

Participatory Materials: Having a Reflective Conversation with an Artifact in the Making

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ABSTRACT

Designing and building mechatronic systems has gradually ceased to be the domain of only highly trained professionals and has become broadly accessible. Drawing from a notion of designing as a conversation with the materials of the situation we built an artifact that could actively engage in its own making by embedding a Wizard of Oz operated animated agent into an Arduino prototyping platform. In a 2x2 between-participants Wizard of Oz laboratory experiment with (N=68) high-school students we specifically examined how this prototyping agent's expression of interest affected perceptions of the agent and learning outcomes dependent on the embodiment of the agent as embedded in the prototyping material itself or as an external entity. We found evidence that embedding an agent into the prototyping material can positively influence learning processes and outcomes while not harming perceptions of the agent.

Author Keywords

Prototyping; design; reflection; emotion; learning

ACM Classification Keywords

D.2.2; H.1.2; H.5.2; K.3.1

INTRODUCTION

Designing and building mechatronic systems has gradually ceased to be the domain of only highly trained professionals and has become broadly accessible. The desire to make new technology as easily accessible as possible has led to developments such as the Arduino prototyping platform [28], a small microprocessor board with ports for sensors and actuators and a simple programming interface. The

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introduction of new prototyping platforms is paralleled by an emergence of online communities (e.g. www.instructables.com) that make support for this technology available on demand and in a wide variety of modalities. The DIY Maker Movement is further evidence of this shift in accessibility of highly sophisticated technology.

Based on an understanding of designing as a reflective practice [35, 36], a common feature of toolkits to support prototyping of interactive systems has been to support a reflective process of learning by doing through an integration of rapid cycles of designing, testing, and analysis [15]. For example, SUEDE supported prototyping through iterative development of speech interactive systems [22]. Extending this idea to physical prototyping support, d.tools combined a visual programming toolkit with an extensible physical interface architecture, allowing designers to learn by rapidly iterating through cycles of software and hardware design. Another way of supporting reflective design practice has been through agents. For example, Fischer and colleagues [11], inspired by Schön's work, embedded a software agent into an architectural design tool. The agent offered critiquing statements to promote a reflective design practice. To our understanding, no research has extended this work to physical prototyping contexts and explored the integration of an interested embodied agent into a physical prototyping toolkit.

Inspired by Schön's notion of designing as a conversation with the materials of the situation, we wondered: "What if a prototype in the making could actually converse with its designer?" Would it matter if a prototype seemed to be interested in and care about the designer? We therefore built an artifact that could actively engage in its own making by embedding a Wizard of Oz operated animated agent into an Arduino prototyping platform (Figure 1A). We then observed how high school students with little knowledge about electronics interacted with the electronics prototyping platform. We contrasted this "embedded" condition with an "external" physical prototyping agent (Figure 1B) that was similar to typical external robotic agents that have been used before. Additionally we varied whether the prototyping agent demonstrated an interest in

the designer and design activity by asking interested and reflective questions. Consistent with prior research we found that expressions of interest increase perceptions of liking and social presence. However, we found evidence that the locus of agency significantly affects the learning experience as well. For example embedding the prototyping agent can make the learning task seem less stressful. Finally our study provoked the question whether the technology's expressions of reflective engagement can be beneficial or harmful dependent on the agent's locus of agency.

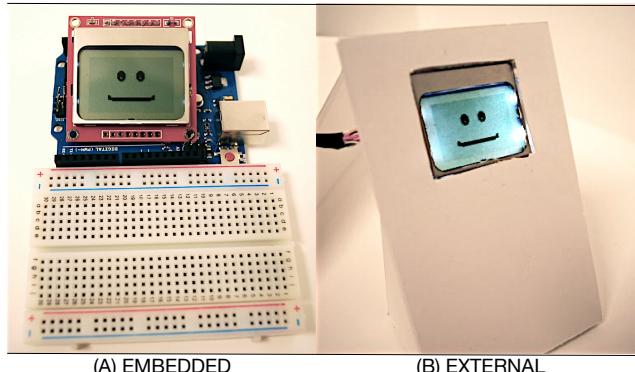


Figure 1 – The embedded and external prototyping agent as used in our study.

DESIGNING AS A CONVERSATION WITH MATERIALS

In contrast to Simon [37] who described designing within an optimization and decision making paradigm, Schön [35, 36] conceptualized designing as a reflective conversation with the materials of a design situation. According to Schön [36:p.4], designers “are in a transaction with a design situation; they respond to the demands and possibilities of a design situation, which, in turn, they help to create.” We aimed to create a design situation in which a prototyping device would actively engage in that transaction by literally conversing with the designer. In essence, we have taken Schön’s notion of design as a reflective conversation to its hyperbolic extreme.

