Intelligent Tutoring goes to the Museum in the Big City: A Pedagogical Agent for Informal Science Education

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Abstract. In this paper, we describe *Coach Mike,* a virtual staff member at the Boston Museum of Science that seeks to help visitors at Robot Park, an interactive exhibit for computer programming. By tracking visitor interactions and through the use of animation, gestures, and synthesized speech, Coach Mike provides several forms of support that seek to improve the experiences of museum visitors. These include orientation tactics, exploration support, and problem solving guidance. Additional tactics use encouragement and humor to entice visitors to stay more deeply engaged. Preliminary analysis of interaction logs suggest that visitors can follow Coach Mike's guidance and may be less prone to immediate disengagement, but further study is needed.

Keywords: pedagogical agents, intelligent tutoring systems, coaching, informal science education, entertainment, computer science education.

1 Introduction

Since their inception in early 1960's, the list of intelligent tutoring system (ITS) success stories continues to grow [1, 2]. Most of these systems have been developed for use in formal learning environments and have the singular aim of producing cognitive gains in learners. Although the number of ITSs that consider non-cognitive issues, such as affect and metacognition, has grown rapidly in recent years [2], the most commonly sought outcomes of ITS research continues to be cognitive gains and deep understanding. While this focus is certainly justified, it is also worthwhile to take a broader perspective and investigate technologies that seek to inspire learners and promote the intrinsic value of learning. For the last half-century, this has been the goal of research on learning in informal settings, such as museums and science centers, where free choice and self-direction play prominent roles [3, 4]. Visitors decide *where* to go, *what* to do, and *how long* to do it. This elevates the prominence of motivation and affect given its role in these decisions. Any advanced learning technologies used in informal contexts should address these important non-cognitive factors. In this paper, we investigate the question of how ITS techniques can be applied in an informal setting where visitors are free to disengage at any moment.

1.1 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 [5], and continues as a permanent exhibit in the museum (see Figure 1). The primary purpose is to give visitors an opportunity to learn programming basics in a fun and engaging context. Each physical block corresponds to a robot action. Programs are compiled and executed by pressing a "run" button, which triggers a camera to take a snapshot of the programming area. Further, individual blocks can be placed on a tester so the visitor can see their effect. Commands are recognized by fiducial markers on top of the blocks, then transmitted to the robot. The programming language, *Tern*, includes basic movement actions, such as LEFT and FORWARD, others for sound and play, like GROWL and SHAKE, and some basic control structures. Studies have focused on Robot Park's tangible interface versus a graphical one, showing its ability to produce longer stay times, more sophisticated programs, and deeper conversations between visitors [5].

Figure 1. The original Robot Park Exhibit at MoS.

1.2 Pedagogical agents and informal science education

An established approach for reducing early disengagement from an interactive exhibit is to design for *immediate apprehendability*. This principle states that exhibits should use simple interfaces, leverage familiar ideas and controls, and give immediate feedback that allows visitors to self-monitor and observe changes [6]. The presence of museum staff has also been linked to a variety of positive outcomes, such as longer stay times [7] and greater proficiency with exhibits [8]. Given this result, it begs the question: would a virtual staff member achieve similar results?

In general, pedagogical agents can profoundly influence users' virtual experiences [9, 10]. Although the evidence is fragmented regarding their impact on learning [11], substantial evidence exists tying pedagogical agents' *external properties* (e.g., appearance) to non-cognitive outcomes, such as *satisfaction*, *interest*, and *sense of presence* [12]. Given the particularly important roles of these factors in informal settings, pedagogical agents seem like a natural fit. Indeed, a number of interactive virtual characters and robots have been developed for museums and other informal settings. These include our prior work with MoS, the virtual human twins Ada and Grace [13], the virtual robot Tinker [14], and the museum tour guide robot [15].

2 Coach Mike: An informal intelligent tutor

We have rebuilt Robot Park with a 42” LCD screen to hold an embodied pedagogical agent named *Coach Mike* along with the original display to show programs. He seeks to help visitors understand and interact with the exhibit. In this section, we describe the conceptualization, design, and implementation of the system.

