Collaboration in Cognitive Tutor Use in Latin America: Field Study and Design Recommendations

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ABSTRACT

Technology has the promise to transform educational practices worldwide. In particular, cognitive tutoring systems are an example of educational technology that has been extremely effective at improving mathematics learning over traditional classroom instruction. However, studies on the effectiveness of tutor software have been conducted mainly in the United States, Canada, and Western Europe, and little is known about how these systems might be used in other contexts with differing classroom practices and values. To understand this question, we studied the usage of mathematics tutoring software for middle school at sites in three Latin American countries: Brazil, Mexico, and Costa Rica. While cognitive tutors were designed for individual use, we found that students in these classrooms worked collaboratively, engaging in interdependently paced work and conducting work away from their own computer. In this paper we present design recommendations for how cognitive tutors might be incorporated into different classroom practices, and better adapted for student needs in these environments.

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Cognitive tutors, collaborative learning, cultural adaptation

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General Terms: Human Factors, Design

INTRODUCTION

In recent years, school access to computers has greatly increased worldwide and across socioeconomic groups, with the growth of initiatives like One Laptop Per Child and Intel classmate PCs. Within these evolving contexts, effective educational software could make a huge impact: it is easily deployable, and when amortized across users it is low cost compared to physical resources like textbooks. Yet, it has capabilities that far surpass physical resources, such as the ability to provide structured guidance and support. However, creating this impact is more complex than simply distributing educational software widely. Not only does the content of the software need to be translated and localized, but attention needs to be paid to how teacher practices and student interactions with educational software vary across contexts. In this paper, we examine the cross-contextual generalizability of pedagogical assumptions of cognitive tutors, educational software that has been demonstrated to be effective at improving learning outcomes. We observe student and teacher use of the Middle School Mathematics Cognitive Tutor (CT) in classroom settings in three Latin American countries to gain insight into how the CT might be adapted to different settings.

Cognitive tutors are an example educational technology that has the potential to transform education. A cognitive tutor assesses skill mastery as a student solves problems, and provides context-sensitive hints, error feedback, and adaptive problem selection [23]. Their self-paced learning and tailored content and support provide students with individual attention, and free teachers to act as classroom facilitators [21]. Cognitive tutors were initially designed to support problem solving in well-defined domains such as math and science, and have been demonstrated to improve a number of studies, particularly for students of low socio-economic status [13]. In recent years, cognitive tutors have also been successfully used in ill-defined domains such as developing intercultural competence [e.g., 18].

In order to study the CT across learning contexts, we conducted a twelve-week multi-context field study of the CT, observing over seven hundred students in Brazil, Mexico, and Costa Rica. Generally, evaluations of cognitive tutors have been limited to schools in the United States, Canada, and Western Europe. However, individuals in the United States frequently (though not always) differ from students in the Latin American countries we investigated along several dimensions, including power distance (equality of power distribution), tolerance for ambiguity, and individualism versus collectivism [10]. In addition, access to resources varies between developing and developed contexts, and these differences affect how technology is used [19]. In taking a technology that has been successful in one context, and transporting it to a different context, we can identify which aspects of cognitive tutors are context-specific and develop guidelines for more effective use in new contexts.

In this paper, we survey related work on generalizing education technology, and discuss the specific tutor studied. We then present qualitative observations of CT use in three Latin American settings. Our findings have three themes: the school conditions in which the tutor was used, the way the CT was integrated into classroom practice, and collaborative student use of the CT. From these, we develop design recommendations for the future development of cognitive tutors that are educationally effective across a broader set of contexts. Our contributions are both a richer understanding of ways educational technology designed for one context might be adopted to different contexts, and practical recommendations for how best to accomplish this goal.

EDUCATIONAL TECHNOLOGY IN DEVELOPING CONTEXTS

Warschauer writes, "*Technology projects around the world too often focus on providing hardware and software and pay insufficient attention to the human and social systems that must also change for technology to make a difference.*" Access to technology is increasing worldwide, but must be incorporated into existing social and institutional structures to have a truly positive impact [25].

Hoadley and colleagues extend Warschauer's argument by arguing that desktop technologies can be disruptive, difficult to use, and impossible to maintain in developing contexts. Thus, the platform for educational technology is very important for adoption and impact [9]. It has been possible to reach a broad audience using platforms already popular in developing regions, such as mobile phones [14, 11] or bargain video game consoles [15]. Existing tools have also been adapted to be more suitable for developing contexts, such as making low-cost programmable bricks with local materials and local construction [22], or adjusting to high student-to-computer ratios by giving each student a mouse that controls a cursor on a shared display [16].