BACKGROUND AND HYPOTHESES

The idea to equip technology with socially engaging interfaces to create effective learning contexts is not a new one. It dates back to 1970 when Jaime Carbonell [5] demonstrated a text-based artificial agent that engaged students by asking and answering questions. Since this pioneering work computer scientists have recognized more and more the importance of the social and affective context in building effective learning environments. Consequently much work has focused on the question of how animated and emotionally expressive agents could be used to improve interactions between people and technology and particularly improve learning outcomes. (See [7, 9, 13, 18] for comprehensive reviews of on-screen agents).

Adding physical embodiment to a social agent is believed to further improve learning outcomes, because physical

embodiment can further increase perceptions of social presence in comparison to an on-screen agent [42, 24, 21]. Therefore it is no surprise that researchers have increasingly explored the use of robots in learning contexts [38, 19, 34].

While many researchers have explored the role of affect in improving learning experiences this work has mainly relied on the role of affect in improving the agent’s believability and in providing feedback about the agent’s state to the learner [3]. Not much work has exploited the relational functions of emotions in regulating the quality of interpersonal interactions. The only exception is the work by Saerbeck and colleagues [34], who found that a socially supportive robot that expressed relational empathic engagement verbally and non-verbally towards students (e.g. by smiling and nodding) increased motivation and objective learning outcomes in comparison to a non-socially supportive robot.

Consistent across all studies on physically embodied agents (independent of their roles as companions, tutors, experts, or students) is their embodiment as entities separate from the learning medium or learning content. To our knowledge no research has explored how the quality of the interaction with an interested agent and its learning outcomes are affected when the agent is embedded in a physical learning medium itself, such as an electronics prototyping toolkit. Our research therefore aimed to explore how an agents’ display of interest in the designer and the design activity, affects learning relevant outcomes under different conditions of the agent’s locus of agency.

Interest and Perceptions of the Agent

Showing engagement and expressing interest towards a person is one of the most effective ways of rapidly building fruitful interactions. Successful negotiators use interest frequently at the beginning of negotiations because interest expressions set a positive tone that is flattering and orients the addressed party positively towards the person expressing interest [30]. People expressing engagement through interest become more likeable and they make the addressed party more susceptible to influence [30]. Additionally interest signaled through attentiveness plays a critical role in the early stages of building rapport between people [40]. To our understanding there is no prior work examining how interest displayed by an agent (towards the person interacting with it or towards the activity that that person is engaged in) affects interaction processes and perceptions of the agent itself. However based on theory that people interact with technology in much the same way as they interact with other people we expect that interest displayed by an agent will have the same effects on perception as displayed by a person [31]. Additionally there are indications that animated-ness alone is enough to affect perceptions of agents positively. For example, Koda and Maes [23] found that people perceived an agent with an animate face more likeable and engaging than an agent without a face. Similarly Baylor and Ryu [4] found an

animated learning agent more engaging and socially present (person-like) than a non-animated learning agent. In sum, we expect that:

- H1: Agent Likeability – Irrespective of the agent's location, a prototyping agent that displays interest in the designer and the design activity will be perceived as more likeable than an agent that does not express interest towards the designer.
- H2: Agent Social Presence – Irrespective of the agent's location, a prototyping agent that displays interest in the designer and the design activity will be perceived as more socially present than an agent that does not express interest towards the designer.

Locus of Agency and Task Perception

Embedding a social agent into the electronic prototyping medium eliminates the need to split attention between the prototyping medium and an external agent. Previous research found a tendency of typical external learning agents to distract from the learning task [41, 9]. Further, such distractions by an external question asker have been shown to increase stress during a problem-solving task [27]. We therefore expect that an external agent causes stress by diverting attention and disrupting the prototyping activity:

- H3: Task Stressfulness – Participants will perceive the task as less stressful when interacting with an embedded prototyping agent than when interacting with an external prototyping agent.

Locus of Agency and Interest and Subjective and Objective Learning Outcomes

"To be interesting, be interested! [6, p. 88]." This wisdom from the self-help corner of your local bookstore reflects the finding that interpersonal expressions of interest compel a complementary or reciprocal response [20]. Emotions such as interest are contagious – people mimic each other's emotional expressions and converge emotionally [13]. For example Barsade [2] showed that one confederate's expressions are enough to influence the emotional tone of an entire group and thereby group outcomes. It is no surprise that negotiators use interest statements to draw attention towards them in a favorable way [30]. Finally, Hancock and colleagues [14] showed that emotional states are contagious even over chat demonstrating that a full spectrum of behavioral modalities is not required to transfer emotional states. Given that people have a tendency to treat technology as social actors [31], we expect that a learning agent's expression of interest will be contagious as well and induce positive affect in the learner. Feeling more positive can be expected to improve learning performance as positive affect has been shown to favorably influence many learning relevant processes such as creativity [12], problem solving [17], and learning motivation [32].

We also expect the locus of the agent's agency to have an effect on subjective as well as objective learning outcomes.

