Engaging Children in Math Education using a Socially Interactive Humanoid Robot*

LaVonda Brown[1] and Ayanna M. Howard[2]

Abstract— **Studies have shown that teaching processes, which incorporate robotic-based engagement methods, can approach the effectiveness of human tutors. Not only have these socially-engaging robots been used in education, but also as weight-loss coaches, play partners, and companions. As such, in this paper we investigate the process of embedding social interaction within a humanoid-student learning scenario in order to re-engage children during high-demand cognitive tasks. We discuss the overall system approach and the forms of multi-modal verbal and nonverbal (i.e. gestural) cues used by the robotic agent. Results derived from 20 children, age 13 through 18, engaging with the robot during a tablet-based algebra exam show that, while various forms of social interaction increase test performance, combinations of verbal cues result in a slightly better outcome with respect to test completion time.**

I. INTRODUCTION

The primary objective of tutoring, a practice designed to supplement classroom-based learning, is to assist and guide students to become independent learners. To be effective in this practice, a human tutor must provide direction maintenance – i.e. when the learner disengages from the task at hand, the role of the tutor is to keep him or her in pursuit of the specified objective [1]. In prior work, it has been theorized that robotic-based education (RBE) methods can approach the effectiveness of human tutors by coupling methods in computer-based education (CBE) with human-equivalent behavioral cues of engagement [2]. By using social cues, a long-term relationship between the robot and the subject can be fostered [3]. This relationship drastically increases the subject's motivation to complete a task and the subject's desire to spend time with the robot for a long period of time. In addition, ample studies have shown that the effect of being perceived as a social interaction partner can additionally be enhanced by a physical robotic embodiment [4]. These characteristics are ideal for a student interacting with a robot tutor in a learning environment. As such, in efforts to analyze the RBE approach, research has been conducted on implementing sociable characteristics [3], [5]–[9] in educational robots [5]–[7], [9], [10].

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[1]LaVonda Brown is a Ph.D. student in the School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA lavonda.brown@gatech.edu

[2]Ayanna M. Howard is a Full Professor in the School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA ayanna.howard@ece.gatech.edu

In the realm of education, robots are currently being used to teach math [11], history [7], new languages [5], [12], and new tasks [6], [9]. Some studies vary the type of feedback (positive, negative, neutral) [7] and behavioral techniques [13] given from the robot, while others vary the type of learning adaptation [11] provided from the system. Generally speaking, students are more attracted to the robot when it exhibits positive feedback [5], [7], are more motivated to learn from the robot when there is individualized learning [6], [11], and have increased recall abilities when the robot uses appropriate behavioral techniques to reengage [13].

Saerbeck et al. investigated whether or not social engagement with a robot interface could effectively by applied to education [5]. Their research was done with an interactive cat (iCat) whose goal was to teach a new language to a child. The iCat platform has the shape of a cat, and its height is approximately 40 cm. The study compared a socially supportive iCat (engaged in social dialog) to a neural iCat (unidirectional knowledge flow). The students involved in the socially supportive iCat case were more motivated, which is essential for any educational technology to have long-term effectiveness.

Michaud et al. believed that mobility, appearance, interaction modalities, and behavior all influence a child's ability to sustain interest and learn [6]. They used Roball, a spherical robot with a diameter of approximately 15 cm, to evaluate autonomous motion in children 12-18 months old. An algorithm was used to adapt the robot's behavior to the child's interaction using proprioceptive sensors. Michaud et al. concluded that mobile robots as assistive technology are great for creating interplay and learning situations. Mobile robots allow adaptation to children and the environment, and they keep children engaged.

Han et al. of Korea developed the world's first e-learning home robot (IROBI) in March 2004 [10]. IROBI, a humanoid robot consisting of only a head and torso, demonstrated the prospect of robots as a new educational media. Users could interact with IROBI using voice and a touch panel, and the robot communicated with people by presenting voice, gestures, and multimedia contents on an LCD screen. During this investigation, Han et al. compared traditional media-assisted learning and web-based instruction (WBI) to Home Robot-assisted learning [10]. Han et al. concluded that IROBI was the most effective in promoting and improving the child's learning concentration, interest, and achievement when compared to other instructional media.

