as intended. While engaged, Coach Mike provides tips on how to start and successfully complete a program, and so these initial instructions appeared to be beneficial.

Visitor Ratings. No significant differences were found between conditions in terms of how visitors rated their experience, interest in learning more about computer science, or in how much they discussed the exhibit after leaving the museum. Robot Park was already a highly successful exhibit and since Coach Mike was designed specifically to not overshadow the exhibit, these ceiling effects are perhaps not so surprising. Finally, when asked specifically about Coach Mike, 59% of visitors described him as helpful. This increased to 75% when asked 6-weeks later in the follow-up.

3.2 Study 2: Enthusiastic Feedback and Self-efficacy

One goal of Robot Park is to instill confidence in young visitors that programming is something they can do – that it is not "out of reach". Thus, we chose to investigate the effects of different types of feedback on computer programming self-efficacy, and to explore the relationship between computer programming self-efficacy and behavior. Self-efficacy – the perception of one's own capability to successfully perform tasks in particular content domain – has been shown to be an important predictor of academic achievement. Factors influencing an individual's self-efficacy have been studied extensively in formal learning environments suggesting that self-regulatory feedback - feedback that encourages a learner to reflect on her own cognition, prior knowledge, or problem solving strategies can have a positive impact on self-efficacy [19]. While little research on feedback and self-efficacy in informal settings has been documented, some research suggests that positive feedback, in the form of personal encouragement, can impact task persistence, which is connected to self-efficacy [20].

Design. We developed two variations of Coach Mike for study 2. The first increased the frequency of positive and self-regulatory feedback, as well as general enthusiasm. "Enthusiastic" Mike was given additional utterances and animations to communicate excitement and deliver the additional feedback. Further, when a visitor had trouble following advice or with the exhibit in general, optimistic utterances were added to laud effort and offer encouragement. The second version of Coach Mike, on the other hand, was void of encouragement, excitement, and personality. His delivery of praise was limited using only simple phrases like "OK" and "Correct", with little animation beyond low beat gestures and lip syncing. In short, "serious" Mike was all business and behaved like a cold and mechanical traditional intelligent tutoring system.

For example, serious Mike might prompt a visitor to find a certain block by saying, "Can you find the Start block and place it on the tester?" If the visitor did so, he would move on and say, "Now find the forward block and place it on the tester." In contrast, if the visitor successfully placed the Start block on the tester, enthusiastic Mike would clap and say something like, "I am so impressed," before moving on to the next instruction. During a challenge, where serious Mike would say "The robot will need to make some left or right turns", enthusiastic Mike would give the same instructional feedback, as well as self-regulatory feedback, such as "Think about what you do when you turn around."

Data Collection and Instrument Design. Data about visitor self-efficacy was collected directly through interview questions. The instrument was designed to be short (3-5 minutes), and clear for all visitors age 6 and older. Researchers also collected information about the time spent at Robot Park, number of programs written, and completion of challenges. This allowed for the assessment of any indirect impact of self-efficacy on visitor behavior at the exhibit.

Self-efficacy was assessed with four questions designed to reflect "gradations of challenge", allowing for the creation of a scale that could effectively measure visitors with relatively low and relatively high self-efficacy for computer programming [21]. The four questions asked each visitor to rate on a scale of 0 (not at all confident) to 10 (very confident) how confident she felt in her ability to do two hypothetical tasks with or without support. The first task – programming a LEGO Mindstorms® robot – represented relatively low task difficulty. The second task - writing a smartphone or iPod app – represented higher levels of challenge. In this case, visitors were asked "Do you think you would be able to figure out how to write programs or software, like apps for a smartphone or tablet, from scratch?" To prevent test-retest effects, these questions were administered only after the visit to Robot Park in both conditions.

There were a total of 238 observations (101 for enthusiastic Mike and 137 for serious Mike). 62% of the visitors were male, 54% were between the ages of 6 and 13, and 77% of the groups consisted of adults with children. There were significant differences between the composition of groups (adults only vs. adults with kids), but no differences in terms of prior programming experience or in self-reported interest.

Challenges and Holding Times. There were no significant differences between conditions in terms of challenge attempts, programs written, or successful completions when controlling for participant age. Feedback treatment did not impact the number of challenges attempted or completed by the respondents. Further, no significant difference between conditions was observed in terms of mean holding time. Thus, enthusiastic Mike did not seem to influence task persistence behaviors that might be associated with increased self-efficacy at Robot Park.

Table 1. Impact of enthusiastic Mike on self-efficacy, multiple regression model

	B	Std. Error B
Respondent is 10 or younger (elementary school)	.548*	.210
Respondent is an adult (18 or older)	.540*	.209
Visitor has little or no prior programming experience	-.863***	.169
Visitor successfully completed one "challenge" at Robot Park	.455**	.170
Feedback Treatment	.345*	.164

Notes: *=p<0.05, **=p<0.01, ***=p<0.001; Adjusted R^2=.259; Total n for this analysis=124. Self-efficacy scale is z-scored.

Self Efficacy. A multiple regression model was created to assess the impact of various factors on visitor ratings of self-efficacy for computer programming, and specifically, whether the feedback treatment impacted these ratings. B values in Table 1 relate each of the independent variables to changes in the SD of the sample's self-efficacy scores (which are z-scored). Visitors who spent less than 90 seconds at Robot Park (5% of the sample overall) were removed from the analysis, as these visitors received little feedback from Coach Mike. A regression analysis suggested that chronological age was not associated self-efficacy ratings in a linear manner, when controlling for prior experience. Having little or no computer programming experience predicted self efficacy scores that were nearly a full standard deviation lower (-.86) than visitors who had moderate to high amounts of prior experience. Completion of a challenge was also associated with higher self-efficacy ratings (.46 of a standard deviation).

This model accounts for known differences between the samples (age differences) and other factors that have been shown to directly relate to self-efficacy (prior experience, including reported prior experience and successful challenge completion immediately prior to the interview). Visitors with enthusiastic Mike had self-efficacy scores that were approximately .35 of a standard deviation higher than comparable visitors who used serious Mike (See Table 1). While this difference is quite small, it suggests that, even in a short-duration, open-ended informal science setting, specific types of feedback may be able to impact self-efficacy beliefs.

4 Conclusion

With an average holding time of 3-4 minutes [16], it is a profound challenge to produce meaningful changes in visitors to an exhibit. In study 1, we found some immediate influences on behaviors that seem positive: a 20% increase in holding time, more time spent programming, increased likelihood to accept challenges, and less misuse of the exhibit. Longer term impacts were not detected, however, most likely due to the fact that Robot Park was already considered a highly successful exhibit. In study 2 we sought to understand how Coach Mike's personality and feedback style could impact the learning experience at Robot Park. Although we found no differences in visitor behaviors between conditions, we did detect a modest, but significant increase in visitors' self-reported self-efficacy ratings when Coach Mike was configured to be enthusiastic and to deliver self-regulatory feedback.

A key weakness in the studies was that they did not include a condition providing the feedback content, but without Coach Mike's body. Thus, these findings do not demonstrate the need for an embodied and animated pedagogical agent. Further, Coach Mike's user sensing capabilities are limited only to exhibit actions (e.g., button presses). Affective and learning support could be improved if he could detect user frustration, or know the make-up of different groups who approach. In general, it is well known that expert human tutors apply a variety of affective and motivational tactics [22], and so building on these results and with enhanced interaction capabilities, we believe that pedagogical agents can enhance informal learning outcomes and even reach visitors in new and perhaps previously impossible ways.

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