While these hardware solutions are an important component of bringing educational technology to developing contexts, educational software is also a necessary area of research. We now have mature, empirically proven technological methods of improving learning being used in schools across the United States, from rural or suburban classrooms, to urban classrooms serving historically disadvantaged populations. Are these technologies equally successful in different contexts, such as developing regions? What needs to be adapted to make them viable across cultural contexts, in both developed and developing regions? While some completed systems have been used in multiple cultural contexts [17], work on adapting these systems to new contexts has focused on translation, localization, and interface design (see [6] for review). Hence, there is a gap in the literature with respect to understanding how students use existing mature systems across contexts.

MIDDLE SCHOOL MATHEMATICS COGNITIVE TUTOR

The Middle School Mathematics Cognitive Tutor (CT) was developed between 1999 and 2004 at Carnegie Mellon University. It spans over 30 units covering different mathematical topics for students in U.S. grades 6-8 (approximately 11-14 years old). In our investigation, we used the Scatterplot unit of the CT [4], after determining with each school that scatterplots were an appropriate topic for their curriculum. In this unit, students read a scenario in which a scatterplot can be used to answer a question about data. For example, a scenario might describe kids who have a lemonade stand and want to know whether they sell more cups of lemonade on hot days. The goal is to answer this question by plotting two numerical variables (e.g., cups and temperature) on a graph. In the tutor (see Figure 1), students are scaffolded in labeling axes, choosing a scale, plotting points, and answering interpretation questions. The CT delivers immediate corrective feedback on each step, an approach shown to support learning in an American context [8]. Students can also request a multi-level hint at any step. The first hint students receive tends to reference the underlying concept, and subsequent hints increase in specificity. The system assesses students' knowledge based on their problem solving and presents this information as a "skill bar" that increases or decreases as they solve problems with particular skills.

Target Use of the CT

The design of cognitive tutors, and the algorithms they use to model learning, assumes that students generally work at

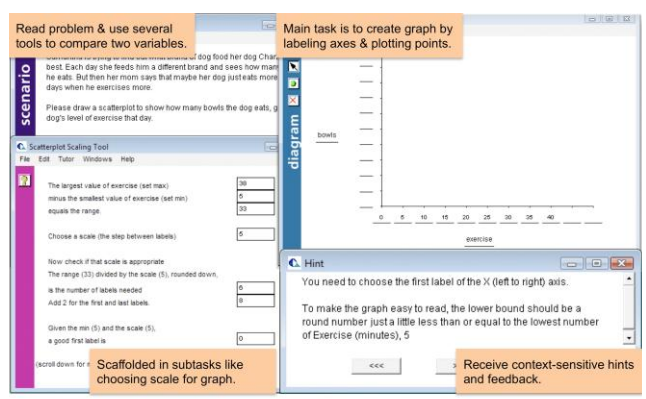


Figure 1. English-language version of the Middle School Mathematics Cognitive Tutor. Students must compare two variables on a graph. They use several scaffolding tools to complete the task, and receive context-sensitive help.

their own individual computers and at their own pace [23]. Students proceed using the CT's help and feedback as the teacher circulates around the room providing extra support to students that need it [4, 21]. The CT's model of student knowledge assumes that the student is solving problems without the assistance of others [7]. Recent additions to cognitive tutors also assume individual work. For example, [1]'s model of ideal help-seeking in cognitive tutors focuses solely on help-seeking within the tutoring environment, and not on help students seek from their teacher and peers.

Based on published classroom observations, these assumptions are generally met in use of the CT and related software in American classrooms. Though there are qualitative reports of student collaboration while using the CT [21], it occupies a relatively low amount of class time. For instance, in quantitative field observations of student behavior in suburban American middle schools, using this same tutor lesson, students spent only 4% of their time talking on-task to the teacher or another student. They spent 78% of their time working on their own [4]. Since that study, the third author has spent over 500 hours conducting quantitative field observations in American classrooms, including urban, suburban, and rural classrooms. Though the proportion of collaborative behavior in those observations has not been published, it is similar to the proportion seen in [4].

Preparation of the CT for Use Outside of the U.S.

While the Scatterplot CT unit was developed in English, the students in this investigation were native speakers of Spanish and Portuguese, and generally did not speak English. Therefore, with local support, all of the text in the tutor was translated into the local language of instruction, and then tailored to each particular locale; for example, in Mexico and Costa Rica, after an initial translation, the tutor text was iteratively reviewed and revised by local teachers and researchers in each of the sites separately. Also, scenarios in the unmodified system were in some cases outside of the scope of students' cultural experience. The scenarios and mathematics were examined for culturally appropriate content, and modified as necessary to better fit the local context. For instance, in Brazil, local researchers and teachers changed the previously mentioned lemonade scenario to reflect local practices of selling coconut water on the beach.