2.1 Interpretation at Robot Park

To design Coach Mike, we first turned to 59 museum staff and volunteers who work or had recently worked in Cahner’s Computer Place. They were asked about their experiences with Robot Park and to report (1) typical questions they are asked about the exhibit, (2) what they say to engage visitors, and (3) observations on how visitors interact with the exhibit and respond to help requests. Although some stylistic differences were evident, several themes did emerge:

- To initiate contact, staff often ask “Would you like to program this robot?” or “If you can give directions, you can program this robot.”
- Visitors tend to ask about the purpose of the exhibit and how to use the blocks.
- Initial explanations often involve exhibit internals (e.g., use of computer vision) and basic instructions on how to move the robot with the tester or run button.
- Specific programming problems are usually suggested for visitors, such as touching the target (which is built in to Robot Park just beneath the sign) or moving the robot in a specific pattern.
- Visitors usually ignore available documentation.

Most generally, these reports suggest that staff tend to encourage visitors to use Robot Park, explain how the software can read and execute programs, and then show them enough of the Tern language to enable visitors to write their own programs.

2.2 Personality, body, animations, and voice

As noted earlier, the appearance of a pedagogical agent can influence affective outcomes. In previous work, we conducted surveys with museum visitors that suggested they preferred a virtual human guide that was approachable, energetic, intelligent, understanding, and patient [13]. We decided to seek these same qualities for Coach Mike. However, with a target audience of ages 7-12 and the general appeal of tangible interfaces to children [5], we chose to use a 3D, cartoon-style body, reminiscent of characters from modern animated films. This also helped distinguish Coach Mike from his fellow virtual staff members, Ada and Grace, who are photoreal and work in the same space, Cahner’s Computer Place. Lastly, to further distinguish Coach Mike, and with the hope that he might act as a role model for younger visitors, we decided to use the creator of Robot Park as inspiration for his appearance.[1]

[1]Dr. Michael Horn, now an Assistant Professor at Northwestern University, created Robot Park in his dissertation research on tangible interfaces at Tufts University.

Figure 2. Mike is a 3D cartoon-style pedagogical agent designed to be approachable, supportive, and understanding (among others). These stills are from animations for thinking, giving positive feedback, and displaying a block (magically).

Coach Mike has a total of 46 animations that range from very subtle to emotionally charged (see figure 2). The set includes basic gestures for breathing, basic idling (e.g., hands forward, hands back), natural communication (e.g., hands out and open, nodding, pointing), reactions to visitor programs (e.g., thinking, thumbs up, clapping), conveying empathy (e.g., head scratching, leaning), and showing blocks. We note that we decided to have blocks magically appear, hover for several seconds, then disappear with Coach Mike behaving as if he were a magician (the right-most image of figure 2 attempts to convey this idea). Other animations include one for flexing his muscles, knocking on the glass, looking all around, and raising his arms to signal a touchdown (as in American football). We have plans to examine the role of these animations in influencing visitor behaviors, attitudes, and interest in Robot Park.

Finally, although recorded speech is generally regarded as superior for clarity and conveying emotion [13], we decided to use synthesized speech for Coach Mike's voice. Given the need to mention a variety of blocks in different contexts, as well as provide support for several specific problems, we decided the flexibility afforded by synthesized speech outweighed the benefits of pre-recording all possible utterances. After considering roughly 20 commercially available speech synthesis systems, we chose a voice from *NeoSpeech* (www.neospeech.com) for its excellent clarity.

2.2 Implementation

Behind the agent is an ITS that shares many similarities with traditional tutoring systems, but also differs in some key ways. For instance, when no one is using Robot Park, Coach Mike waits patiently, occasionally entertaining himself by knocking on the glass (of his monitor), looking around, or using some minor passive gestures. These idle behaviors play a potentially critical role in the decisions of visitors to engage or not. When a visitor is detected, he directs his attention to the work area and greets that person. How the session proceeds from there depends primarily on the subsequent actions (or inaction) of the visitor.

