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One Mouse per Child: interpersonal computer for individual arithmetic practice

C. Alcoholado,* M. Nussbaum,* A. Tagle,* F. Gomez,* F. Denardin,* H. Susaeta,* M. Villalta* & K. Toyama†

*School of Engineering, Computer Science Department, Pontificia Universidad Católica de Chile, Santiago, Chile

†School of Information, University of California, Berkeley, CA, USA

Abstract Single Display Groupware (SDG) allows multiple people in the same physical space to interact simultaneously over a single communal display through individual input devices that work on the same machine. The aim of this paper is to show how SDG can be used to improve the way resources are used in schools, allowing students to work simultaneously on individual problems at a shared display, and achieve personalized learning with individual feedback within different cultural contexts. We used computational fluency to apply our concept of 'One Mouse per Child'. It consists of a participatory approach that makes use of personal feedback on an interpersonal computer for the whole classroom. This allows for *N* simultaneous intelligent tutoring systems, where each child advances at his or her own pace, both within a lecture and throughout the curricular units. Each student must solve a series of mathematical exercises, generated according to his or her performance through a set of pedagogical rules incorporated into the system. In this process, the teacher has an active mediating role, intervening when students require attention. Two exploratory studies were performed. The first study was a multicultural experience between two such distanced socio-economic realities as Chile and India. It showed us that even in different environmental conditions, it is possible to implement this technology with minimal equipment (i.e. a computer, a projector, and one mouse per child). The second study was carried out in a third grade class in a low-income school in Santiago de Chile. The students were asked to solve mainly addition exercises. We established statistically relevant results and observed that the software proved most beneficial for the students with the lowest initial results. This happens because the system adapts to the students' needs, reinforcing the content they most need to work on, thus generating a personalized learning process.

Keywords arithmetic teaching, interpersonal computer, multiple mouse, One Mouse per Child, shared display.

Introduction

Interpersonal computers

Today's computers are designed under the assumption that a single person interacts with the display at any given moment, manipulating the input device exclusively. Single Display Groupware (SDG) allows multiple people to share the same space and interact simultaneously over a single communal display on the same machine, each with his own input device (Stewart *et al*. 1999). A solution is to provide each child with a mouse and a cursor that controls his own objects on the screen, thus effectively multiplying the amount of interaction per student per personal computer (PC) for the

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Correspondence: Miguel Nussbaum, School of Engineering, Computer Science Department, Pontificia Universidad Católica de Chile, Santiago, Chile. Email: mn@ing.puc.cl

cost of a few extra mice (Pal *et al.* 2006; Pawar *et al.* 2007). This is highly attractive for schools in developing countries where high student–computer ratios are a common problem. One version of this idea has been implemented to allow 20–30 students in a single class to respond to multiple choice questions designed by a teacher (Moraveji *et al.* 2009).

As in SDG where a large display is used by several people at the same time, in interpersonal computers, the display of information is shared by a group of users, where the control is distributed by multiple inputs; this allows several people to interact at the same time, in the same place (Kaplan *et al.* 2009). When information is shared, Cao *et al.* (2008) introduce the notion of a cross-modal display as a proposal for enhancing the privacy of public information displays. The presentation must allow multiple users simultaneously accessing the information, which contains public and personal elements, to interact on a communal display. When small groups (three to five peers) share a screen so that each user has his own work space, the activities can be synchronous, e.g. turn taking (Moed *et al.* 2009) or asynchronous, defined by the students' role in the activity (Infante *et al.* 2010).

The use of multiple inputs has been studied by a number of researchers who have sought to demonstrate the effects when peers work with a single screen (Paek *et al.* 2004). It is fundamental in favouring interactivity among students, as well as motivation levels that the activity makes each student work with objects that are solely his; each student controls his own input device, which forces him to participate and become the protagonist of his own learning process (Infante *et al.* 2009). Infante *et al.* (2010) indicate that students focus their attention on the common screen where individual resources are shared, transforming it into a learning place in which students discuss, collaborate, and negotiate.

Given that research in interpersonal computers has been performed in different countries – as for example in India (Moraveji *et al.* 2009; Amershi *et al.* 2010), China (Moraveji *et al.* 2008), and Chile (Infante *et al.* 2009) addressing specific functional and usability issues – our first research question is: considering that interpersonal computers are an alternative for maximizing resource utilization in schools, how do different cultures influence the usability of this technology, taking into account differences in knowledge and technological abilities?

Active participation

Experience and active participation in the educational process are two elements that have revolutionized the traditional concept of teaching and learning over the course of the 20th century. The writings of Dewey, Vygotsky, Piaget, and others have taken on renewed relevance for specialists attempting to explain and improve the quality of learning. Participatory interaction is the focal point for organizing the experiences of those who take part in the learning process (Cooper & Others 1991).

Most pedagogical propositions that involve computer support share an interactive concept of the learning process (Panitz 1999). Interaction presupposes active, flexible and experiential pedagogical processes in which the instructor's pedagogical action effectively manages the inherent uncertainty (Shulman 2005).