FIELD STUDY PROCEDURE

Following the iterative translation procedure, the on-site investigation occurred over the course of twelve weeks, with four weeks dedicated to each of three sites (Brazil, Mexico, and Costa Rica). The first step at each site was a meeting between the international team and local teachers and researchers at the school computer lab, to demonstrate the software, answer questions about the study and material, and for teachers to work through a full problem in the tutor so that they were comfortable using it in class. These meetings were followed by a week of software installation and piloting with students who were not part of the full study. As much as possible, teachers supervised the student pilots, so that they would know what to expect from facilitating a Cognitive Tutor classroom. International researchers also gathered information about the school context.

During the following three weeks, each student used the CT in a classroom setting for eighty minutes. At least two researchers were present in the computer lab in each session, taking field notes as they positioned themselves around the lab in order to observe computer screens. Field notes captured on- and off-task behavior including collaboration, teachers' instructional procedures, student impasses, and affective reactions. Diagrams of machine and participant locations were drawn at intervals throughout CT sessions.

The teachers were asked to conduct every session on their own, and behave as they would if they were to include the technology as part of their typical practice. They were told that researchers would be available for technical support should any problems arise with the tutors or the computers. While the study procedure was kept as consistent as possible, given the nature of classroom research in multiple diverse contexts, we adapted it to each context as individual school conditions dictated. We describe these adaptations as part of the "Findings: Deployment of the CT" section.

Following tutor use, we conducted in-context guided interviews with participants [20], which began with a set of prepared questions but were allowed to digress into follow-up questions. Teachers and principals were interviewed individually in order to make them more comfortable in discussing sensitive topics surrounding school conditions. Teacher interview questions explored the social context of the participants at the site, the procedures and values they held in their traditional classrooms, and their experiences leading the CT sessions. Students were interviewed in groups of two to four at a time; groups were found to facilitate communication for students who were otherwise shy. Student interview questions explored social context, students' values about learning, and their experiences with using CT and other technology. These interviews were recorded and were conducted in the local language by a member of the research team who spoke the language. Two groups were taken aside for a think-aloud procedure while using the CT at each site.

FINDINGS: SCHOOL CONTEXTS

Based on our participant interviews and field notes across researchers, we can describe the conditions where cognitive tutors could potentially be deployed, and put the results of tutor usage in context. Across the three sites, we iteratively organized our findings into three main themes that affected our educational technology deployment: socio-economic context, typical classroom instruction, and technology use.

Socio-Economic Context

In Brazil, we deployed the CT in a middle school in an impoverished area of a large city in the northeast, known both for resorts and a significant industrial base. Class sizes ranged from 20-40. Given the economic situation in the neighborhood of the school, many teachers drove from up to three hours away, and did not always arrive to teach their class. Students, however, had a significant incentive to attend, as all students received free lunch and snacks during the day. Even so, as the school was located in a community in which religion was strong, many students were absent for up to a month at a time on family religious pilgrimages.

Figure 2. Images from the computer lab at each of the three sites. From top: Brazil, Mexico (combined with library), and Costa Rica.

There was low accountability for student absences. When teachers were absent, there were no substitutes, so students either sat unattended in their classroom, played games in the central courtyard, or sat in on other classes. Students wore t-shirts, jeans, and sandals that had been given to them by the school. The computer lab in the school was located behind a heavily locked and barred door designed to deter robberies.

In Mexico, we deployed the CT in a public middle school serving a lower and lower-middle class area of a large town in a Southeastern state. In this school, class sizes varied from 20 to 46 students. Students wore school uniforms purchased by parents and were provided with textbooks from the government. Lunch was not provided; rather, students were divided into two school sessions, a morning session from 7am until 1pm and afternoon from 1pm until 7pm.

In the Mexican site, as in Brazil, there were no substitute teachers. Instead, there was a system of aides. When teachers were absent, an aide would sit in the class and give students a prepared problem to do. If too many teachers were absent, an aide or other teacher periodically checked in on the class to make sure they were not misbehaving.

In Costa Rica, we deployed the CT in a middle school serving a medium-size town. Students were issued a school uniform shirt, but bought their own pants and shoes. Lunch was provided to all students in a cafeteria where they ate alongside their teachers, and afterwards all were expected to assist in cleaning their plates and utensils. These meal arrangements, also common at other schools in the area, are perhaps reflective of the lower Power Distance seen in Costa Rica compared to other Latin American countries [10]. Both students and teachers reported that teacher absences were rare, although school sessions were sometimes canceled for days due to heavy rains.

