Lessons Learned from In-School Use of rTAG: A Robo-Tangible Learning Environment

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ABSTRACT
As technology is increasingly integrated into the classroom, understanding the facilitators and barriers for deployment becomes an important part of the process. While systems that employ traditional WIMP-based interfaces have a well-established body of work describing their integration into classroom environments, more novel technologies generally lack such a foundation to guide their advancement. In this paper we present Robo-Tangible Activities for Geometry (rTAG), a tangible learning environment that utilizes a teachable agent framing, together with a physical robotic agent. We describe its deployment in a school environment, qualitatively analyzing how teachers chose to orchestrate its use, the value they saw in it, and the barriers they faced while organizing the sessions with their students. Based on this analysis, we extract four recommendations that aid in designing and deploying systems that make use of affordances that are similar to those of the rTAG system.

Author Keywords
Classroom integration; social robot; teachable agents; embodied learning.

ACM Classification Keywords
K.3.1. Computer Uses in Education

INTRODUCTION
Technology has become an important element of many classroom environments (e.g., by 2009, 97% of American teachers had computers in their classroom [10]). Students routinely type their assignments on word processors or search for information relevant to their class on the Internet [29]. They can construct knowledge collaboratively in blog posts or discussion forums [6], explore complex concepts within a virtual world [2], and even interact with tutoring systems that analyze problem solving and tailor future exercises [35]. A recent meta-analysis suggests that over the past 40 years, classrooms using digital technologies result in a significant student achievement over classrooms that do not [33]. These benefits are not restricted to students: Educational technology enhances teachers' ability to prepare students for an increasingly collaborative and information-oriented work force [11,36].

To date, the majority of mainstream educational software has been designed for personal computers and related devices. While this kind of software can be beneficial, the WIMP (window, icon, menu, pointing device) paradigm of personal computing does create an artificial separation between the input device, system output, and underlying real-world representation [15]. This paradigm also encourages a style of interaction where students simply sit in front of a computer and interact with a virtual environment on a screen. While tablet and mobile devices have become more popular in recent years, many educational apps still apply a similar style of interaction. Thus, some researchers are beginning to explore the affordances of more embodied and tangible interactions, ranging from collaborative activities surrounding an interactive tabletop [17], to classroom-sized distributed simulations that teach science [22], to interactive robots that teach language learning [32]. Preliminary investigations have highlighted that such technologies can be highly engaging for students and foster learning, but more work is needed to understand the utility of these technologies, particularly in classroom settings.

The Robo-Tangible Activities for Geometry (rTAG) system supports physical, embodied interactions with a robot. The system consists of a Cartesian plane projected onto a white floor mat where a robotic agent, named Quinn, navigates. rTAG facilitates students in mastering the domain through processes related to tangible embodied learning and learning by teaching [24]. Previous work has focused on user studies in laboratory environments [23,24] and there is little in the way of an established body of literature to guide

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the translation of rTAG from a laboratory setting to classroom use.

Understanding the barriers that teachers experience in their use of different forms of technology in the classroom is vital for the successful integration of those technologies. Because of the popularity of WIMP-based forms of technology, there is a well-established body of work that examines how to integrate these technologies into classroom practice. For example, a recent review by Bingimlas surveys several barriers to integration at the teacher level (lack of teacher confidence, lack of teacher competence, resistance to change) and at the institutional level (lack of time, lack of training, lack of access to resources, lack of technical support) [4]. Bingimlas' review parallels several related analyses that divide barriers into those constraints imposed on the teachers, and those related to the teacher's attitudes and beliefs [1,3,9].

Recommendations for overcoming these barriers related to traditional WIMP interfaces focus heavily on providing teachers with resources and training. For example, Hew and Brush suggest maintaining a shared vision for technology integration, overcoming scarcity and resources, changing attitudes and beliefs, and providing professional development [13]. It is important to note that professional development should not consist only of instructing teachers on how to use the system, but should also provide a pedagogical background that helps in understanding why the system is effective [3]. To provide this kind of support, it is necessary to understand how teachers perceive the value of the system, what barriers to implementation exist, how they can be overcome, and how teachers can integrate the systems into their current classroom practices.

Since basic technology integration within classrooms has historically suffered from logistics, time, and financial constraints [25], it is reasonable to think that these issues hold, or may even increase when integrating more advanced technologies in the classroom. Teachers may find pedagogical activities using complex technologies too time consuming due to the amount of training required to understand how to use them, or due to the time required to integrate them into classroom activities.

Our overarching research interest is in improving understanding of how to facilitate the integration of non-WIMP educational technologies into classroom practice. As a step towards that, we describe in this paper the design of the rTAG system, with a specific focus on the elements that make it suitable for use in classrooms. We then qualitatively analyze the data collected from the deployment of the rTAG system in a school context using Thomas' General Inductive Approach [34]. This analysis focuses on the teachers' viewpoint, identifying: (1) how they orchestrated the system's usage; (2) The value that they saw in this system; and (3) barriers faced by them in this implementation. From this analysis, we extract design recommendations that can apply to other learning environments that employ nontraditional interactions in a school setting.