Students learn better when verbal and visual materials are close together [29]. In line with this finding, a long-standing critique of animated agents has been that they can hamper performance as they can divide attention away from the task and be distracting [9]. This idea is supported by a study in which a learning agent making non-task related comments was perceived as more memorable but also as more distracting [41]. Embedding a learning agent into the prototyping medium itself guides attention towards the task, is less distracting and therefore can be expected to have a favorable impact on subjective and objective learning outcomes. In summary we hypothesize that:

- H4: Subjective Learning Outcome – Interacting with an interested prototyping agent will lead to improved subjective learning outcomes (as measured by how confident participants feel about their acquired electronics prototyping skills) in comparison to interacting with a non-interested agent. At the same time interacting with an embedded agent will improve subjective learning outcomes in comparison to interacting with an external agent.
- H5: Objective Learning Outcome – Interacting with an interested prototyping agent will lead to improved objective learning outcomes (as measured by the prototyping performance in an open-ended prototyping task) in comparison to interacting with a non-interested agent. At the same time interacting with an embedded agent will improve objective learning outcomes in comparison to interacting with an external agent.

THE EXPERIMENT

In a 2 (locus of agency: embedded vs. external) x 2 (prototyping agent interest: interested vs. uninterested) between-participants experiment (N=68), we studied the effects of an interested physically embodied agent and its locus of agency on agent perceptions, task perceptions, and learning outcomes. Participants were guided through an electronics building and programming tutorial by the agent. After participants completed the tutorial and a questionnaire, the agent was turned off and participants prototyped on their own for up to 15 minutes.

Participants

68 high school students (35 men and 33 women, balanced across conditions) ages 15 to 18 ($M = 16.6$, $SD = 0.63$) participated in our experiment. We recruited all participants from a high school summer program at a research university. Each student received a \$15 gift certificate.

Manipulations

Interest Manipulation

The expression of interest towards the participant and the prototyping activity was modeled after a behavioral description of interest as it occurs in marital interactions

[8]. Features of interest include: 1) non-verbal attention and positive affect (i.e. eye contact, nodding, smiling), 2) open ended questions and 3) Elaboration and clarification seeking. In conditions where the agent was interested in the participant, the agent's face showed attention and positive affect through facial expressions (i.e. nodding when the participant answered a question, smiling when the user lit up the LED). This was done following a Wizard-of-Oz protocol by which an experimenter viewing the subject from a camera controlled facial expressions. The agent also asked open ended, interest questions, that were intended to demonstrate an engagement with the prototyping activity itself: "This looks very interesting. What are you doing right now?" If the participant responded to the question then the agent sought elaboration with a request to know more about the participant's answer. These responses were highly generic and pre-programmed. Unlike previous designed social agents that attempted to figure out what the user was doing and try to help them, such as Microsoft's Clippy, our device simply gave tutorial instructions and asked questions. The device then responded no matter what the user was saying or doing. It was our goal that the prototyping device itself would be perceived as the social agent rather than as a social agent external to the prototyping medium.

In uninterested conditions the agent's face moved randomly, without attention, but with similar frequency to interested cases. The agent made neutral statements such as "Building electronics can take a lot of time" and did not seek elaboration. Verbal and non-verbal behaviors for each condition are listed in Table 1.

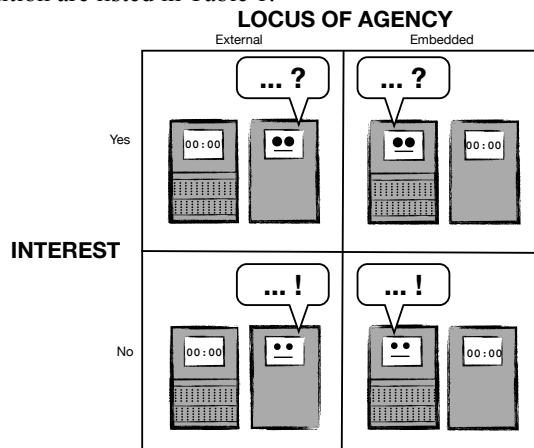


Figure 2 – Overview of experimental conditions with the prototyping platform on the left and the “box” on the right.

Locus of Agency Manipulation

Locus of agency was manipulated by placement of the LCD face, speaker, and foam-core housing in relation to the Arduino and breadboard used by the participant. We built both embedded and external foam-core agents with the same LCD to ensure that we manipulated locus of agency and not other parameters. Additionally, the speaker was

placed behind the LCD to link the face and voice as one agent.

In embedded conditions, the prototyping agent was embodied on the device that participants were building. The LCD face was placed on top of the Arduino with a breadboard underneath, giving the sense that the Arduino and breadboard were part of the learning agent. The external model was programmed to be a digital clock. When embedded, spoken instructions referenced the device itself using phrases such as "Start building the circuit on *my* breadboard." The speaker was placed underneath the onboard device so that the voice and face were linked.