Prior work that has used robots in the educational venue have traditionally not used a full humanoid (consisting of a torso, head, two arms, and two legs) as the delivery platform. However, our objective for this investigation is to use a full humanoid robotic platform as the educational agent. Because of this, it is important to note that anthropomorphism of robots is believed to have a negative effect on children and elders [14]. Anthropomorphism is the term used to describe the behavior of attributing humanlike properties and mental states to nonhuman agents and objects. Being that humanoid robots are designed so that their appearance and movements are that of a human being, and sociable robots are designed so that their interaction is that of a human being, it is a concern that sociable-humanoid robots can be detrimental to development. Sharkey and Sharkey caution researchers of the ethical issues associated with allowing/encouraging children and/or elders to form a relationship with a robot [14]. They suggest that if anthropomorphism of robots is involved, it should not be used to permanently replace a human being. As such, in this study, we also want to tease out data that ensure the learning cycle is not negatively impacted by interaction with a humanoid robot.

In this paper, we detail a system that integrates a humanoid robotic educational agent into a math-learning scenario. Since a primary objective of a human tutor is direction maintenance [1], we want to test the hypothesis that a humanoid robotic educational agent that can adaptively engage the student during the learning process can positively impact the student's performance. Section II provides an overview of the learning environment, whereas Section III discusses the robotic educational agent and its associated behaviors used to engage the student. In Section IV, we discuss the engagement model used to identify user state, and the experimental protocol used to evaluate the effectiveness of the humanoid robotic agent is presented in Section V. The results and discussion points are made in Sections VI and VII, and lastly, the conclusion and future work of this investigation are stated in Sections VIII and IX.

II. THE LEARNING ENVIRONMENT

In traditional learning scenarios, active engagement is an important goal for both students and teachers [15]. One of the most non-engaging, yet necessary, elements of the current learning environment is the process of testing [16]. As such, in this research, we focus on the math testing scenario to evaluate the role and effectiveness of engagement using a robotic agent. For our work, we employed a 10-question multiple-choice algebra test, which was proctored using a Samsung Galaxy Tablet (Fig. 1). We adapted a tablet-based calculus test that was used in a prior study [2] to develop our algebra test.

III. THE ROBOTIC EDUCATIONAL AGENT

For the robotic educational agent, we utilized the DARwIn-OP platform (Darwin) [17], a humanoid robot with 20 actuators, resulting in 6 DOF for each leg, 3 DOF of freedom for each arm, and 2 DOF for the neck (Fig. 2). To enable interaction with the human, Darwin was programmed with a range of verbal and nonverbal behaviors.

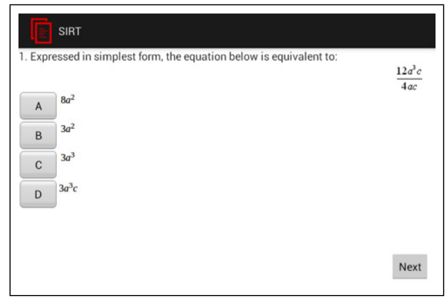


Fig. 1. The Learning Environment - Algebra Test Question Screen.

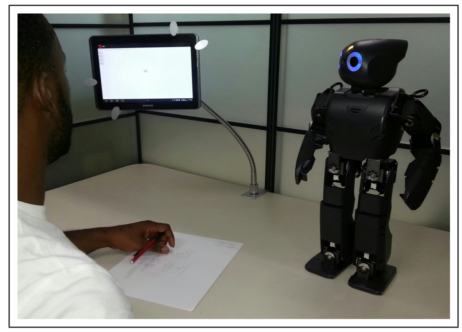


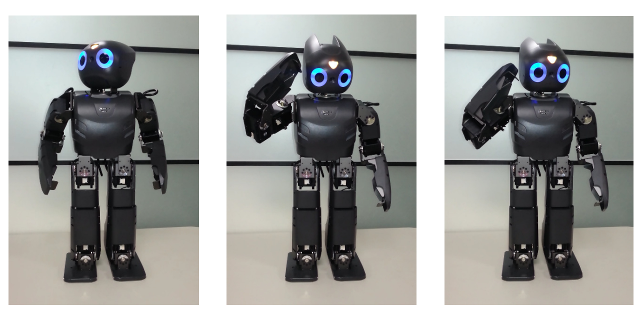
Fig. 2. The Robotic Educational Agent Darwin.