Regardless of the theoretical approach, educators and specialists consider that student participation generates better conditions for learning (Ahles & Contento 2006; Lim 2008). The quality of that participation is one of the foci of study of current pedagogical propositions (Shulman 2005). Studies have demonstrated the importance of active participation by students in the learning process for phenomena such as achieving better results, both with technological support (Zurita & Nussbaum 2004) and without it (Boaler & Staples 2008); improving students' perceptions of self-efficacy (Hamman *et al.* 2007); and developing meta-cognitive reflexive practices and student commitment to the learning process (Dede 2009).

Active participation can be achieved through interactive learning environments that provide feedback to the students' actions. Feedback can be delivered through evaluation of activities and can be seen as an instance that promotes learning as opposed to a specific event with the sole purpose of assigning grades, specially considering that when children become involved in the evaluation process, it is viewed as learning rather than a measuring process (Davies 2000).

When a shared screen is present, as with an interpersonal computer, it is possible to provide personal feedback to each of the students. Given that the screen is seen by all the students, they can see each other's

Table 1. Exploratory studies performed using the same type of technology for one classroom: shared display, one computer and one mouse per child for teaching Basic Math.

	Country	Age	# students	# of sessions (time per session)	Purpose
Comparative analysis in different cultures: usability analysis	India	9–10	30	4 (90 min)	Usability analysis
Comparative analysis in different cultures: usability analysis	Chile	9–10	20	4 (30 min)	Usability analysis
Achievement and conduct assessment in a second study in Chile	Chile	8–10	40	7 (30 min)	Achievement and conduct assessment (qualitative and quantitative)

progress, introducing an element of competition between them, while the teacher can observe all students' work knowing which children need their support. This form of group display introduces various technical challenges as well as benefits that are discussed in this work.

Math teaching

Understanding numbers and their representation is a fundamental goal when teaching mathematics (NCTM 2009). This requires understanding mathematical operations, considering the actions they represent, as well as the possibility of discovering unknown numerical information from known numerical information. According to Berch (2005), processing the meaning of the numbers allows students to solve problems by understanding everything from the meaning of a single number to development strategies; from creating numerical comparisons to creating procedures for numeric operations; and integrating their knowledge to interpret information. In this sense, computational fluency in whole number arithmetic is vital; the corresponding procedures are so basic and have such a wide application that Ball *et al*. (2005) suggest that they should be practised to the point of automaticity through efficiency and accuracy. To this end, progress in learning calculating procedures should be closely linked to the process of learning numbers so as to support it. To achieve this, it is necessary to carefully plan the sequence of numbers to be included when practising operations.

When teaching math, it is important to establish bases for knowledge to progress onto learning more complex operations. We must therefore make sure that all students acquire said bases. If the work is too easy or too difficult, students will not get involved, and learning math will be a constant struggle throughout their education. When faced with an entire class, where each student is different, teaching with consideration to individual rhythms can be a great challenge. However, it is crucial that each student feels constantly challenged in order to achieve success. This can be achieved by incorporating gradual rhythms into each task, so the student will not become frustrated and will not abandon the challenge (Sangster 2006).

Our second research question is: is it possible for all the students in a class to work simultaneously on their individual basic math problems at a shared display on just one computer and still achieve personalized learning with individual feedback? The aim of this research question is to explore how an interpersonal computer supports personalized learning in a given curricular context, thereby understanding how students and their teacher respond to this technology.

Therefore, the purpose of this work is to show how a participatory approach that makes use of an interpersonal computer for the whole classroom can be implemented for teaching basic math. This is done through a sequence of 'drill and practice' exercises, with feedback for each student and the teacher, which allows the latter to address misconceptions and do some formative teaching as appropriate. The One Mouse per Child (OMPC) application that follows the previous aims is described in the next section. Two exploratory studies were performed as shown in Table 1. In the first, described in the later section, we show a usability analysis of the technology based on a comparative study of the use of the tool in two different cultures, India and Chile, and in the second, the section following, we show the experimental work performed to carry out a