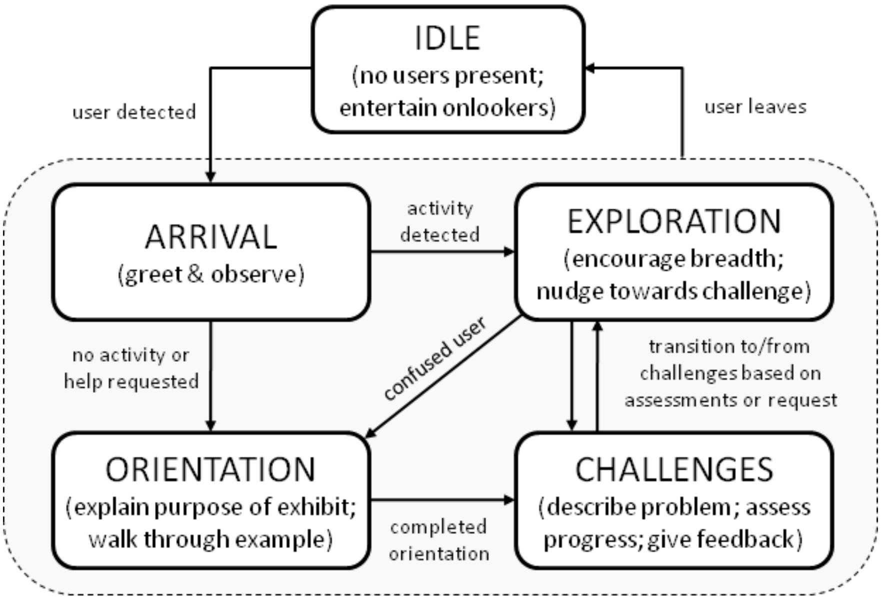

Figure 3. State diagram for Coach Mike's interactions with visitors at Robot Park. The goal is to balance support for free exploration with specific problem guidance.

To allow Coach Mike to interact with visitors and monitor interactions with Robot Park, we augmented the existing system [5] with several new software components:

1. *Physical tracking*: weight-sensitive mat, robot camera, help button
2. *Virtual Human system*: animation, speech, lip syncing, art (see [13])
3. *Pedagogical Manager*: session manager, intelligent tutoring system

The Pedagogical Manager acts as the hub by monitoring physical inputs from the exhibit (including tested blocks and programs), triggering virtual human actions (i.e., speaking and animating), assessing user actions, and providing learning support.

Pedagogical decisions are driven by a rule-based cognitive model of coaching implemented in Jess (www.jessrules.com). We chose Jess because of its ability to model a frequently changing world state and for the flexibility it provides for a modular representation of tutoring tactics. Built to simulate MoS staff's strategies (section 2.1), the model encodes a variety of tutoring and motivation tactics to orient people to the exhibit, encourage them to try new things, suggest specific problems (aka, "Mike's challenges"), and give knowledge-based feedback on their programs. A general aim is to balance the importance of exploration and play with the goal of giving feedback and guidance (as traditional ITSs do) for specific challenges.

Our model of coaching operates in three general modes: *Orientation*, *Exploration*, and *Challenge* (see figure 3). These capture the styles of interaction we observed with museum staff in our early analysis of interpretation at Robot Park and define the expectations maintained by the system for user behaviors at different times. Of course, informal settings demand robust and flexible policies (to support self-directed learning), and so when divergence from expectations is detected, Coach Mike adjusts accordingly – this is typically a shift to supporting exploration. Below we discuss these modes in more detail as well as the transitions between them (see figure 3).

Orientation. If no activity is detected upon arrival or if the visitor stops exploring fairly quickly, Coach Mike will provide a basic orientation showing how to write a simple program:

CM: Can you find the START block and place it on the tester? [*animation of START block appearing over CM's hands*]

V: [*holds the START block over the tester*]

CM: Great! [*thumbs up animation*] **Now can you find the FORWARD block and place it on the tester?**

V: [*holds the FORWARD block over the tester*]

CM: Awesome! Now can you attach them on the table and press the RUN button? [*two blocks come together in CM's hands*]

V: [*attaches blocks, presses RUN, robot moves forward*]

CM: [*gazes at robot area during execution*] **Nice! When you pressed the RUN button, the camera took a picture of your program and transmitted it to the robot.** [*gesture to robot*]

This continues with Coach Mike asking the visitor to add another block to the program and extolling the value of programming with multi-step programs. If users demonstrate an ability to write a multi-step program on their own, this is not delivered and if difficulties arise, Coach Mike will repeat or provide additional guidance.