A. *Nonverbal Behaviors*

Nonverbal behaviors, or gestures, for the robotic agent included eye gaze, head nods/shakes, and body movements. These gestures were preprogrammed from a previous study [2] using Darwins default program ActionEditor. Table I shows a sample of the nonverbal behaviors used in this investigation, and Fig. 3 shows three snapshots of the *head scratch* gesture. A total of eight gestural behaviors were programmed onto the humanoid platform.

B. *Verbal Behaviors*

Verbal behaviors enable the educational agent to provide socially supportive phrases for reengagement as the student



(a) (b) (c)

Fig. 3. The head scratch gesture broken down into three parts. (a) Initial Position - Darwin is standing and has eye contact with the tablet-based test. (b) Darwin's right arm scratches his head. His head is down and eye contact is with the pencil and paper. (c) Darwin's arm stops moving, and his head moves up to make eye contact with the subject. He then returns to the initial position.

TABLE I

SAMPLE OF NONVERBAL BEHAVIORS FROM THE ROBOTIC EDUCATIONAL AGENT

Gesture	Behavioral Meaning	Description of Motion
Eye Contact	Attention is directed towards an object	Head (eyes) is aligned with a specified target
Hand Wave	Goodbye	Arm is bent and raised next to head; forearm moves back and forth
Head Nod	Back-channel signal meaning continue; okay; yes	Head moves in an up and down motion
Head Shake	Negative connotation; sad; no	Head moves from side to side while facing the ground
Head Scratch	Confusion; lost	Arm/hand moves back and forth next to head (Fig. 3)
Fast Arm	Positive connotation; approval; excitement	Arm is bent and raised next to head; arm then quickly moves downward

navigates through the test. During the utterance of verbal phrases, Darwin turns his gaze towards the student; otherwise, he remains looking at the tablet. Studies have shown that an open dialogue integrating socially supportive phrases between teacher and student is ideal for optimal learning [5]. In result, we have chosen to use the library of socially supportive phrases shown in Table II. These phrases were recorded using text-to-speech (TTS) software and stored on Darwin's external SD card as mp3 files.

IV. THE ENGAGEMENT MODEL

In this work, we determine the behavioral user state by monitoring the student's interactions with the tablet. For a baseline metric of engagement, three event processes were observed: total time required to answer a question; accuracy of responses; and proper function executions. By looking at variables such as the speed and the validity of the answer submitted, assumptions are made about the users state of mind (Table III) [18]. This information also assists with the development of appropriate socially supportive responses for Darwin. For example, if the student responds to a series of questions at a fast pace, but the majority of the answers are incorrect, the student may be disengaged, bored with the problem set, or need questions of less difficulty.

In the cases where the student may take a long time to answer the question, it is necessary to interrupt this inactivity (eliminate idle time) and effectively increase engagement. Studies have shown that idle time can be reduced by monitoring the beginning and end of tasks [19]. By interrupting inactivity, the idea that the robot and subject are working together as a team is enhanced. For this study, the tablet will inform Darwin when the subject begins a task or question, selects an answer, submits an answer/finishes a question, and is inactive for a period of time. Based on this information, Darwin will respond appropriately.

TABLE II

SAMPLE OF VERBAL RESPONSES FROM THE ROBOTIC EDUCATIONAL AGENT

Answer	Speed	Phrase
Correct	Fast	"You're really good at this."
		"You're on fire!"
		"Awesome!"
	Slow	"You're doing great! I had trouble with that one too."
		"I appreciate the effort you're putting into this test."
		"This is hard, but we're doing great."
Incorrect	Fast	"Can you slow down a little so we can do it together."
		"You're leaving me behind."
		"Please wait for me."
	Slow	"This is really making us think."
		"This section is hard."
		"Don't sweat it; we'll get the next one."
None	Inactive	"Are you still there?"
		"Let's make an educated guess."
		"I was completely stumped on this one."

V. EXPERIMENTAL DESIGN

To evaluate the effectiveness of the robotic educational agent engaging students during the learning process, we employed a between-groups design for this study. To guarantee that the skills are evenly distributed between the groups, the subjects were selected at random. A total of 20 high school students took part in this experiment consisting of both females and males in the age range of 13-18 years old. Our experiment involved one factor, type of reengagement, with four levels. Each level is defined as follows:

- **None:** Represents the control group. No agent is present.
- **Verbal:** The agent will say socially supportive phrases for reengagement as the student navigates through the test. He will gaze towards the student when speaking to him/her; otherwise, he will remain looking at the tablet.
- **Nonverbal:** The agent will use only gestures for reengagement as the student navigates through the test.
- **Mixture of Both:** The agent will use both gestures and phrases for reengagement as the student navigates through the test.