During external conditions where the agent was embodied off-device, the external model had a face and the embedded screen was made into a digital clock. The agent then referenced the Arduino board and breadboard as objects, using phrases such as "Start building the circuit on *the* breadboard." The speaker was placed behind the external model to link the voice and face as one unit.

	Interest: No	Interest: Yes
Non verbal behavior	Random display of facial movement according to the following distribution: Gaze: 56% Smile : 2% Nod: 5% Confused: 2% Focused: 3% Neutral: 32%	Reactive non-verbal movement according to a specific protocol: A hidden experimenter who observed the participant's behavior through a camera controlled the behavior. The non-verbal affective behavior of the agent was mimicking that of the participant. For example if the participant smiled, the agent smiled back.
Verbal Behavior	<p>Five factual statements:</p> <ol style="list-style-type: none"> 1. "Building a circuit can be very interesting." 2. "Making electronic devices takes a lot of time." 3. "Almost all new technologies use electronics." 4. "You have three different parts you can use to build this circuit." 5. "Many new devices have complicated electronics." 	<p>Five open ended questions with follow up:</p> <ol style="list-style-type: none"> 1. "You can make pretty much anything with electronics. What's the coolest thing you would like to work on?" Follow up: "Cool! Tell me more." 2. "This looks really interesting. Can you tell me what you are building right now?" Follow up: "That is interesting. I'd like to know more." 3. "Building electronics can take a lot of time. What are you working on right now?" Follow up: "Can you tell me more about that?" 4. "You are using all these neat parts. Is there one that you find really interesting?" Follow up: "Can you tell me more about that?" 5. "This looks quite complicated. What's the most complicated thing you have ever made?" Follow up: "Oh! I'd like to know more."

Table 1 - Interest manipulation behaviors

Procedure

After completing a parental consent form (if participant was under 18), participants were invited to the lab. Upon arriving, participants signed an assent form and filled out an online pre-task questionnaire, collecting information on their personal and academic backgrounds. After completing the questionnaire, participants were asked about their experience with building electronics and programming. The researcher then reminded students that no experience was required and that the participant would be completing a tutorial with the learning agent. The experimenter gave a brief tutorial on the components used during the task such as the Arduino, breadboard, and programming environment. The experimenter then left into another room to control the agent (unbeknownst to the participant).

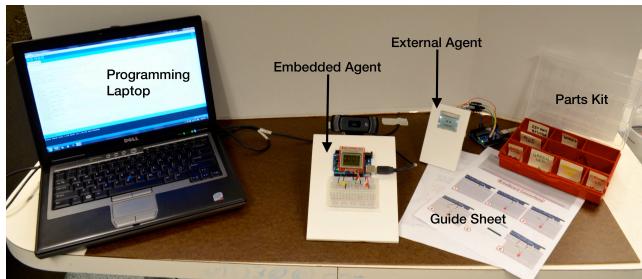


Figure 3 – Setup as participants saw it.

The tutorial began when the agent spoke, saying “Let’s learn how to light up a light emitting diode (or LED) using my/a [depending on condition] microprocessor board and a breadboard.” Participants were either guided through the task by the agent embedded in the Arduino board itself or by the external agent depending on the locus of agency manipulation. During the task, the agent guided the participant through building and programming a blinking light circuit using a guide sheet with illustrations. The agent asked open-ended interest questions or made factual statements, dependent on whether people interacted with an interested or uninterested agent, respectively. An example of an interested, embedded interaction would be as follows:

Agent:	Are you ready to get started?
Participant:	Yes.
Agent:	<i>My microprocessor board has numbered pins or little holes in black boxes that we can plug wires into to control electronic components. Lets get started by grabbing some components. Grab your favorite color LED, a 220 ohm resistor, and 3 short wires from the box. Do you have all the parts?</i>
Participant:	Yes.
Agent:	OK, Lets start building the circuit. Start with picture 1 and let me know when you are done.
Participant:	OK, I’m done.
Agent:	You can make pretty much anything with electronics. What’s the coolest thing you would like to work on?
Participant:	Flashing lights.
Agent:	Cool! Tell me more!
Participant:	I’m interested in concert experiences and I like it when, uh, when concerts, when lights start flashing to the beat of music, and I’m interested in seeing how that works and how I can improve that technology.

If an issue arose or a participant became stuck on a step during the experiment a researcher would enter the room and help the participant complete the step. Once the participant completed the task, a researcher came into the room and instructed the participant to complete a questionnaire. At this time, the agent was turned off and all continuing prototyping activity was unmediated by the agent. After completing the questionnaire, the researcher then instructed the participants to build anything of their choosing. Participants could use more electronics components, the programming environment, and additional craft supplies (paper, scissors, and markers) to create a device. Participants were told they could take as much time as they would like, but the researcher would stop the participant after 15 minutes. Participants were then debriefed and discussed the study with the researchers.