The school property itself was surrounded by locked gates and barbed wire, and had prior issues with armed robberies. Within the gates, the school walls (and those of other schools in the area) were covered in murals of jungle wildlife, painted by the students. These murals reflected the great importance placed on caring for the environment (ecotourism is a significant factor in the Costa Rican economy).

Teaching and Learning Practices

In each of the three sites, we interviewed teachers in order to understand their typical classroom procedures. These interviews took place in context, with teachers walking us through materials that they would typically use to teach. In each country, standard classroom practice for math instruction had a pattern of teacher demonstration followed by multiple days of group exercises.

At the Brazilian site, classes typically consisted of the teacher demonstrating a worked example briefly at the beginning of class, followed by students doing group exercises that came from a list at the end of a textbook. Despite the students' age (12-15), teachers reported that students were still working on basic math skills such as addition, subtrac-

	Brazil Site	Mexico Site	Costa Rica Site
Math Skills	struggling with basic operations	learning geometry, some difficulties with basic math	learning trigonometry, mastered basic math
Computer Skills	minimal exposure	recreational exposure	used in school
Computer Lab	12 computers, unused	49 computers, unused	30 computers, used in classes
City Population	1 million	50,000	10,000
City GDP Per Capita	$3,366USD	$5,417USD	$6,590USD
2009 PISA Test	57^{th} of 64 countries	51^{st} of 64 countries	N/A

Table 1. Comparison of the three populations on math skills, rank on the 2009 Program for International Student Assessment math test, computer skills and use, city size, and 2008 gross domestic product per capita in the city of our field site.

tion, multiplication, and division. Teachers informed us that they strongly encourage collaboration during classwork and even on assessments, from providing explanations to just sharing answers. Students were often assessed orally.

At the Mexican site, math classes consisted of an introductory lecture and worked example on a topic followed by 2-4 days of group work on a related exercise taken from materials provided by the government-standardized curriculum. Students were officially studying geometry, but teachers informed us that they felt students were underprepared by their previous courses and needed to review basic math skills. In class, students frequently talked out loud to one another off-topic during all classroom activities, including both groupwork and lectures. Teachers reported that this did not concern them, as they believed the talk would eventually turn to math-related topics.

At the Costa Rican site, math classes consisted of a lecture on a topic followed by a few periods of group work. Students were learning trigonometry, and teachers were confident that students had mastered basic math skills.

Digital Literacy

At the Brazil site, students reported that they were frequent computer users and that they were proficient in their use. However, when asked for detail, the majority of students reported that they did not have computers in their houses, and used computers at most once a month in internet cafés, where they used social networking sites and played games. Observations of these students using computers revealed a range of ability; some did not know how to operate a mouse or move a window, others were proficient in searching and posting pictures on the internet. All interviewees reported having a television in their home, even though many of their homes were off the electricity grid. A small percentage of interviewees had owned a cell phone.

Teachers showed a range of skill with the computers. Some had never used a computer, while others had one at home. Teachers who did not have computer skills relied on more proficient students to support other students with the CT.

The school in Brazil had a computer lab with 22 machines purchased by the federal government in an initiative to give every school access to technology. Computer viruses had infected all of the machines, but were seen as harmless pranks by administration. Twelve were functioning, but had no internet access. Computers were not used by classes for a number of reasons: many teachers had no experience with technology and were unfamiliar with educational uses of computers, and because the lab was typically locked due to security concerns.

At the Mexican site, students were familiar with computers and most used computers for social networking and listening to music. Half of interviewees reported having a computer in their home, and those who did stated that they used them to complete homework assignments. Students were also very familiar with other technologies: all had a television and cell phone and several owned a gaming system such as Xbox or PlayStation.

Teachers were familiar with computers, but used them only for preparation for class (e.g., typing up worksheets, searching for curriculum materials). One teacher had set up a blog for her students to follow. An exception to this rule was a teacher who reported that he did not trust computers and never worked with them; as noted below in the “Findings: Deployment of Cognitive Tutor” section, this teacher avoided attending any of his students’ sessions with the CT.

The combination computer lab/library in Mexico was outfitted with 41 Telmex Intel computers provided by the federal government, and 8 desktop machines. The school director’s office had internet. Although they had been in the school for a year, teachers reported that we were the first group to use the Telmex computers. Reports differed on why the lab was not used: the principal was not enthusiastic about technology, there was no educational software, or the teachers weren’t proficient in teaching with computers. However, during the study, several teachers stopped to ask if they could use the computers when we finished.

At the Costa Rican site, students had exposure to computers at school, and were capable users. Most had a computer in their home or were able to find one for recreational use such as social networking, and several reported having multiple machines in their home. Interviewees reported using a video chat program from home to jointly complete homework assignments (or answer-share) with their classmates when they finished school for the day.