The experimental setup (Fig. 2) utilizes a Samsung Galaxy Tablet to display the exam. The tablet is placed on an adjustable stand at eye level, and Darwin is positioned to the right of the tablet, yet between the tablet and the student.

TABLE III

ENGAGEMENT MODEL

Answer	Speed	User's Behavioral State
Correct	Fast	Engaged
		Not challenged enough
	Slow	Engaged
		Challenged
		Requires more time to think
Incorrect	Fast	Not engaged
		Unmotivated
		Not challenged (too hard/easy)
		Bored
	Slow	Engaged
		Challenged
		Struggling

Darwin is conveniently placed in a position where he is always able to see and interact with both the tablet and the student.

At the start of the application, Darwin gives a verbal introduction along with gestures to introduce himself and the activity that the students are about to perform. The purpose of this introduction is to eliminate the novelty of the robot from the investigation and prepare the students for the test by instructing them to gather their materials. The script of this verbal introduction is shown below:

> *"Hello. My name is Darwin. We will be going through a series of 10 math questions to learn the material together. I appreciate you taking the time out of your busy schedule to work with me. Get your pencil and paper ready so we can start. Press begin when you're ready."*

The subjects will then navigate through the test until they reach the completion screen. Thereafter, Darwin shows his gratitude and gives a farewell.

As each student progresses through the test, his or her interaction with the tablet is communicated to Darwin via Bluetooth. To enable real-time performance, only the numbers 0-9 are transmitted from the tablet to the Darwin. Each number conveys a different message to Darwin about the interaction between the student and the tablet [2]. Essentially, every button that is pressed is sent to Darwin, as well as the time intervals taken to navigate through the test [2].

Upon opening the tablet-based math test, a message is sent to Darwin, and he then begins his introduction on the welcome screen. If a multiple-choice answer is selected (A, B, C, or D), a message is sent to Darwin and he will respond appropriately based on the engagement type (verbal, nonverbal, or both). An answer is classified as either being *fast*, *slow*, or *average* based on the time elapsed on each question: if the subject submits a response in less than 30 seconds this is fast; if the subject submits a response in between 30 seconds and 90 seconds this is average; if the subject submits a response in more than 90 seconds this is slow. The answers are also classified based on whether or not the answer is correct.

We focus on decreasing idle time by monitoring task or question duration. Therefore, when there are long time intervals that consist of no interaction between the human and the tablet, a message is sent to Darwin. A long time interval is defined as 90 seconds; therefore, every 90 seconds of inactivity or idle time, Darwin is notified, and he will respond appropriately based on the engagement type. Lastly, a message is sent to Darwin at the completion of the test.

Depending on user state, Darwin provides the users cues that are either verbal, nonverbal, or a combination of the two (depending on the experimental group). For both verbal and nonverbal behaviors, the behavior was selected at random based on the message sent to Darwin from the tablet. For the engagement type that incorporates both verbal and nonverbal cues, the gestures and phrases were scripted and paired prior to Darwin's random selection. As such, we were able to expand Darwin's library of verbal and nonverbal cues by pairing the same phrase with multiple gestures. Although a phrase when it stands alone may mean one thing, by adding a gesture, the underline meaning of the message can be altered. Upon execution of a pair, both the gesture and the phrase are performed simultaneously. For example, if the message sent to Darwin states that a slow correct answer was submitted, he may say, "You're doing great! I had trouble with that one too," while nodding his head.

For the experimental design, we utilize the same test, environmental setup, and engagement model across all students (so that cues will happen at the same time). The only thing that changes between groups is the type of cues that Darwin provides. For the control group with no agent, Darwin is simply removed from the table and not visible.

VI. RESULTS

In this research, we look to validate the hypothesis that the use of a robotic educational agent can increase test performance by adaptively engaging with the student. Adaptive engagement is based on the concept that the engagement model is driven by identification of the student's behavioral state. To prove or disprove this hypothesis, we will look at the different types of information that we collected separately. These include test completion time, the Likert scale questions that we asked in an exit survey, and the comments that participants left at the end of the survey.

A. The Completion Time

We logged the total test time for each participant; the means for the four groups are shown in Fig. 4, and the statistical analysis is shown in Table IV.