MATERIALS AND MEASURES

Learning Agent Design

The prototyping agent was comprised of an Arduino UNO, a Nokia 5110 LCD display, a small speaker, and a foam-core housing. The agent was designed to interact both non-verbally and verbally with the participant. Non-verbal expression of interest was accomplished by displaying a stylized face with various emotional expressions and by moving it on an LCD display. We designed a pallet of expressions that could be used to signal interested engagement nonverbally: making eye contact with the speakers, gazing, smiling, frowning, and nodding during a conversation. The LCD backlight was lit during each facial transition to draw the participant’s attention. During neutral states, the LCD cycled in brightness in a periodic “breathing” pattern to evoke a sense of presence. Facial movement was controlled by one of the researchers or randomly via a Processing script. To allow the agent to communicate verbally, a small speaker was placed behind the LCD screen and foam-core housing. We used this verbal communication to give tutorial instructions and to either ask interested questions or neutral statements. The Mac OSX “Apple Alex” voice with a US English linguistic style was used at normal speed. The tutorial prompts and questions were pre-written and triggered by one of the researchers during each experiment. The agent was embodied in a simple, white, foam-core box. This allowed for the faces to be the most prominent feature of the device and keep a consistent aesthetic between both the embedded and external agents. To control for the devices having screens, both the embedded and external models were present among all conditions with the unused agent displaying a digital clock.

Electronics Prototyping Task

The experimental protocol included two types of prototyping interactions. The first was a scripted, tutorial-like prototyping exercise. The second was an open-ended prototyping exercise. During the experiment, the

participants completed a short electronics and programming tutorial modeled after the introductory activity in *Getting Started with Arduino* using the Arduino UNO development board [1]. The learning agent guided participants on how to make a light emitting diode (LED) blink using a numbered Arduino pin as an output. The task included circuit building and short programming sections. Participants used a breadboard, wires, LEDs, and resistors to create their circuits. Participants programmed the Arduino using a laptop computer and a modified version of the "Blink" example source code in the Arduino IDE. After completing the tutorial, students were given 15 minutes to explore the Arduino prototyping environment using more electronics components, without the aid of the agent.

Measures

Measures of 1) liking of agent, 2) agent social presence, 3) task stressfulness, 4) electronics prototyping confidence, and 5) prototyping performance were collected during this study. Liking of agent, agent social presence, task stressfulness, and prototyping confidence were collected using 10-point, Likert questionnaire items given directly after the guided tutorial. Objective learning outcome was measured through video analysis of the 15-minute unguided exploratory activity. In addition to these exploratory measures, we also had manipulations checks for the participant's perception of agency location and interest.

Agent Perception

Agent perception was assessed by measuring Liking of Agent and Agent Social Presence. Liking of Agent was operationalized as a three-item index. We asked participants if they thought the device which guided them through the task was Friendly, Likeable, and Fun. Items were rated on a 10-point Likert scale ranging from "describes very poorly" (1) to "describes very well" (10). This index was reliable (Cronbach's $\alpha = 0.71$).

The Social Presence measure was operationalized using a standard social-presence measure [24]. Items were rated on 10-point Likert scales ranging from "not at all" (1) to "absolutely" (10). The index was reliable ($\alpha = 0.70$).

Task Perception

We assessed task perception by measuring how stressful participants perceived the task to be. Task stressfulness was operationalized as a three-item index. Participants rated on a 10-point Likert scale ranging from "describes very poorly" (1) to "describes very well" (10) how much the task experience could be described as Stressful, Afraid, and Made Me Nervous. The index was reliable ($\alpha = 0.70$).

Learning Outcomes

Subjective and objective learning outcomes were assessed by measuring prototyping confidence as well as prototyping performance, respectively. Our prototyping confidence measure was operationalized as a four-item index adapted

from a study on evaluating self-efficacy during a soft circuits curriculum [26]. The following items were based on a 10-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (10): i.) I am confident that I can draw a diagram of a simple circuit, including a light and a battery, ii.) I can easily build a simple circuit from a light and a battery, iii.) I am confident in my ability to explain what I built today to a friend, and iv.) I can easily learn how to make electronic devices that are more complex. The index was highly reliable ($\alpha = .89$).

The objective prototyping performance measure was operationalized by coding the video records that were made during the open-ended prototyping phase. We coded three dimensions – hardware, software, and aesthetics of the student's prototype on a three-point scale (1 = small attempt to change device, such as moving the LED to 3 - impressive attempt to change the device, such as adding three LEDs and making a stop light). These three scores were summed to create an overall prototyping performance score.

RESULTS

All measures were analyzed using two-way analysis of variance (ANOVA). Agent perception, task perception, learning outcomes, and manipulation checks were analyzed with Agent Interest and Locus of Agency as independent variables. All analyses were preformed with 62 participants. Six participants (3 from each of the embedded and external interested conditions) did not respond to all initial questions of the agent and were removed from the final analysis as their non-responsiveness led to a different experimental treatment from the other participants.