RELATED WORK

Integrating Non-WIMP Environments into Classrooms

Kharrufa et al.'s research on the deployment of digital tabletops in a classroom [17] identified five themes, including *control* (how much a teacher felt in control of the classroom), and *awareness* (how aware teachers felt of what students were doing). Their findings show that the deployment had both positive and negative responses from students and teachers. They highlight the importance of supporting teachers through flexibility, or making the system flexible enough to adjust to teachers' plans, and awareness, or making teachers aware of students' progress.

Another similar deployment was made by Hayes et al., who investigated the use of CareLog, a system that aids in the capture and analysis of student behavior information within the context of a special education school [12]. Their five-month study yielded various design principles focusing on empowering teachers to make informed decisions. Poole et al. also discussed the deployment of an ubicomp system that targeted positive health behaviors within a school [29]. Using diverse sources of data, their qualitative analysis also resulted in design recommendations (such as to focus on student-teacher interaction, to be mindful of school boundaries, and to design for group experiences).

As a precursor to the integration of tangible embodied learning environments into classroom practice, Moher [22] describes the integration of "embedded phenomena," which moves technologies off desktop computers into classrooms. These embedded phenomena include simulations of scientific events, such as observations of orbital dynamics and seismic events occurring on a fault line running through the classroom, through media presented on tablets affixed to the walls. Students interact with the simulations over weeks or months, collecting data and making predictions. Although the paper's focus was on describing interactions with the technology, the authors acknowledge that teachers' knowledge of individual students was critical to ensuring that students learn effectively from the simulations. Lui et al. [20] also described the integration of immersive simulations in the classroom, and emphasized the necessity of iterative design and co-design with teachers.

These contributions highlight the importance of teachers in the successful implementation of non-traditional systems in school environments. This paper aims at further expanding knowledge on this form of integration, focusing on the perceptions of the teachers and on the particular affordances of the rTAG system.

Robotic Learning Environments

rTAG is, at its core, a robotic learning environment. The system was inspired by Papert's robotic LOGO system, in which students used LOGO primitives (commands) to control robots [26]. However, rTAG uses embodied interaction and a teachable agent framing in ways that extend beyond the LOGO paradigm. rTAG also leverages principles of robotic learning environments to create more social engagement with the activity, something others are beginning to explore as well. For example, Saerbeck et al. [32] used the iCat robot to investigate how a socially supportive cat influenced the task of language learning. In contrast to a neutral cat, users of the socially supportive version learned more and were more motivated. Leite et al. [19] also relied on the iCat framework, creating a robotic agent that empathized with human chess players. During a game of chess, the robot would generate empathetic messages to the human player, such as "don't be sad, you didn't have better options". Compared to those who had a neutral robot, users who worked with the empathetic version provided higher ratings of degree of companionship with the robot. Kanda et al. [16] conducted a two-month trial in an elementary school with a social robot called Robovie, who could express various social behaviors, such as calling children by name. The focus of this work was to explore the possibility of social human-robot relationships; thus, integration issues were not addressed.

Teachable Agent Environments

The second inspiration for rTAG is teachable agent systems. Teachable agents have emerged from the body of research showing that students benefit from tutoring other students [28]. For instance, when students know they will be tutoring their peers, they are more motivated to attend to educational material. As their partner takes steps and makes errors, they reflect, noticing their own misconceptions; as they give explanations, they elaborate on their knowledge and construct new knowledge [31].

Accordingly, developers have designed educational systems where students teach an agent about the subject they are learning. The most investigated teachable agent system is Betty's Brain, designed to help students learn about causal modeling [5]. Students teach Betty, their agent, by using resources such as text and videos to draw causal networks. Students can ask Betty questions that she will answer based on the network, and at some point, Betty will take a quiz. In Betty's Brain, the teaching mechanism is one of framing--it is the students that create the causal network, and thus, when Betty takes a quiz, it is their work that is being tested. In contrast, other teachable agent platforms such as SimStudent leverage the co-learning potential of teachable agents. After each problem-solving step SimStudent takes, she asks her human tutor if the step is correct, and updates her knowledge with the response. As a result of this learning process, SimStudent makes errors that simulate ones a human student might make, leading human tutors to reflect on their misconceptions [21].

Studies show that students are highly motivated to teach their agents, feel responsible for them, and so try harder and attend more to instructional material [7]. Moreover, peer-to-agent tutors notice their own misconceptions and elaborate on their knowledge as they watch their agents solve problems [5]. Thus, teaching a computer agent is highly beneficial for the student doing the teaching: it can lead to more learning than being taught by a computer agent [18], is nearly as effective as being taught by a human tutor [30], and is more effective than classroom instruction [27]. Recently, Hood, Lemaignan, and Dillenbourg extended a Nao robot so that students could teach it about handwriting [14], further suggesting that the promise of teachable agent interactions can be extended to teachable robot scenarios.

THE rTAG SYSTEM

System Overview

rTAG is designed to teach basic geometry concepts to middle school children [23,24]. It is assembled using components that may already be common in some school settings, including iPod Touches, Wii Remotes, a LEGO® Mindstorms® NXT robot, and a projector.