B. Survey

After the subjects completed the test, we asked them to rate their agreement with a series of statements on a

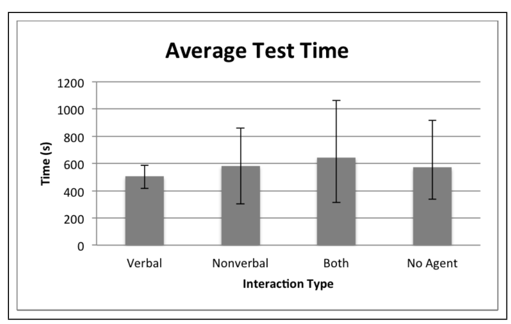


Fig. 4. The average test completion times shown along with the range for each group.

TABLE IV
TOTAL TIME (S) STATISTICAL ANALYSIS

	Mean	Standard Deviation	p-value
Verbal	505.4	72.45	0.80
Nonverbal	583.0	240.28	
Both	645.2	290.31	
No Agent	570.2	230.03	

5-level Likert scale that ranged from 1 (Disagree) to 5 (Agree). One question asked for a 'yes/no/maybe' answer, which we converted to a scale from 1 (No) to 3 (Yes). For each of the questions on our survey, we performed an ANOVA (Analysis of Variance) test to see if the differences between groups were significantly different. Table V shows the average response to each question and the p-values from the ANOVA tests, which are separated by test groups.

C. Freeform Feedback

In addition to the questions discussed in the previous subsection, we also left room on the survey for subjects to provide freeform comments that reflected their experience as a whole. Though not everybody decided to accept the invitation, 9 of the 20 participants provided comments. Of the five subjects in the Nonverbal Category, three of them left responses stating that Darwin's lack of verbal cues gave off the impression that he was giving no feedback at all. The nonverbal responses were:

- "He didn't say anything while I took the test."
- "This was kind of weird having a robot watching you while taking test. Also he was giving really weird signals so I didn't understand if I got the questions right or not."
- "When I answered a question, Darwin shook his head each time, making me think I was wrong. And he never gave me any feedback. That would've been nice."

Of the three verbal responses, two of the students stated that Darwin had a positive impact on the learning environment. Their verbal responses were:

- "Darwin actually made me feel more confident in myself on preforming on the test."
- "Darwin did provide encouragement for my efforts."

Lastly, two of the students felt as though Darwin was a distraction and had little effect on the learning environment. These responses were:

- "Darwin just felt like he was in the way. He was an addition that I did not need and made very little difference."
- "I feel that Darwin was more of a distraction to me during the test than he was a source of encouragement."

VII. DISCUSSION

By monitoring and acknowledging the beginning and end of tasks, Darwin was able to effectively decrease idle time and maintain the subject's attention. The verbal group was able to perform this objective best with an average test time of 505.4 seconds (Table IV). In addition, the verbal group had a standard deviation (SD) of 72.45 seconds, while the remaining groups had an average SD of 253.54 seconds. This not only shows that the verbal cues were able to decrease time, but they were also able to do so uniformly throughout the group. This small range and SD makes it easier to guarantee a lower test completion time. On the contrary, the group with both verbal and nonverbal cues had a very large range and SD, which is not ideal for decreasing idle time on a consistent basis.

There was a statistically significant variance in how appropriate the subjects deemed Darwin's reactions to be during the test. The nonverbal group thought Darwin's actions were not appropriate with a score of 1.8 (Slightly Disagree = 2; SD = 0.84), while the remaining groups had an average score of 4.3 (Slightly Agree = 4; SD = 0.99). This also supports the freeform responses received from the nonverbal subjects about how "weird" Darwin's movements were during the test. The lack of understanding of Darwin's actions was interpreted as him not giving any feedback at all, which resulted in a more unpleasant learning experience.

Because boredom is often associated with poorer learning and behavior problems [20], it is important to note that there was a statistically significant variance in how bored the subject deemed him- or herself to be throughout the test. For both the verbal group and the group with a mixture of verbal and nonverbal cues, the average response to the question on boredom during the test was 1.8 (Slightly Disagree = 2; SD = 1.07). The nonverbal group followed with a score of 3.4 (Neutral = 3; SD = 1.52), while the group with no agent was the most bored with a score of 4.6 (Agree = 5; SD = 0.55). This shows that the verbal group and the group with both verbal and nonverbal cues were able to minimize boredom the best when compared to the other groups.