Manipulation Checks

To confirm the intended manipulation of the agent's locus of agency we asked participants to select the image of the agent that interacted with them was located (1:External, 2: Embedded). As expected, participants in embedded conditions recognized the agent as embedded in the prototyping board ($M=1.97$, $SD=0.041$) and participants in external conditions recognized the agent as external ($M = 1.06$, $SD=0.039$), $F(1,62)=259.9$, $p<0.001$.

To confirm the intended manipulation of expressed interest by the agent we asked participants "The talking device was interested in me." on a 10-point Likert Scale ranging from "describes poorly" (1) to "describes well" (10). As intended, participants of interested conditions rated the learning agent as more interesting ($M=7.9$, $SD=0.366$) than in uninterested conditions ($M=6.29$, $SD=0.331$), $F(1,62)=10.7$, $p<0.002$.

Agent Perception

As expected from H1, participants rated the interested learning agent ($M=7.8$, $SD=1.6$) more likeable than an uninterested learning agent ($M=6.7$, $SD=1.4$), $F(1,62)=4.95$, $p<0.05$. Pairwise comparison of external agent cases uncovered a marginally significant difference between

interested and uninterested conditions $F(1,32)$, $p<0.10$ (Figure 4A).

We found a significant main effect in agreement with H2. Participants perceived the interested agents as having more social presence ($M = 6.9$, $SD = 1.3$) than the uninterested agents ($M = 6.0$, $SD = 1.3$), $F(1,62)=6.506$, $p<.05$. Pairwise comparison confirmed that participants rated the interested agent significantly higher during onboard conditions, $F(1,30)=10.88$, $p<0.05$ and marginally significantly higher for external conditions $F(1,32)=7.53$, $p<0.1$ (Figure 4B).

Task Perception

As expected in H3, we found a main effect for agent location on perceived task stressfulness, with participants rating the task as more stressful when the agent was external ($M=3.5$ $SD=1.7$) than when it was embedded ($M=2.7$, $SD = 1.4$), $F(1,62)=4.19$, $p<0.05$. Pairwise comparison confirmed that participants rated the external condition more stressful than the embedded condition during interested cases, $F(1,30)=4.74$, $p<0.05$. There was also a marginally significant difference with participants reporting more stress during the interested condition and less stress during the uninterested condition for external conditions, $F(1,32)=2.855$, $p<0.1$ (Figure 4C).

Learning Outcomes

H4 was not supported. We found no significant main effects for agent locus or agent interest on prototyping confidence. However, we found a significant interaction effect for agent locus and agent interest $F(1,62)=5.17$, $p<0.05$. Pairwise comparison showed that participants reported higher confidence when using an interested embedded agent over an interested external agent $F(1,28)=4.67$, $p<0.05$. There was also a marginally significant difference of participants reporting higher confidence with the interested embedded agent over the uninterested embedded agent, $F(1,30)=3.50$, $p<0.10$. (Figure 4D).

H5 also received no support. We found no significant main

effects for agent locus or agent interest on participant's prototyping performance. Instead we found a marginally significant interaction between agent locus and agent interest, $F(1,62)=3.16$, $p<0.10$. Pairwise comparison revealed that participants of uninterested, external conditions had higher performance than participants of interested, external conditions, $F(1,32)=5.9$, $p<0.05$. Participants also preformed significantly better during uninterested, external conditions over uninterested, embedded conditions, $F(1,32)=4.04$, $p<0.05$. (Figure 4E).

DISCUSSION

When one talks about participatory design, one usually thinks about the end users. In this study, we bring the notion of "participatory design" to the technology itself. That is, we ask the question whether it makes a difference whether a technology is engaged and involved in its own creation. While the results are preliminary, we found evidence that embedding an agent into a prototyping medium can have definite advantages over the use of traditional external agents. In particular an embedded agent was perceived as more socially present and likeable than an external agent and reduced task stressfulness.

Hypotheses 4 and 5 received no support, but more interestingly we found significant cross-over interactions for interest and locus of agency on prototyping confidence and prototyping performance. Pairwise comparisons of the treatment groups revealed that although the agent looked identical in all conditions, having the agent speak about itself had powerful effects. In combination these results could indicate that interest affects learning processes differently dependent on its expression by an external or an embedded agent. More specifically, interest could have negative learning consequences when expressed by an external agent and positive impact when expressed by an embedded agent.