The system is comprised of three main components. The first is the problem space, which consists of a Cartesian plane projected onto a white floor mat. This plane contains a virtual agent, and can also have zero or more points plotted onto it. The second component is Quinn, a teachable and affective agent that is comprised of a LEGO® Mindstorms® NXT robot and an iPod Touch placed on its top. This iPod Touch displays Quinn's face and outputs its voice, through which it can give affective responses. It also provides the entry point for interacting with Quinn. The last component is the mobile interface, which consists of another iPod Touch, this one held by the student when interacting with the system. Through the mobile interface, the user selects commands for Quinn.

Before using the system, students are told that they need to help Quinn learn how to solve geometry problems—examples of problems are: "*Plot point (3, 1)*" and "*Plot point (-2, 3)*". To solve these problems, students have to issue commands to Quinn, so that it will move to the specified location and plot the point. To give a command to Quinn, students must first touch its face (the iPod Touch screen that is on top of the robot). This triggers a pop-up on the student's mobile interface, from which he or she can select an action for Quinn to perform. Actions include *move n units*, *turn d degrees (counter-clockwise)* and *plot point*. Therefore, a possible solution plan for the problem "*Plot point (3,1)*" could consist of performing the actions *move 3*, *turn 90*, *move 1*, and finally *plot point*. Before each action, the student has to approach Quinn and touch its face in order to trigger the menu on the mobile interface. Since Quinn is always moving, this means that the student will always be moving as well.

After plotting the point, the student can check if the solution is correct or incorrect by tapping on the "Check Answer" button available on the mobile interface, which triggers the system's response with both visual and audio feedback on correctness. Following this feedback, Quinn smiles for positive (correct) outcomes and frowns for negative (incorrect) ones, and then makes a social statement related to the outcome of the problem such as "*We worked hard to solve that problem.*"

Design Principles

The rTAG system combines robotic learning environments and teachable agent learning environments. Quinn is a robotic agent that moves within the physical space. Students also move within the physical space, and thus concepts such as differentiating between axes or translating points may be encoded in movements such as pointing or walking to a point. Further, the rTAG system uses a teachable agent framing where users are told that they are teaching Quinn how to solve the point plotting problems. As described in the related work section, teachable agents have been shown to have a positive impact in learning and engagement, as students attend more to the domain material, reflect on the knowledge required to solve the problem, and feel responsible for the agent's performance.

rTAG was designed to explore the potential for installation in classroom environments. First, it was designed to help address the barrier of insufficient school resources. A fully assembled system costs roughly $2000. While this is too expensive for a typical classroom, it is much more affordable than most embodied learning environments (e.g., US$35,000 for SMALLab [37]), and with optimizations and price drops on components such as the projector, we anticipate that it will be possible to further reduce the cost. Furthermore, the system is built with components that may already exist in a school, such as LEGO® Mindstorms® NXT robots, regular laptops, and portable web browsing devices such as the iPod Touch (Fig. 1 left). In addition, because the system is a physical installation, it allows several students to position themselves around the edges, making observing and engaging with the system more accessible to large classrooms of students.

rTAG also includes design features intended to improve teacher confidence and competence while using the system. It is built from recognizable subcomponents that many teachers are already familiar with: LEGO® Mindstorms®, iPod Touches, and Wii Remotes. As such, its functionality and design aims at being more interpretable than the black box approach of some commercial systems.

We have built both virtual and physical versions of rTAG, which creates a bridge between the familiar WIMP version of the system and the less familiar non-WIMP version of the system. The virtual version, named vTAG, has the same functionality as rTAG, but all the interactions and actions take place through a regular WIMP-based interface. The screen is divided in 3 sections: on the left is the Cartesian plane with a circle representing the robot selected with a mouse click, on the top right is the face of the robot Quinn and on the bottom right is the interface to give commands to Quinn, which looks the same as the iPod interface (Fig. 1 right). It is possible for teachers and students to become comfortable using the WIMP version, called vTAG, before transferring to the non-WIMP version. Collectively, the rTAG and vTAG versions are referred to simply as the TAG system.

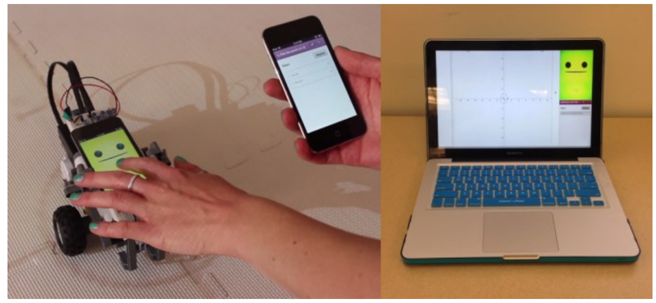

Figure 1. rTAG (left) and vTAG (right).

rTAG is designed to leverage teacher objectives in a way that, ideally, engenders positive attitudes and goodwill towards the system. In addition to targeting the geometry domain, it targets cross-curricular skills like collaboration and critical thinking, which are important skills for a successful life, and are being increasingly worked on by schoolteachers due to standards such as the Common Core [8]. It presents an engaging and novel activity that may motivate students to attend more to learning content. We return to implications of these features later.

