Using Need Validation to Design an Intelligent Tangible Learning Environment

Abstract
Tangible learning environments may be improved if combined with another successful educational technology, intelligent tutoring systems. However, design principles for tangible environments and intelligent support are often at odds. To reconcile these differences, we employ a need validation methodology to understand student needs in an intelligent tangible learning environment. We found that students seek activities that provide them with feelings of discovery, inter-group competition, and an appropriate level of challenge. In addition, students value physical movement, interactivity, and perceived relevance to their learning objectives. We discuss design implications of these findings for combining the benefits of tangible learning and intelligent support systems.

Author Keywords
Tangible learning environments, intelligent support systems, user-centered design.

ACM Classification Keywords
H5 Information interfaces and presentation; K.3.1 Computer Uses in Education
**Introduction**

By identifying effective education technologies and integrating them into a single powerful system, we may be able to combine the strengths of multiple approaches. One technology that could have a large impact on learning is *tangible learning environments* (TLEs), where students interact in a physical space with digitally augmented devices. In theory, these environments help learning because they encourage sensory engagement, active manipulation, and physical activity [7, 10]. Despite this promise, there has been little empirical evidence for these environments’ benefits [3]. These environments might not be as successful as they could because they provide students with little explicit support, despite evidence suggesting that, at least in some domains, explicit support is important for learning [4].

Adding intelligent support components to tangible environments might be one way of making them more effective. Intelligent tutoring systems (ITSs) model student knowledge and problem-solving skills, and use this model to provide tailored support such as hints, feedback, and problem selection [11]. These systems yield dramatic learning gains in science and math domains in K-12 classrooms [e.g., 5].

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Table 1. Difference between tangible learning environments and intelligent support environments.

ITSs and TLEs often have conflicting design principles (see Table 1). In articulating the motivation for tangible learning environments, researchers have taken constructionist perspectives, where students generate knowledge through the process of constructing a meaningful artifact [8]. Encouraging this approach to learning necessitates that certain assumptions be made about the learning activity: students define their own goals for what they want to achieve, and they use digital tools to support themselves in achieving the goals [6]. In contrast, intelligent tutoring principles emphasize that learning objectives should be well-defined, so that appropriate scaffolding can be designed and student behavior can be easily modeled. Feedback and help should be given in order to keep students moving along that well-constrained and pre-defined path. Ideal intelligent support within a tangible environment will provide guidance students need to benefit from the environment without sacrificing the freedom that tangible environments afford.

Our overall research goal is to determine how to augment tangible learning environments with intelligent support to create *intelligent tangible learning environments* (ITLEs). Our approach involves three steps: 1. Use a design space to generate ideas that combine instructional and motivational principles, 2. Get user input on design concepts, 3. Analyze data by focusing on needs, not activities.

**Design Space & Concepts**

Our first step was to generate several concepts for ITLE activities that incorporate user needs. We constrained our ideation in two ways. First, we chose middle and high school geometry as our learning domain, with sample tasks ranging from plotting ordered pairs to proving two triangles are similar. Second, we chose an iRobot Create as the central piece of technology to incorporate into our ideas, inspired by Papert’s Tangible Logo [9]. Off the shelf, the iRobot Create is capable of running simple programs that allow it to move forward and backward and turn left and right. As part of brainstorming, we relaxed most technological constraints on the robot. We assumed that users could interact with the robot using gestures or speech, and
that they and the robot could interact with projected geometry figures in the environment.

We engaged in structured brainstorming, using a framework for educational game design developed by Aleven and colleagues [1] that suggests that while brainstorming, designers consider both instructional and motivational principles (which they refer to as aesthetics). We selected four instructional principles to explore based on our analysis of the literature on TLEs and ITSs: tangible representation, embodied interaction, scaffolded problem-solving, and student-agent relationships. We then chose four motivational principles described by [1] that were most relevant: Discovery, challenge, fellowship, and narrative.

We generated 24 scenarios spanning the full range of concepts related to use of the iRobot that we might be interested in exploring. Each scenario employed at least one instructional and one motivational principle that we had selected. In some cases, the use of the motivational principle was negative, in that it provided students with the opposite of what we believed might be motivating. Each scenario had three storyboard panels to be read in sequence from left to right, with captions explaining what was going on. Figure 1 is a scenario that primarily engages the instructional principle embodied interaction, as the robot and the students are interacting with a geometric figure in physical space. It is a positive example of the motivational principle discovery, as a surprise figure appears upon successful completion of the problem. In the Scenarios, we called the iRobot “Rover.”

**Need Validation Method**

We used the scenarios as a tool for soliciting user reactions and ideas by applying need validation, the first component of Davidoff and colleagues’ Speed Dating design method [2].

**Participants**

Three groups participated in need validation for a total of 11 participants (five in Group 1, three in Group 2, and three in Group 3). Participants were each paid $20. Participants were between 13 and 16 years old ($M = 14.9$), and all but two participants had already taken geometry. Students within a group knew each other, having signed up for the study together.

**Procedure**

Design sessions lasted two hours. We began by explaining the purpose of the sessions to students and demonstrating the functionality of the iRobot. Sessions then consisted of four alternating periods of soliciting
user reactions and asking users to generate ideas. For the user reactions phases of the sessions, we focused on the use of sketches (based on the scenarios described above) to solicit user feedback. Following need validation [2], we presented students with each sketch, and asked a discussion question. Once students were done discussing a sketch, we presented them with the next sketch. Sketches were aggregated into themes (e.g., feedback delivered by the robot), with an average of six sketches related to a theme. We presented students with all sketches related to one theme prior to moving on to a brainstorming phase. For the user brainstorming phases of the sessions, we used the sketches students had just seen as a jumping-off point for brainstorming. For some groups, participants found it natural to sketch their ideas; for others they simply brainstormed by discussing ideas with the rest of the group. Once participants stopped generating ideas, we moved on to the next user reactions phase.