Teachers were experienced computer users, and reported using them for class preparation and social networking. They owned cell phones and texted frequently during breaks. The teachers we worked with took part in a program initiated by the local university, designed to support them in integrating technology into the classroom, but rarely did so in practice. They reported that the computer lab schedules were often full with other courses, and that preparation time was too great for technology-enhanced instruction.

The school in Costa Rica had two computer labs, provided by a private foundation. Each lab was supervised by an attendant, and used by students for classes and internet access. There were currently 30 desktops across the two computer labs, following a theft in the school the previous year. For the study, our collaborators brought 10 laptops from a local university to temporarily replace the stolen machines. These computers allowed us to conduct our observations in a manner that was closer to typical classroom practices. Lab attendants reported that most courses in the computer lab were either computer skills classes on making presentations and documents, or were using the internet for information search.

FINDINGS: DEPLOYMENT OF THE CT

General Reception towards the Cognitive Tutor

Across the three sites, there were several commonalities that indicated that the CT might be a welcome addition to the classroom. Each school's principal expressed interest in using more educational technology (despite reports to the contrary from the lab manager at the Mexican site), and was an active partner in organizing the study. All students appeared excited and motivated by technology, whether or not they were proficient or frequent users.

In general classroom practice, teachers reported not having appropriate educational software or enough time to prepare lesson plans that incorporated technology. Thus, most teachers were enthusiastic about using the CT, which they perceived as requiring little additional preparation, and serving as a good supplement to their exercise-based classes.

Student and Teacher Participation

In the Brazilian site, around 100 students ages 12-15 participated. Because the number of computers in the lab was smaller than the size of a class, groups of twelve students were pulled from one class at a time to use the CT over two class periods of forty minutes each. Although the math teachers were enthusiastic participants in the initial informational meeting, for most of the study they were not present in the computer lab. Given that their classes were split for the study between the computer lab and the classroom, the teachers believed that being in their regular class was important, and that others would be able to handle the instruction in the computer lab. Additionally, as described above, there were frequent absences on the part of the teachers, and no substitutes. This led to teachers from other subject areas helping during periods that they had free from teaching. On occasion the principal of the school participated too. If neither teachers nor the principal were present, researchers supervised students.

At the Mexican site, the principal insisted that all students have the chance to use the technology. Thus approximately 600 students ages 13-15 and seven teachers participated. During use of the CT, each class of students was brought in to the computer lab in place of their typical math period, with each class participating for two periods of forty minutes each. Teachers (or, on occasion, knowledgeable substitutes) were present to conduct their classes for the duration of the study. The only teacher who was reluctant to use technology made himself absent for all of the sessions that his students participated in, and thus his sessions were given a substitute or supervised by the research team.

At the Costa Rican site, around 90 students and two teachers participated. The study was supervised by the regular math teachers, but occurred at a time where classes had just finished for the semester and students only attend exams. Therefore, we observed student use of the CT in groups of approximately 20 at a time selected from the same math class, for single 80 minute periods.

Structure of Cognitive Tutor Session

In the Brazilian site, students filed in excitedly and wanted to sit beside friends. There was confusion at the beginning trying to determine how to login to the system, as the names they used frequently did not match their names on the school roster. In addition, typing skills were low. As students started the first tutor problem, they were typically confused about the content, and had many questions at each step about how to proceed. Due to low literacy levels in addition to low math skills, they had difficulty understanding the tutor hints. Nevertheless they gradually moved through the first problem with each other's help, and that of any aides present. Occasionally the aides requested the researchers' help when unsure of how to proceed. Some aides also indicated that if we were going to be watching them, we ought to share the load of supporting students.

In Mexico, students took their assigned seats, and were able to help one another login to the tutor. The supervising teacher then typically walked the students through the problem, either verbally or using a projector to demonstrate. When teachers felt the students understood, they let the students work on their own, and walked around to help. They also asked the researchers to help, because the class sizes were so large that they had trouble getting to everyone who needed help. During the second session, students started using the tutor immediately. Because screens on the Intel PCs were small, and the CT has multiple windows, students had some difficulty navigating from window to window when working through the problems.

In Costa Rica, students took their assigned seats. As in Mexico, the supervising teacher either used a projector or a whiteboard to walk students through the problem, and then let the students work on their own, walking around to help. When students transitioned to solving problems on their own, they tended to work in small groups and were more successful than in the other sites.

In all three sites, certain collaborative patterns of use emerged when they used the tutor, concerning students working interdependently, working at locations all over the classroom, and giving particular kinds of help to each other. We believe they are particularly relevant for cognitive tutor design for use in these settings, and describe them below.