DEPLOYMENT

We conducted a week long study to evaluate the impact of the TAG system in a school setting, inviting teachers from a California public school district to bring their students to one or more sessions taking place at a room in the district's office in which we had set up several stations of the TAG system. This district is particularly engaged in integrating technology and fostering domain-independent skills. This is clearly visible in their Mission Statement, which highlights the "4 C's": collaboration, communication, critical thinking, creativity, as well as STEAM initiatives. Both the district's superintendent and technology administrator, our contacts within the school, demonstrated great interest in this project, which further shows the district's commitment to adopting technology. In this district, 79% of students qualify for free or reduced price meals.

Twelve teachers, from 4 different schools, scheduled one session each for their classes. Classes had 25-40 students, with 8 classes from 3rd, 3 from 4th and 1 from 5th grade. Five teachers opted to have additional facilitators (parents, administrators, or teacher interns) in their sessions.

Three researchers travelled to the school one day before the study to set up the system, but only two remained to oversee the study. The room was arranged in a semi-circle with a total of 5 stations, as shown in Fig. 2. There was one rTAG station located in the middle of the room, 3 virtual TAG stations (vTAG) and one LEGO® Mindstorms® NXT

2.0 station. We physically separated the vTAG stations to minimize bias from adjacent vTAG stations. The LEGO® station had a robot built similarly to Quinn, but without a face interface. Instead, students used the regular EV3 interface to program it to move. This station, therefore, represented a more common usage of this kind of robot. Each station had a concise system manual and solutions to the problems. Video cameras were arranged around the room to get both a wide angle view of the room and a closer take of the students' interactions with the system, while minimizing interference or distractions as much as possible.

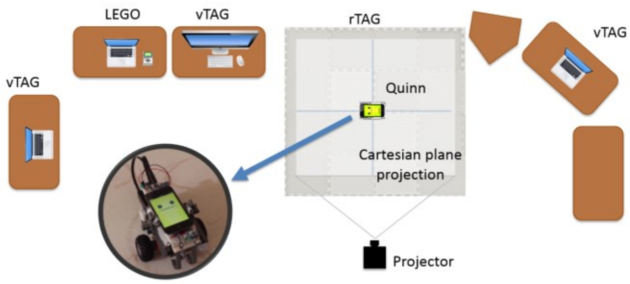

Figure 2. Physical organization of the room.

Consenting teachers were encouraged to be part of all the study activities that took place before, during, and after the immersion session. Before the session, teachers received a summary of the study activities and the description of the system combined with a short video showing how it worked. They were encouraged to send us a new set of problems for their students to match their learning goals (none requested this), send us a lesson plan (1 did) and come to a training session before their scheduled session so they became familiar with the system (less than half did). In the one-hour training session, teachers were debriefed about the goals of the study, the setup and the teaching framing and learned how to give Quinn commands.

The immersion session had a brief introduction from the research team, a training phase followed by an immersion phase, and concluded with a short unstructured debriefing phase. The training phase was intended to be led by the teacher, instructing students on how to perform all TAG actions that they would need to solve problems (e.g., move and turn Quinn, check the answer). Right before the immersion phase, the class was notified that teachers were the ones in charge of the session and experimenters would be available to help only with technical difficulties. The debriefing phase consisted of a few questions from the teacher or experimenter about student impressions of Quinn, the system, and their general experience. After each day, the researchers were responsible for shutting down the system, as well as starting it again on the following day.

After the sessions, the teachers were invited to participate in a 2-hour focus group activity on the final day of the week. Five teachers participated in this activity, in which they reflected on the TAG system (~30 minutes), collaboratively designed a lesson plan (~30 minutes), developed storyboards to show an ideal student interaction with the system (in two groups, ~30 minutes), and shared their designs (~30 minutes).

Finally, two of the five teachers involved in the focus group participated in a follow up semi-structured reflective interview. Both teachers watched the footage of their sessions before the interview.

METHOD

To better understand the affordances and limitations of integrating the TAG system within a school setting, we analyzed teacher's actions and perceptions through three objectives: 1) understand how they orchestrated their sessions, which helps us understand the physical and logistical constraints of the system, 2) understand the value they saw in the system, giving us insight into what worked for them, and 3) understand barriers they faced while using the system, which helps us understand complexities and limitations of the system. By examining how they used the system, why they might want to use it, and what obstacles they faced, we will be able to better understand how to iterate on the design of the system to make it more suitable for classroom use.

Analysis of the interviews, focus groups, and session footage was performed using the General Inductive Approach method outlined by Thomas [34], with the goal of extracting themes from the data. Two members of the research team independently followed this approach, occasionally meeting to converge on the themes that were identified and the quotes that were related to them. The process is as follows: 1) initial reading of the data in order to gain familiarity with it; 2) identifying segments of data (e.g., interview responses, teacher interactions with students) that related to our three objectives (orchestration, value, and barriers); 3) labeling the segments and creating categories; 4) reducing overlap and redundancy between categories; and 5) creating a model that incorporates the most important categories. This procedure followed the *independent parallel coding* strategy outlined by Thomas for checking consistency of qualitative coding [34]. We now describe the themes that arose from this analysis.