Analysis
We audiotaped the sessions, and retained student sketches as data. In our analysis, we looked for two aspects of student reactions [2]. First, we identified strong positive and negative reactions to elements of scenarios that we had purposefully introduced (e.g., discovery, fellowship, challenge, and narrative). We drew links between these strong reactions and student ideas during brainstorming. Second, we identified recurring emergent themes we had not purposefully introduced that students brought up spontaneously during user reactions and brainstorming.

Results: User Needs
Strong Reactions
Our first method of analysis was to look for strong positive or negative reactions to elements that we had introduced into the sketches. The need of discovery resonated with students, where something previously hidden was revealed as part of learning activities. We illustrate this finding with student reactions to a connect-the-dots scenario, which was designed to prime the discovery reaction (see Figure 1). When we designed the scenario, undergraduate pilot subjects considered it to be one of the least exciting scenarios, as it simply involved a figure appearing when points were correctly plotted on the graphs. However, the reaction of the middle and high school students were different. Students responded excitedly: “I think it’s a good idea... it’d be fun, like, to try to get the mysterious picture, and see what it is.” (P11).

We also presented students with several ideas attempting to prime their feelings of fellowship. We had thought that scenarios where students worked together would be motivating to students. However, the ideas that resonated the most were the ones that specifically involved intergroup competition. A sketch that got one of the most positive reactions was one where groups would teach their robot different shapes, and than the robots would face off to see who could draw the most shapes. In direct relation to the sketch, P5 said, “That’s cool that different ones would face off, I like that”, with P3 responding “It would get everyone really excited”.

Students had some of their most emphatic reactions to scenarios that had examples of interactions that were too challenging or not challenging enough. Students had strong negative reactions to scenarios that they felt
supplied little support, such as A in Figure 2. They complained about doing a lot of work without perceiving the value, “Hmm, this [has] happened to me… I did all of this, and I have to figure out where I went wrong” (P6). On the other hand, students also reacted to too much feedback, as depicted in C in Figure 2. They commented: “I don’t think Rover should tell them what they did, because, they have to, like, figure it out.” (P9) Student comments relating to challenge nearly always focused on the motivational elements rather than on the cognitive elements. They expressed a desire to demonstrate their knowledge, going so far as to say: “I’d rather teach it something rather than having it teach me something” (P1).

Emergent Needs
In addition to students reacting strongly to elements of the scenarios that we had purposely introduced, there were three additional needs mentioned repeatedly by the students. The enjoyment students predicted over the simple act of physical motion was a theme that occurred across several scenarios. P5 said, when talking about the sketches in general: “We’re at school 7 hours a day, sitting in the classroom with, like, off-gray walls… it’s like a prison… You get to like jump up and move around… that’s like great for your mind.”

Interactivity was another theme that was brought up repeatedly during the design sessions. Students often referred to simple forms of interactivity with high enthusiasm. When discussing the idea of a projected figure, one student said, “And then you’d probably get color too…” “cause graph paper is boring. If it’s projected, you can try to make it fun” (P8). When brainstorming, students referred to specific features of the problem that could become interactive, saying things like, “Make angles turn colors when measured”, and “Rover will glow if you’re right or X if you’re wrong.” Students found value in simple augmentations to escape the tedium of typical classroom activities.

Relevance was also a theme. Students pushed back against the learning content contained in the sketches, saying it was too simple: “[I’m] trying to think how Rover can be used in more complex ways.” (P6) Later, P6 added, “I think the first thing we need to decide on is what aspect they need to learn, and how they’re going to learn it… We need to borrow a geometry book for next time, and just take the problems, and find out how Rover can help with them.” Students identified several areas of geometry with which they had trouble, and developed concepts for those scenarios.

Discussion and Conclusions
In this paper, we presented the results of ideation-stage design work for combining ITSs and TLEs. Using a need validation methodology that forms one half of [2]’s Speed Dating procedure, we found that students
desired an element of discovery in their activities, inter-
group competition, and the appropriate level of
challenge. In addition, we found that incorporating
simpler elements of physicality, interactivity, and
relevance appealed to students. Future work in this
area will involve constructing an ITLE that will
incorporate the elements that students desired most.

These findings present guidelines for how to navigate
tensions between ITSs and TLEs. ITSs demand well-
defined learning objectives while TLEs encourage self-
defined objectives. Our results suggest that, at least
that for domains like geometry, students need to be
given objectives that they perceive as relevant. If self-
defined objectives are a key element of the
instructional strategy, our results suggest that
instructional materials communicate to students the
relevance of the learning activity to their current
geometry classes. In addition, ITSs suggest students
should be provided with heavy support instead of tools
that facilitate exploration, as in TLEs. As we discovered
when exploring the need of challenge, students were
quick to reject the idea of minimal feedback, not
wanting to “get stuck.” They were also resistant to
being given too much help. When allowing students the
freedom inherent in TLEs, intelligent support models
can function not by giving feedback with every action,
but by ensuring students feel like the next correct step
is within reach. Overall, our approach provides insight
into how students view their needs when interacting
with an advanced learning technology.

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