FINDINGS: COLLABORATIVE PATTERNS OF USE

Interdependent Pace of Work

I1: Teacher led instruction

One collaborative pattern we observed in both the Mexican and Costa Rican sites was synchronized whole-class advancement through the tutor, led by the teacher. In many introductory sessions, the whole class worked at the same pace, led by the teacher guiding students step by step through a problem in the tutor. Teachers seemed to find this to be a useful technique when students were unfamiliar with the tutor. The teacher would describe a single step in the tutor, and then wait as students executed the step on their own computer. The teachers would then either demonstrate the step themselves on a projector or provide the students with the correct answer. Many teachers requested a projector to facilitate this process, often using the only projector in the school.

I2: Teacher guided practice

A related collaborative pattern was whole-class advancement through the tutor, but with opportunities for students to work independently. As students acquired more expertise in using the CT, teachers would instruct them to do two or three steps on their own, but then stop the whole class to wait for everyone to catch up, saying "Is everybody here?" In this pattern, students typically did not show exploratory behavior with the tutor; they would wait patiently for the teacher to say they could continue, and follow the teacher's instructions closely.

When asked about the rationale for structuring the class in this way, teachers said that is important to keep everyone on the same page, an easy way to familiarize the students with the system, and more efficient than repeatedly answering the same questions from students. Interestingly, in almost all cases, after this guided period of instruction which generally consisted of one full problem in the tutor, teachers would make an announcement to the class proclaiming that now it was time for students to work on their own, and the teachers would not be helping (this statement was never true; teachers did help during the self-paced period). Teachers said that

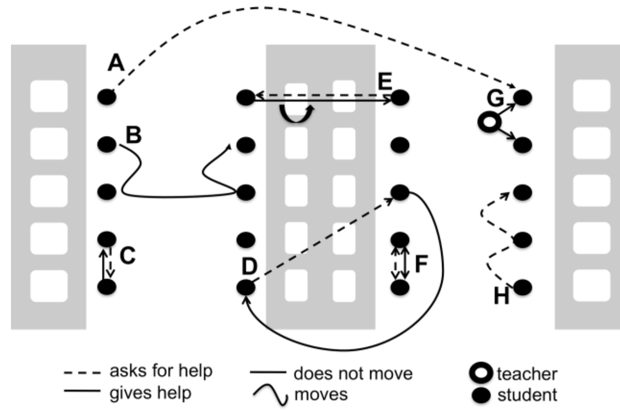


Figure 3. The ways in which students moved around the classroom and interacted with classmates across sites.

this announcement was made because otherwise students would not work, but at the first sign of difficulty would wait for the teacher to give help.

I3: Student-led group work

A third pattern we observed involving interdependent pace of work was student-led group problem solving. As students moved into an individual work phase, their pace of problem-solving often remained interdependent, but in spontaneously formed small groups seated at adjacent computers. When one group member would successfully complete a step, they would inform the other members of their group of the correct action, and the other members of group would then take the correct step. Between groups, it varied whether one person always took on the explainer role, or whether different members of the group did. During this type of work, the teacher circulated around the classroom to help individual students and groups.

I4: Shared interfaces

At the Costa Rican site only, students were more likely to work at an individual pace. However, when they worked synchronously, groups of two to three would work completely interdependently on the same computer, sharing the mouse and keyboard (despite the fact that each student had access to an individual machine).

Variable Location of Student Work

In addition to problem-solving interdependently, we found that students frequently helped each other, and thus a lot of students' work did not occur at their own computers. Figure 3 aggregates data from all three sites to depict ways in which students interacted with their peers in order to give or receive help. Students interacted either from their seats (represented by straight lines) or by moving around the class (represented by curved lines). Teachers encouraged these collaborative behaviors as they circulated around the classroom (represented by G in Figure 3). To the observer, classrooms were chaotic, with constant movement by students and loud cross-class collaborations. We estimate that in the Brazilian and Mexican sites, roughly 60% of student work did not occur at their own computer, a much higher proportion than the 4% seen in past research on CT usage in the

United States [4]. We divide the variable location of student work into two patterns of collaboration.

L1: Directed help

One pattern related to location of work was the directed exchange of help between students. This pattern represents help given after one student calls out or signals to a specific friend for help. For example, in Figure 3, D and E represent help given in response to one student calling out to a friend for help. In D, the helper moves around the table, while in E the helper remains in her seat but rotates her laptop.

L2: Spontaneous help

A second pattern related to location of work involved help that did not appear to be purposefully directed to a specific friend in need. In cases such as A and H, help-related actions were spontaneous. In H, the student goes from computer to computer looking for the answer she needs. When students were done with a problem step, they also might move around the room from classmate to classmate giving them information (as with student B in Figure 3).