RESULTS

Orchestration

Orchestration refers to the activities that the teachers chose to employ in order to facilitate their use of rTAG, including activities both before and during the session. It was analyzed by looking mainly at the session footage, but it was complemented with the data from the interviews and focus groups. The goal was to understand how teachers used the rTAG setup, and if it differed from the more common vTAG setup. We organized orchestration into five subcategories: pre-session instruction, session introduction, student distribution, session management, and rotation of students. Table 1 summarizes the findings for this category.

For the remainder of this paper, we will refer to specific sessions by a code in the form *X-Y*, where *X* is the day of the session and *Y* is the number of the session that happened on that day. Session 3-2, therefore, is the second session on the third day. We will also refer to the two focus groups as FG1 (comprised of T1, T2, and T5), and the second as FG2 (comprised of T3 and T4).

Subcategory	Typical behavior	Atypical behavior
Pre-session instruction	No instruction; teach the domain; teach how to use the system	None
Session introduction	Researcher or teacher handled the system	Teacher chose assigned student to handle the system (1-1, T1)
Student distribution	Teacher distributed students around stations; pre-formed teams	Quinn station not used from the start (1-1, T1); LEGO® station not used at all (1-1, T1)
Session management	Teachers moved around the room; used adult supervisors	None
Student rotation	Within stations: up to the students; between stations: up to the teacher	Between stations: up to the students (1-1, T1; 2-2, T2; 2-4, T2); rTAG managed by supervisor (1-1, T1)

Table 1. Summary of the orchestration strategies and exceptions used throughout the sessions.

Pre-session Instruction

Most teachers did not prepare their students during their regular classes prior to the session, due to time constraints. Some of the teachers who did shared that they showed students the video of the system and Quinn that we sent them, went over the commands to teach Quinn, and described some geometry concepts like positive and negative coordinates, the quadrants, angles, and degrees. While debriefing after the sessions, teachers reflected on how they would prepare their students for the session. Regarding teaching the domain, T5 said: "*See, what I did beforehand, before coming, so they kind of already knew what to do, I taught them the coordinates*". As for showing how the system works, T1 planned on integrating her current practice of demonstrating the system using a projection onto a whiteboard, where she could freely annotate the screen. FG1, of which both T1 and T5 were part of, proposed a lesson plan that followed the same direction, reinforcing the notion of pre-lesson teaching vocabulary and group guidelines. FG2, however, proposed ideas like using YouTube to show how to use the robot and training team captains who could help other students.

Session Introduction

During the introduction phase (explaining how to use the system to the class) in the immersion session itself, six teachers led the session for their students, although three of them couldn't remember some details of the system and required assistance from the researcher. For the remaining six sessions, the researcher was the one performing the training. The main difference between how the teachers vs. researcher introduced the system pertained to time. Teachers spent approximately five minutes showing students how to use the system, while the researcher would spend around fifteen. This finding could relate to the teachers' perceptions that students are able to pick up new technology very fast. T1 says: "*With the technology that we have this school year, I just have found that these kids are really quick. (...) Literally, I did a five-minute demo in front of the class with my computer on the projector of how to make a Google drawing. Five minutes was all they needed, and they were done. They were off. They were running. They were making their Google drawings. It was amazing*". This reflects on the lesson plans and storyboards developed during the focus group session. The only situation similar to an in-session introduction was mentioned by FG2, and it simply stated that teachers should talk about appropriate behavior and good sportsmanship before the session.

As for the content of the instruction, one teacher, who had already taught students the domain before the session, still focused on reviewing the domain content, and not the system usage. But regardless of whether the teacher or researcher introduced the session, the overall strategy was similar: students gathered around a given station (usually a vTAG one), where the teacher or researcher would demonstrate how the system works. One notable exception, however, occurred in session 1-1, where the teacher (T1) chose a "*very tech savvy*" student to man the station while she explained how the system worked.

Student Distribution

After the introduction phase, teachers would distribute the students around the different stations. In six out of the twelve sessions, teachers had already assigned students to teams before the start of the session. In five of the sessions, teachers took some extra time to create the teams and then assigned them to each station. In session 1-1, students could choose which station to go to.

Usually, all stations were used from the beginning of the session. However, on session 1-1, T1 decided to hold off on using the physical system until later, judging that using that setup upfront would have been "*wasted*" time. In this session, rTAG was used only after she gauged that most students had already used the vTAG station. This strategy is reflected in FG1's storyboards, where the rTAG station would be used only after students had already completed a few tasks on pen and paper and using the virtual setup. T1 also didn't make use of the LEGO® station, arguing that it would be "*too much*" for "*that short amount of time*"

Session Management

During the session, teachers usually moved around the room, to ensure each group made progress and that all students had an equal opportunity to try using the system. Five sessions also employed other adult supervisors, such as members of the school staff or some students' parents. Talking about these helpers, T1 says: "*The fact that there was another adult there that they knew and were comfortable with, I think helped, whereas if she weren't there, they probably would have just skirted along the back and probably never even—would have never even attempted.*" Not all helpers were adults: Some students took a leadership role, going around the stations to help other groups. This happened either by initiative of the students, or in some cases, by explicit leadership assignment from the teachers. In fact, teachers in FG2 supplemented this goal in the lesson plans, explicitly assigning some leader students, who would be responsible for coaching their peers. More generally, both groups planned for group interactions. This reinforces the collaboration affordances of this system, which were deemed valuable by the teachers, especially given the new Common Core Standards that are being adopted. T4 stated: "*The good thing, I thought, the Common Core says communication, collaboration. We do some of that, but this was really good.*"