An explanation consistent with these observations is that interest led to an increase in attention towards the learning

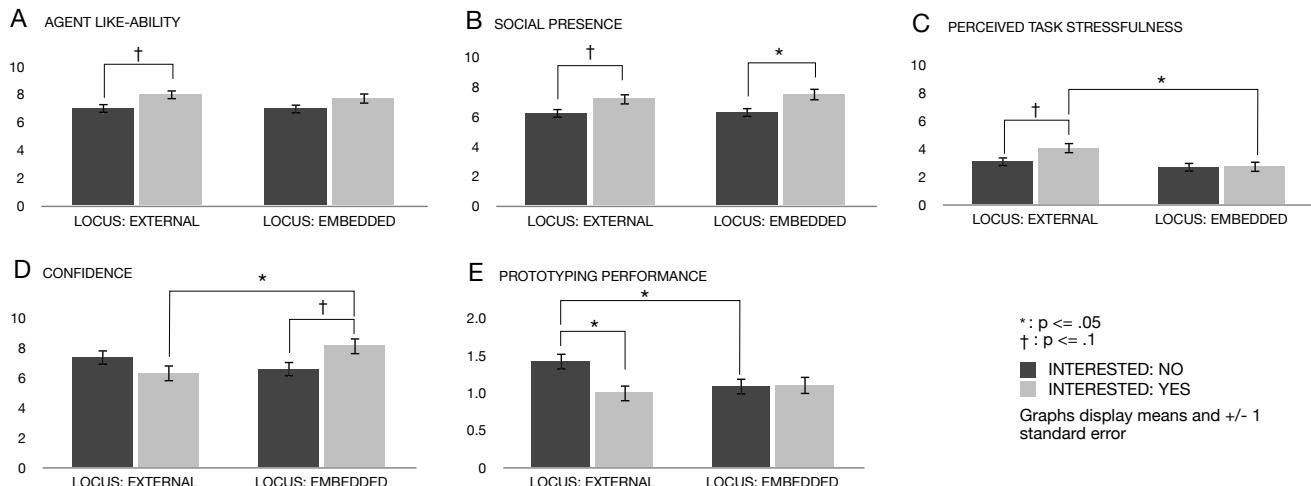


Figure 4 – Results for Agent Like-ability, social presence, perceived task stressfulness, confidence, and prototyping performance.

agent as it was involved in highly engaged and lengthy “conversations.” In the external agent condition, interest expressions might therefore have guided attention away from the task, making the agent seem distracting and interruptive. The negative impact of the distractiveness might have outweighed the positive impact of interest on learning process. On the other hand, in the embedded agent condition interest expressions might have guided attention towards the task, allowing the user to fully harness the positive effects of interest without pulling attention away from the task. In line with this idea, Thrun and colleagues [39] demonstrated that behaviors associated with the expression of interest such as smiling, looking at people, and positive emotional speech content can be highly effective behaviors for robots to compel the attention and engagement of museum visitors. Given that some positive emotions have different relational effects and some are more attention-grabbing than others, these findings could also explain why some researchers reported animated learning agents to have negative impact on learning outcomes by being distractible [9, 41] while others found no such distracting effects [19].

Limitations

An important limitation needs to be addressed. We do not know if the effects we found are mediated by role-perceptions of the agent. Expression of interest and locus of agency could both influence the perception of the agent’s status, or role. For example when the agent was external it might have been perceived as a teacher, higher in status, and therefore more dominant than when the agent was embedded. An external agent asking questions might be perceived as more controlling and expert than an embedded agent – which was talking about itself – doing the same.

Embeddedness might have led to a perception of the agent as more of a peer and therefore resulted in different learning outcomes. However we did not find any qualitative evidence that participants referred to the agent differently under our various experimental conditions. In support of this, our manipulation check confirmed that a question-asking agent was perceived as genuinely interested

independent of its locus of agency. Additionally we asked participants to rate on a 10-point Likert scale ranging from “Not at All” to “Absolutely” as to “How much did you feel as if you and the talking device were a team?” We found no significant differences for this measure of the participant’s perception of the agent as a teammate between either the non-interested ($M = 5.29$, $SD = 0.00$) and interested ($M = 6.16$, $SD = 0.00$) $F(1,62)=0.834$ $p=.21$ conditions nor between the external ($M = 5.38$, $SD = 2.78$) and embedded ($M = 6.00$, $SD = 2.93$) $F(1,62)=0.834$, $p=.34$ conditions.

Qualitative Observations

One of the most striking outcomes of our study was how powerful the interest manipulation was in engaging the students in short meaningful conversations with the agent. Many students shared personal stories with the agent:

- Agent: This looks quite complicated. What's the most complicated thing you have ever made?
 Participant: The most complicated thing I have ever made was trying or attempting to work an electromagnetic induction system, and it worked, but it took a lot of time.
 Agent: Oh! I'd like to know more.
 Participant: So me and my friend, as I told you earlier, were working on this self-sustainable engine, and we worked a lot on it, and we were using electromagnetic induction to create the energy we need, and so we spend a lot of time developing this technology, and that was the most sophisticated or complicated thing I have ever worked on, but it is not the only complicated thing that I have ever worked on. (OI-04).