When probed on their helping behaviors, students explained that everybody needed to finish, and that the academic performance of their whole class was important. Students said they felt kinship with their classmates, given that they were often classmates several years in a row.

Content of Help

Despite these commonalities in movement around the classroom, the kinds of help students gave varied between settings. In general, help consisted of a verbal explanation, telling another student the answer, or even demonstrating the next correct step by physically taking control of another person's computer (or a combination of these).

The verbal content of explanations differed from site to site, and appeared to be related to the prior knowledge of the students. We identified three collaborative patterns related to the verbal content of help. At the Brazilian site, where students had very low prior knowledge, we observed students circulating around the classroom (as in B or H in Figure 3), giving or seeking the answers to the next problem step (*C1: Answer-based help*). In contrast, students at the Mexican site primarily exchanged help focusing on how to use the technology rather than problem solving (*C2: Technology-based help*). At the Costa Rican site, students reported giving full explanations to help their classmates understand the material (*C3: Concept-based help*), although they were observed to give answers and acknowledged doing so when questioned. These differing approaches emphasize the opportunity in supporting students whose natural inclination is to collaborate to give more conceptual help.

DESIGN RECOMMENDATIONS FOR CT USE IN HIGHLY COLLABORATIVE SETTINGS

By encouraging teachers to use the CT as they would typically conduct a regular class, we open the door to students using the CT in a highly collaborative manner. In order to achieve the full learning benefits of intelligent tutors, it may be necessary to redesign the underlying systems, which assume that students are working for the most part at their own pace and computer [23].

Collaborative Knowledge Tracing

One of the most important aspects of CTs is their ability to track the current knowledge level of the student. This knowledge tracing allows the student and the teacher to know when the student has achieved mastery on a skill, and enables the tutor to select appropriate problems for each student. However, we saw that as students worked in almost all collaborative patterns (*I1*, *I3*, *I4*, *L1*, and *L2*), the answers entered into a tutor were frequently not reflective of the knowledge of the student using that machine. We believe it would be beneficial for the knowledge-tracing algorithm to view the classroom as a *network* of connected nodes instead of a collection of individual users, accounting for when multiple students are completing problems jointly.

To implement this modification, one could explicitly estimate the probability that the student has been told the next step in the problem. In classical Bayesian Knowledge-Tracing [7], skill mastery is estimated based on four parameters, including the probability that students will perform a step correctly even if they have not mastered the skill (P[Guess]). It is possible to incorporate other probabilities in P(Guess) to account for other sources of error [5]; here, it would be appropriate to include the probability that a student answered correctly due to another student's help (e.g., A in Table 2). This probability could be estimated empirically based on data on the problem-solver's behavior (as in the "contextual guess and slip" approach in [cf. 3].

This approach will necessitate the inclusion of data on the problem-solving pace of all students in the networked classroom. It may be possible to determine over time which students' performances are linked, by tracking the timing of different students' steps. It may similarly be possible to assess whether students are working together (*I3)* or following the teacher's lead as a whole class *(I1)*.

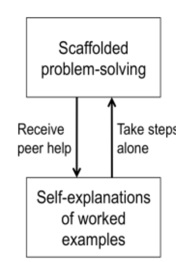
A. Knowledge Tracing	**B. Model Tracing**	**C. Adaptive Scaffolding**
P(Guess') = *guess**(1-*helped*) + *helped* Where *helped* = probability student was helped *guess* = probability student guessed	IF don't know *x* AND person *y* knows *x* THEN ask *y* about *x* IF know *x* AND person *y* doesn't know *x* THEN tell *y* about *x*	

Table 2. Three redesign proposals for the Middle School Mathematics Cognitive tutors.

It is worth noting that in a different context, these assessments might be seen as identifying an undesirable behavior; in these classrooms, it is a step towards more accurate assessment for the predominant style of usage.

Help-Giving

As discussed above, existing models of help-usage in tutors assume that help comes from the tutor [1, 23]. However, in the settings described here, the source of help was most frequently another student in the class (I3, L1, L2). Students' collectivist behaviors reflect an opportunity to actively encourage students to seek and give help at *appropriate* times during their problem-solving, from *appropriate* people. There are asynchronous systems such as iHelp that match students based on their expertise and preferences [24], but these systems do not take into account real-time problem-solving progress.

Working in conjunction with a classroom-level knowledge-tracing algorithm, if a student is clearly struggling, the system could encourage them to seek help from someone who has already mastered the relevant skill. On the other hand, students who have mastered a skill quickly could be encouraged to help others who have not (sample rules for this approach can be found in B in Table 2). This would support more effective help, by taking advantage of students' natural inclinations to collaborate, but by pairing students who might maximally benefit from working with one another.