Student Rotation

Rotation of students happened in two levels: within and between the stations. The first relates to how students would control which member of their group would be interacting directly with the station. With the exception of one session (1-2), in which the teacher had a predefined order of which student should be interacting with a station, teachers gave the students freedom to manage this, at most resorting to some organization by the student leaders in each group. Students employed various ad hoc strategies: one group, for instance, used the "rock, papers, scissors" game to decide who would go first. However, many students interacted in very fluid ways, such as sharing the solution generation to a single problem by passing the iPod Touch around, allowing another student to touch Quinn (on the rTAG station), or by passing the mouse around (on the vTAG stations). Rotation between stations was usually controlled by the teachers. They would rotate the groups after a given amount of time which varied among sessions, from 5 to 45 minutes.

The exception happened in sessions 1-1 (T1), 2-2 (T2), and 2-4 (T2), where students were given the freedom to move between stations. While all TAG stations were usually regulated by the students themselves, T1 (session 1-1) decided to have a tighter control over the rTAG station. On session 1-1, a facilitator trusted by the teacher managed the use of rTAG. Students would sit around the setup, while one student, chosen by the facilitator, would use the system. After the student solved a problem, this facilitator would select another student to solve the next problem.

It is interesting to note that even though rTAG is a system with many novel affordances, it was still used much like the vTAG stations were (with the notable exception of session 1-1). Teachers normally did not do anything special with the rTAG station. This warrants further research, but it is possible that some of the principles behind rTAG, such as using recognizable subcomponents, may have helped teachers to perceive it as a more regular system.

Figure 3. Students using rTAG during a session.

Value

Having examined how the sessions were orchestrated by the teachers, we now turn to analyzing the value they saw in the system. The four subcategories we identified are: increase of engagement, physical robot affordances, technology exposure, and domain-general skills.

Engagement

Teachers saw student engagement as one of the positive assets of the system. This was very evident from both the interviews and the footage of the sessions. To illustrate, in the sessions where a teacher or facilitator asked the students who wanted to go next on the rTAG station, students would always promptly raise their hands. Another evidence of engagement was that whenever time was up for a given session, those who had not had the chance to interact with the rTAG station would loudly express their discontent. Teachers perceived this. For example, T1 said: "*They were excited about him [Quinn]. They just thought he was cool*". T2 went deeper: "*That's what I think is really key, is that if they aren't even realizing that they're learning, that they think that they just went on this field trip and had fun, but now they know how to plot points on the positive and negative side. They just think they went and played with a robot, which I think is cool.*" The focus of the excitement, at least in this instance, was on the physical robot.

Robot Affordances

Teachers perceived the physical robot as an important benefit of the system. T1 emphasizes that the novelty of the robot would make this a remarkable experience for students: "*I think this was something that the kids are going to remember because it was separate from the classroom, different from something they were doing on their netbooks. The robot was right there in front of them.*" T1 also mentioned a boost in perseverance due to the robot, especially due to its social attributes: "*I think it would motivate them to persist in a problem and to keep going and to keep trying to get it the way it was supposed to be and get Quinn where he was supposed to go. I do think it makes a difference. I think it's something they can relate to, as opposed to this faceless no name little box with wheels. I think it does make a difference*". In fact, T2 contrasts rTAG with its virtual counterpart: "*the reaction's better with the physical because it's like an actual being. It could be their pet or something. Whereas, on the computer, it's just so second nature.*" It is possible that this heightened engagement may be due to a novelty effect, and would likely decrease over time as they grow accustomed to the system. Teachers may be aware of this. FG1, for example, has proposed gamification additions to the system, which may help to maintain engagement over time.

Technology Exposure
Another common theme among teachers was related to the value of exposing students to technology. Teachers in this school aim to make their students proficient in using digital tools, e.g., most students have their own laptop, and conduct a great amount of the classroom work in them. Teacher T1, for example, integrates Khan Academy into a morning routine: "*the kids are all on Khan Academy. One of our morning activities is the kids' work on Khan Academy. Part of Khan Academy, there is a coding section to it, and I had a group of boys that really wanted to explore it, and so I said sure. I sent about five of them off to a little corner in my classroom, and for several weeks, they explored the coding part of it*". Her goal has been to "*integrate technology into everything that we do as much as possible*". In this context, the teachers saw great value in the rTAG system. To them, this was another opportunity of showing their students some of the affordances made possible by technology, possibly making them more proficient in its use, while also leveraging their curiosity.

Domain-General Skills
Teachers emphasized domain-general skills that can be acquired through the usage of this system, such as critical thinking and problem solving. T1 believes "*that they have to be able to analyze what they're doing and problem solve and decide, what's a more efficient way that I could have done this. I think that's a huge, huge benefit of this program.*" Further evidence is seen through the storyboards, where one group explicitly mentioned the goal of developing the four C's: collaboration, communication, critical thinking, and creativity. The other group planned to attribute the role of leader to some students, giving them the responsibility of coaching other students, which is another valuable domain-general skill. This focus on domain-general skills is possibly due to the increasing requirement for compliance to the Common Core State Standards [8].