The follow-up question in particular seemed to have been effective in encouraging interactions. Often, these interactions led participants to reflect on their designs. For example:

- Agent: Building electronics can take a lot of time. What are you working on right now?
 Participant: I'm working on building a light, uh, an LED light.
 Agent: Can you tell me more about that?
 Participant: So, I basically started by connecting the ground, uh, ground, uh, what's it called, circuit, no, not circuit, I created a circuit by connecting the wires from the ground, uh, like thing and then I created a flow of electrons and that flow of electrons will release photons that will go in the light that I chose and it will create the energy, uh, light, there, and I placed a resistor there, so that there will be no extra electrons that will damage the LED light that I created.

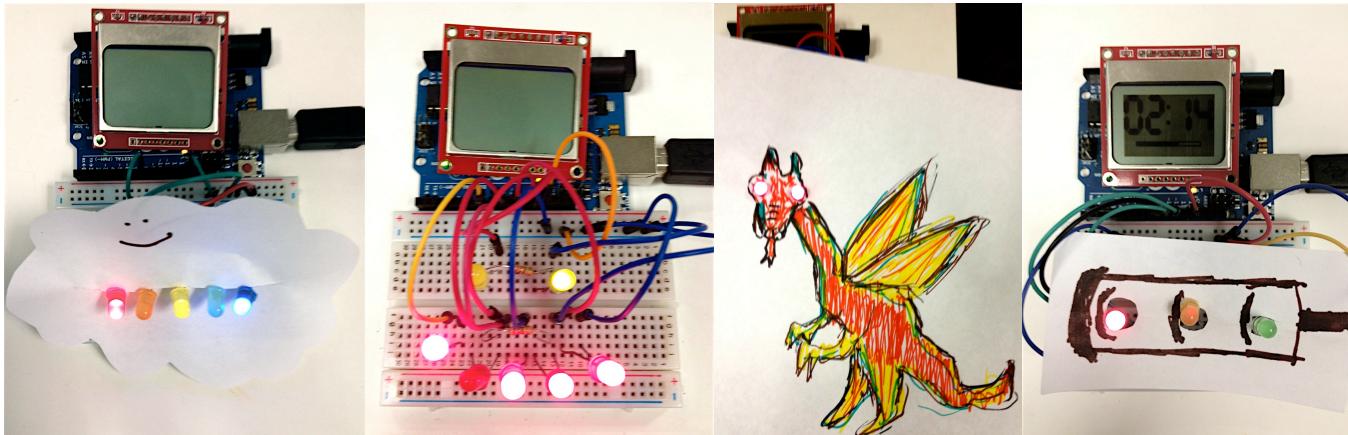


Figure 5 – Example designs built by the participants during the open-ended prototyping phase.

An ANOVA with question type (initial vs. follow-up) and agent locus (external vs. embedded) as independent variables and the average time spent to answer all five question as dependent variable confirmed that follow-up questions provoked significantly longer answers ($M=46.5$, $SD=42.8$) than the initial questions ($M=22.2$, $SD=17.1$), $F(1,56)=2.804$, $p<.01$.

This finding is especially interesting because the reflections of the students were so rich compared to the generic nature of the questions and responses made by the device. This suggests that future systems may not always need to be highly intelligent and situation aware. Instead systems may use open-ended questions about the thoughts of the designer to provoke meaningful reflection. Additionally, through interested inquiry the devices cannot be “wrong” about what is going on, thus preventing the devices from appearing “dumb” and hindering the experience of the designer.

Finally, students responded differently to an on-board and an off-board agent. For example, when interacting with an external interested agent, eight participants responded with “I don’t know” when being asked a question. When interacting with an embedded interested agent only one participant reacted in that seemingly defensive way, a highly significant difference, $p<.001$, suggesting that a device talking about itself elicits more engagement.

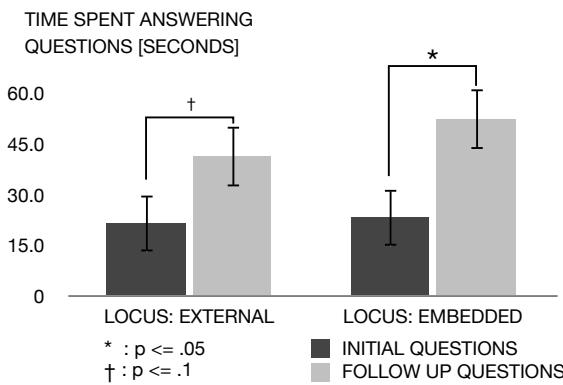


Figure 6 - People spent on average twice as much time answering the follow up questions than the initial questions.

CONCLUSION

Our study is the first to explore the strategy of embedding an active participatory agent into a physical prototyping platform in order to create more engaging and reflective design interactions. Although we are still far from our design materials actually being able to converse with us, our study has shown that even simple, programmed comments can enable reflective conversation. Extending upon the basic questions we have asked, we imagine being able to use the format of generative design questions [10] to further enable interactive conversation among designers.

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