Interestingly enough, although two of the students stated that Darwin was a distraction in the freeform responses, the survey question that asked if Darwin was a distraction showed otherwise across these groups. The average score across all groups with Darwin present was 2.3 (Slightly Disagree = 2; SD = 1.35). Overall, the subjects enjoyed taking the exam when Darwin was present. The students in the group with both verbal and nonverbal cues enjoyed the test the most with a score of 4.4 (Slightly Agree = 4; SD = 0.89). The verbal group followed with a score of 4.0 (Slightly Agree = 4; SD = 1.41). Next, the nonverbal group followed with a score of 3.2 (Neutral = 3; SD = 1.48). However, when Darwin was not present, the students did not seem to enjoy the test as much with a score of 2.2 (Slightly Disagree = 2; SD = 1.30).

VIII. CONCLUSION

Across all interaction types – verbal, nonverbal, and both – the subjects enjoyed Darwin's presence. A mixture of both cues and verbal cues only tend to have the least amount of boredom associated with it, which is ideal for a richer learning environment. On the contrary, the group having no educational agent present enjoyed the test the least and experienced the most boredom while taking the test. In regards to minimizing idle time by actively monitoring progression through the exam, the verbal engagement implemented on Darwin was able to reach this goal best. In addition to minimizing idle time, the SD was also extremely low when compared to the remaining interaction types.

Moreover, the average rate of correct answers was 87% (85% for verbal; 85% for non-verbal; 86% for both; and 90% for no agent) with an associated p-value of 0.95. Because there was no statistically significant variance, we

TABLE V

STATISTICAL ANALYSIS OF SURVEY RESPONSES

Topic	Question	Verbal	Nonverbal	Both	No Agent	p-value
Test	I found this test difficult	2.0	2.0	1.6	1.2	0.43
	I performed better on this test than I had anticipated	2.8	2.4	2.4	2.8	0.92
	I was nervous during this test	2.2	3.0	2.0	2.0	0.51
	I finished this test quickly	3.4	3.2	3.4	2.8	0.79
	I was frequently bored during this test	1.8	3.4	1.8	4.6	0.002*
	This test was an appropriate level for my skills	2.6	2.6	4.0	1.8	0.19
	I enjoyed taking this test	4.0	3.2	4.4	2.2	0.07
Darwin	I performed better on the test with Darwin than I would have alone	2.8	2.0	3.0	n/a	0.19
	Darwin distracted me during the test	2.4	2.8	1.8	n/a	0.53
	I was comfortable with Darwins presence	3.2	4.2	4.4	n/a	0.14
	Darwin made me work more quickly than usual	2.4	2.4	3.8	n/a	0.14
	Darwins feedback was helpful	2.8	2.4	4.2	n/a	0.14
	I was afraid of letting Darwin down	2.6	1.8	3.4	n/a	0.15
	Darwin always reacted appropriately during the test	4.2	1.8	4.4	n/a	0.002*
	Darwin made me less nervous during the test	3.4	2.6	3.2	n/a	0.62
	Darwin helped me to stay focused on the test	3.4	2.4	4.0	n/a	0.11
	I like Darwin	3.2	4.2	4.6	n/a	0.20
	Are you interested in taking Darwin to a real test	1.8	2.4	2.4	n/a	0.48

* Statistically significant.

can assume that the interaction type did not affect the quality of the answers. Overall, the use of only nonverbal cues such as gestures shows no significant trends when compared to verbal cues; therefore, this works suggests that verbal engagement is ideal for enhancing test performance in RBE. It is also important to note that after analyzing the completion times, test scores, and boredom and enjoyment levels, anthropomorphism does not appear to have a negative effect on the learning environment.

IX. FUTURE WORK

In this investigation, we have shown that verbal cues alone is able to minimize idle time and decrease boredom when taking a tablet-based math test. In addition, we have shown that a mixture of both verbal and nonverbal cues is not only able to decrease boredom, but also able to maximize the enjoyment involved with taking the exam. The main issue that we foresee with the mixture of both cues is that the range of idle time/test completion time is rather large. With that said, we would like to delve deeper into this issue to see what factors may effectively decrease idle time within the mixed interaction type.

Furthermore, being that the group of individuals tested is very low, we plan to expand the subject pool for further testing to ensure that the results gathered here remain valid. We also would like to redesign the study and include younger children in elementary and middle school for testing. Lastly, we would like to compare and contrast results when other robotic platforms and virtual avatars are used as the educational agent.

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