For students to collaborate, teachers usually divided them into smaller groups and distributed these groups among the several available stations, allowing students to organize themselves within each station. On vTAG, this led to a few engaged students close to the computers, while others would mostly just sit back and watch, or wander around the room. On the physical setup, however, more students usually tried to participate together with who was currently using the system. Teacher T2 noted: "*I see eight or nine kids jumping in and trying to help, or looking to see if it's time to touch. It's just they're more involved, more willing to maybe offer a solution.*" In many sessions, several students could be seen standing on the foam mat discussing the problem, constantly passing the iPod Touch around and taking turns on who would be interacting with Quinn.

Contrasting the vTAG and rTAG setups, we see that most of the values highlighted by teachers were either present only on the rTAG setup (for example, the values related to the robot affordances), or at least heightened by it (for example, rTAG allowed more room for collaboration. Teachers also perceived it to be more engaging). T1 explicitly contrasted rTAG to "*something they were doing on their netbooks*", that is, their regular computers. Nonetheless, vTAG also proved important, as it was intensively used by most teachers during training, likely due to the larger screen and increased familiarity.

Barriers
Our analysis also identified perceived barriers faced by the rTAG system in a school environment. We identified five subcategories: lack of time for teachers to spend on the system, lack of teacher training, student intimidation, technology limitations, and number of students per station.

Lack of Time
Teachers complained about an overall lack of time to perform activities out of their lesson plans. T2 says: "*Do we have the time? We don't. We don't even have the time to do what we're supposed to be doing.*" This is corroborated by the fact that only one teacher sent the lesson plan which we requested from them. T4 states: "*Well, I don't have time to write a lesson plan, but let me look at what I can do*". This is relevant for rTAG, as it requires a larger setup and training overhead when compared to vTAG, possibly drawing teachers away from using the robotic setup.

Lack of Training
Lack of time could also contribute to another barrier, which is lack of training. In the study we gave teachers two days to come to training before the sessions started, but many of them were not present, which made this problem even more evident. As a result, some teachers could not prepare the students well in both the domain and the system, and were

not very well acquainted with it themselves. This resulted in only three out of twelve teachers leading the training completely by themselves, with the remaining nine—including some of those who actually came to training—delegating it partially or completely to the researcher.

Student Intimidation

Teachers also perceived that some students felt intimidated by the rTAG setup, causing them to prefer the vTAG stations. T1 reports: "*I think the ones that stayed on that computer with the larger monitor with my student teacher, those were the ones who were just really afraid and really not quite understanding it.*" This, again, shows the benefit of having vTAG, where students who may be hesitant to try the robotic setup can start to use the system on a more familiar setup. Nonetheless, some were even afraid of the vTAG setup, actively avoiding using it. T1 continues: "*I think there was a little bit of movement of one of those who was afraid and didn't really want to try, was getting close to their turn on one computer, I think they did go to another computer.*" This happened despite the school's adoption of technology on the classroom. She says: "*There were still some that just really were almost afraid of it*."

Technology Limitations

The limitations of the technology involved in the system could impact the workflow of teachers and students. T2 reported having problems when trying to demonstrate the rTAG system to the students due to the iPod's small screen size, since some could not see the little screen. Whereas the teachers were used to connecting their computers to a projector to demonstrate systems, they were unable to do so with the physical setup of rTAG. In addition, previous experiences led some teachers to worry about the fragility of the setup. T1 recounts an experience with projected smart boards, and the fact that if students moved the projector slightly, there would be significant downtime. T1 says: "*When you have the class's attention, and you're doing something and you're in the middle of a lesson and something happens, then their attention is gone.*"

Number of Students per Station

Teachers also reported limitations related to the quantity of students per station. There were too many students at each station, relegating some of them to the role of passive viewers, while only a few members of the group were actively engaged. T1 suggested that a good number would be five students per station, since it would allow all students to have some time with the system, while allowing more timid students to sit back for a little while to see how the system works. T2 favored a number closer to ten students. T4 suggested only three students, arguing that it would give them more time to perform the tasks.

DESIGN RECOMMENDATIONS

We now turn to four design recommendations based on our analysis of the data. These recommendations target the design and deployment of robo-tangible learning environments such as the rTAG system, so that those who are designing non-WIMP based systems may maximize their value while minimizing the barriers for their adoption.

Target Multiple Learning Objectives

As exposed in the barriers section, one big issue for teachers was lack of time. While even simple activities may already be infeasible, a system like rTAG may suffer from longer setup times when compared to a simple WIMP-based computer application. Additionally, the system's learning curve will probably be steeper for both teachers and students due to novel or uncommon interaction methods and technologies. Therefore, it is important for the system to target multiple learning objectives, including those that are domain-independent. Doing so should help to maximize the value of the system for teachers and the return of their time investment, as it would allow them to combine multiple activities that target one objective into one activity that targets multiple. It would also address the issue that Kharrufa et al. ran into, where teachers reported that students were not used to proper critical thinking and collaborative work [17].