Adaptive Scaffolding

The benefits of collaboration, however, are not automatic [12]. Students often shared only the answer to a problem step (*C1)*, rather than giving an explanation that their partner could learn from. To ensure that students give constructive help, it may be useful to view the person receiving help as studying a worked example rather than taking a problem-solving step. Using techniques such as those described above, students can be inferred to be receiving help. One approach would then be to introduce scaffolding encouraging the peer learners to provide an elaborated explanation of the problem-solving step just entered. Many have demonstrated that alternation between self-explanation of worked examples and problem-solving is an effective learning technique (as in [2]). Hence, this design recommendation has the potential to benefit both the struggling partner and the partner with greater knowledge. C in Table 2 represents this concept; students transition between self-explanation and problem-solving based on whether they are judged to be receiving help, or working on their own.

DISCUSSION AND CONCLUSIONS

In this paper, we described a project where we deployed one unit of a mathematics cognitive tutor in three different Latin American school sites. The samples had varying socioeconomic contexts, typical methods of instruction, and experience with technology use. Thus, there was variation in the way the CT was integrated into classroom practice. Nevertheless, across all contexts, we found that students collaborated frequently while using the tutor; the pace of work was often interdependent, and work often occurred at classmates' computers in addition to their own. We propose guidelines for integrating the CT into similar classrooms and three augmentations to cognitive tutor design.

There is a great opportunity for educational technology to have a positive impact in developing contexts. Access to technology is increasing, and computers can now be found in schools in impoverished areas. Our findings suggest that students are enthusiastic about learning with technology. Given the structure of the school systems we observed and the potential lack of teaching resources, intelligent tutors provide an opportunity to support student learning when a regular teacher cannot be present in the classroom, or during periods where students would otherwise be working on paper-based assignments. In terms of content, cognitive tutors that focus on creating fluency with basic skills, rather than on advanced units, have the potential to teach or remediate critical deficiencies in students' understanding. A large barrier to using educational software in classrooms is the preparation teachers require to structure lessons around the software. Cognitive tutors help to mitigate this obstacle by providing self-contained lessons. In cases where teachers cannot be in class, cognitive tutors could assist substitutes or aides and supplement existing lessons.

CT use in these developing contexts was far more collaborative than the typical use of CT, and we have several hypotheses for why this may be so. In the classrooms we visited, students had never used cognitive tutors before, and in the Brazilian and Mexican sites, students had never used computers to learn before. Teachers described students as more engaged and motivated than normal, which could be attributed to a novelty effect. However, these external effects are not likely the dominant cause, since increased engagement has also been reported in classrooms that use technology in the U.S. [19]. In addition, students' variation in basic math skills and computer experience might mean that they required more help to use the CT than analogous students in the U.S., driving them to collaborate more. Following this line of thinking, the differences we observed between each Latin American context may have been related to factors such as prior knowledge and experience with computers. In the Brazilian site, where students we worked with had lower prior knowledge than those in the Costa Rican site, we saw more frequent answer-focused help. Finally, other researchers have theorized that the scarcity of technological resources in developing contexts force students to share resources, and thus collaborate more, which may have played a factor in the behaviors we observed [19].

It is also difficult to discount the possible influence of cultural factors on use of the CT in these settings. Brazil, Mexico, and Costa Rica are considered to be more collectivist cultures than the United States, in that they are "…*societies in which people from birth onwards are integrated into strong, cohesive in-groups, often extended families…which continue protecting them in exchange for unquestioning* *loyalty [10]*." In all three settings, collaborative work was a core part of classroom activities. Teachers valued student collaboration. Students valued helping their classmates and were comfortable asking classmates for help. Students were part of a culture that valued group membership and employed collaboration as an integral part of everyday activities. Therefore, the students collaborated extensively while using a technology primarily designed for individual use.

Regardless of the reasons for the differences observed, this work contributes insights into the opportunities for intelligent educational software in underserved regions, and into the ways different contexts might adapt to a proven technology platform. There may be benefits to deploying existing effective systems in developing contexts, and this direction of research should be pursued. However, a thorough understanding is necessary of how those contexts might incorporate technology into their current instructional practices, and which modifications to the basic assumptions of such systems might be necessary. This understanding might also provide insight for how cognitive tutors may and should be used in contexts similar to the sites we observed, in countries where intelligent tutoring systems have already been deployed. Rather than forcing others to conform to a single model of appropriate technology use, we must understand how the technology can be best integrated in vastly different contexts than those for which it was designed.

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