Exploration. If the visitor begins interacting with the exhibit upon arrival, or has completed (or abandoned) the challenge problems, Coach Mike supports free exploration. Here, the aim is to simply provide encouragement and promote continued engagement, but gently nudge the visitor towards creating goal-directed, multi-step programs. Tutoring tactics are primarily reactive by responding to variety (i.e., the visitor trying new blocks) and writing non-trivial programs (i.e., multi-step). For feedback, Coach Mike will provide specific explanations of blocks on their first use and see associated animations as part of his reaction. Continued exploration produces more reactions, sometimes including commentary on programs (e.g., "That was a long program. I love it!") or about the robot (e.g., "I think the robot is getting tired. Just kidding!").

Challenges. Coach Mike can also suggest specific problems to the visitor. For example, he might ask for the robot to touch the target or move in a specific pattern, such as a square. We chose a *constraint-based* representation for assessing programs because (1) solutions are checked only when submitted, and (2) constraints flexibly allow for multiple solutions [16]. For example, one constraint for the square problem is that the program should have three turns in the same direction. Another checks for moves between these turns. Further, hints and feedback are attached to constraints permitting messages like "The robot will need at least three turns to move in a square." Support for three problems is available and Coach Mike can provide multiple hints (including displaying pictures on the screen) to help visitors who are particularly frustrated. After a problem is solved, Coach Mike reacts by congratulating the visitor and using a special animation such as clapping, a double-thumbs up, or a fist pump.

Table 1. Robot Park analysis with and without Coach Mike. An *empty* session is defined as one with an abrupt departure (0-1 actions). Standard deviations are shown in parentheses.

session data	Robot Park (original)	Robot Park w/Coach Mike
duration (minutes)	2.38 (3.13)	3.25 (4.05)
tester uses	4.34 (9.30)	5.25 (8.81)
number of programs	5.33 (6.07)	6.79 (5.71)
average program length	6.46 (4.13)	5.03 (3.69)
blocks used (out of 11)	7.84 (3.38)	7.60 (3.74)
empty sessions /hour	3.01	0.44

3 Preliminary analysis of visitor interactions

Coach Mike is scheduled to officially open at MoS in February 2011. During testing of a pre-release version of the system, however, we collected system logs from visitors' interactions at the exhibit of approximately 9 hours with Coach Mike active and 6 hours without. This version of the system *lacked* several important features, including most animations, support for all of Tern, and use of the help button. Further, staff was present in both sessions to help visitors in both testing sessions.

We first broke the log files up by session, defined as the arrival then departure of one or more visitors. The logs provided information about all uses of the tester, run button, and programs that were submitted. We counted these actions, the lengths of the programs submitted, and the coverage of the Tern program language by during the session (out of the 11 blocks available, how many were used). Table 1 shows the results of the analysis. Although anecdotally, staff reported that the presence of Coach Mike attracted visitors to Robot Park and the differences in these behavioral measures generally favor the presence of Coach Mike, none of the differences in Table 1 were found to be statistically significant. The lower number of quick disengagements from the exhibit may suggest visitors felt more compelled to engage the exhibit. However, we are unable to conclude from this data that the presence of Coach Mike, in this non-animated and limited form, had a substantial impact on the behaviors of visitors.

4 Conclusion and future work

In this paper we have described a pedagogical agent for informal science education, *Coach Mike*, that inhabits an exhibit in the Boston Museum of Science. Given that visitors can disengage at any moment in this informal setting, the underlying pedagogical model seeks to simultaneously keep the visitor engaged while promoting their learning of programming. Humor and entertaining animations are used to accomplish the former while specific problems, hints, and feedback are given for the latter. Although the preliminary analysis of interaction data revealed no specific benefits of Coach Mike's presence, this pre-release version of the system lacked important functionality for animation and complete support of problem solving. We are currently conducting formative testing, including in-person observation as well as log files analysis, to determine in more detail how people respond to Coach Mike's guidance, whether humor and entertaining animations induce deeper engagement, and how his presence influences conversations about programming and Robot Park.

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