In the case of rTAG, teachers believed that it was a good way of teaching domain concepts, but also saw value in the way that the system could facilitate collaboration, communication, leadership skills, critical thinking, and problem solving. In addition, teachers found the rTAG system to have potential for exposing students to new technologies. rTAG problem sets and related curriculum should be redesigned to more explicitly facilitate these higher-order learning objectives. For example, some of the engineering behind rTAG could be exposed and discussed as a secondary lesson related to student use of rTAG.

Emphasize the Collaborative Affordances of the System

One of the positive aspects mentioned by the teachers was the opportunity for collaboration that rTAG provided. This was also evident on the storyboards and lesson plans developed during the focus group session—all of them included team and collaboration elements. While students normally work on individual computers in the classroom, this setup encouraged them to work in groups. This is seen by contrasting the vTAG and rTAG setups: on the first, students gathered around the computer. Since there was not much room for all of them, a few stayed back and simply watched. On the latter, however, students were able to gather around most of the projected Cartesian plane, sometimes even walking around the physical space while trying to solve the problem together. This result is in agreement with findings from Poole et al., where group experiences seemed to foster participation [29]. This recommendation expands on Poole et al. by emphasizing that systems with tangible and embodied elements should explore their affordances to foster collaboration by design, rather than planning for students to individually use it.

Thus, it follows that rTAG should better leverage the collaborative affordances of the installation so that many students can actively use it at a time. We recommend providing an interface to rTAG that allows multiple students to give the robot commands, potentially by facilitating turn-taking or enabling a voting mechanism.

Optimize Training for the Teachers' Workflows

Since the system employs a novel interaction method, training of both teachers and students becomes an important part of the system's deployment, not only to ensure they correctly use the system, but also to enhance their confidence and reduce apprehension in using the system. To achieve proper means of training, it is important to leverage the familiarity with technology they may already have and to integrate training to their existing workflow. This is analogous, in ways, to findings from Hayes et al., who recommended a minimum disruption of the teacher's classroom organization [12]. For the teachers involved with this current study, they could use a projector hooked up to their computer to perform the training, just as it was their habit. This is only possible due to the capabilities of the TAG system to run in a traditional WIMP interface.

Innovative Use of Commonplace Technology

While the overall interaction with the system may be unusual and requires training, the familiarity with some of the system components may help to bring down this barrier, as well as possibly reducing apprehension of using it. In the case of rTAG, one of the main input methods was through an iPod Touch, which is likely familiar to most students. For example, a student asked: "*Is that an app? I wanna go home and get the app.*" The student had a better understanding of how the system functioned because of his familiarity with its components. The new application of known technology could also motivate students to explore new technology-related possibilities, one of the teachers' desired outcomes. For administration purposes, repurposing technology already owned by a school may reduce costs and facilitate adoption. Something similar was noted by Moher's work on Embedded Phenomena [22], where he chose to use technology already available in the classroom, but for the purposes of scalability rather than familiarity.

DISCUSSION & CONCLUSION

Deploying a non-WIMP based system in a school setting can be a challenging task. While traditional technologies already have barriers to their deployment, a system such as rTAG can increase the complexity of in-school integration. To minimize these barriers, while optimizing the classroom orchestration, and thus maximizing the value in such systems, we proposed four design recommendations for the deployment of non-WIMP (e.g., rTAG) systems in a school setting: 1) target multiple learning objectives, 2) emphasize the collaborative affordances, 3) optimize for training, and 4) innovate the use of known system components.

It is important to note some limitations of the data that we acquired. While we had twelve teachers running sessions, five of them agreed to participate in the focus group session. Of those five, only two participated in an interview session. Therefore, we have much more verbal data from T1 (whose unique behavior was an outlier) and T2 than we have from the other teachers. Furthermore, most teachers could use the system only once for a short session. These factors affect our ability to generalize the results. Nonetheless, the higher-level comments made by these two teachers do not diverge from the goals of the other teachers, as evidenced through the focus group session, such as developing problem solving and collaboration skills. This is compatible with the district's goals, so it may not be so visible in places where there is not so much incentive towards using technology and developing these kinds of skills. Finally, although our recommendations are more focused on the context of the rTAG system and the school we ran our studies in, they have some overlap with the related work on classroom deployment, as discussed in the results, which also contributes to supporting our claims.

As evidenced in the results section, T1 was unique in her approach. While this has implications to generalizability, it can also shed some light into a particular population. T1 is a white, female teacher with 22 years of experience teaching grades 1-3. On a scale from 1 to 10 of technological confidence, she defined herself as an 8+. She employs at least seven different technologies in her teaching, including code.org, Khan Academy, and blogs. This shows that she is extremely confident and engaged in using technology, maybe more so than her peers, which probably motivated her different approach for orchestrating the session.

Throughout the sessions, many of the expected outcomes of the design philosophy behind the rTAG system were clearly observed. Students developed rapport with Quinn, as it was expected from having a physical robotic agent that they could interact with. As expected from the literature available on barriers for the adoption of technology in the classroom, teachers demonstrated some constraints such time, training, and confidence. The design of the TAG system, however, helped to reduce some of those constraints to a certain degree. Future iterations of the system will further develop the system based on the four design recommendations here suggested to maximally facilitate classroom deployments.

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