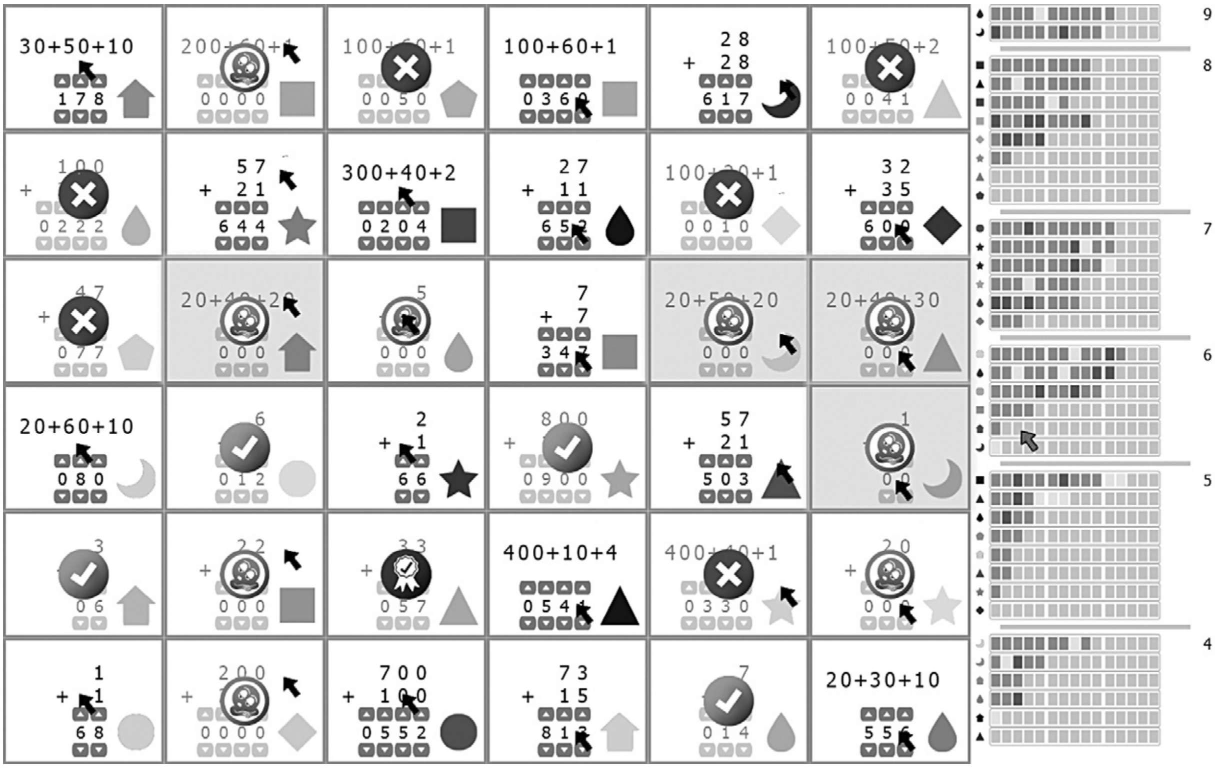

Fig 1 Thirty-six students working simultaneously on One Mouse per Child for Basic Math.

qualitative and quantitative assessment of achievement and conduct. The paper finishes with conclusions. There is an Appendix with the rules of the system used in this experience.

One Mouse per Child for Basic Math

OMPC for Basic Math is an application for teaching arithmetic, oriented towards working simultaneously with an entire class using an interpersonal computer. In our case, for one classroom, this consists of one PC, one projector, one mouse for the teacher, and one mouse for each child participating in the activity. Each student must solve a series of arithmetic exercises, which will be generated according to his performance through a set of pedagogical rules incorporated into the system. In this process, the teacher has an active mediating role as the system's protagonist. The teacher's mouse has special abilities that enable him to intervene in his students' learning process according to what he considers to be pedagogically convenient.

General description

Once the teacher accesses the system and is assigned his cursor, the children must identify themselves with their respective mice. It is necessary to go through an identification process because the mice do not have unique identifiers to recognize them.

Once all the children have selected their name, the teacher begins the activity. Each child has a cell, where he will work individually. No child can exit his cell, or enter another classmate's (Fig 1). All the individual spaces are displayed as a grid, with size varying according to the number of mice connected to the system because the idea is to maximize each child's individual space. According to experimental observations, the maximum viable number of individual work spaces on a 1024 × 768 pixel projection on a conventional 1.5 m × 1.5 m screen is 49, which means that 49 children could work simultaneously in a classroom.

Most classroom-based interpersonal computers with individual mouse input are mainly constrained to point-and-click activities, like true-false or multiple

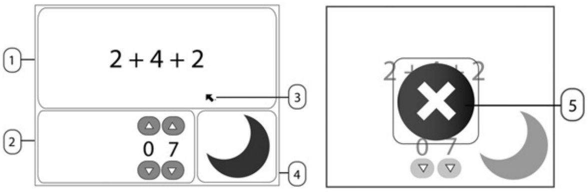

Fig 2 Each child's work space.

choice-based activities (Amershi *et al*. 2010). We added a scrolling technique (Hinckley *et al*. 2002) that makes use of the mouse to avoid incorporating a more expensive and less versatile device, such as the keyboard.

Each student's work space is composed of the five elements shown in Fig 2:

1 Equation: In zone 1, Fig 2, a mathematical equation is displayed for the child to solve. This equation can be written vertically or horizontally (as shown).
2 Answer zone: In zone 2, Fig 2, the child must enter the answer to the equation (zone 1). The number of digits in this area depends on the length of the correct answer.
3 Player's pointer: This represents each child's cursor, which can only move within the cell formed by zones 1, 2, and 4.
4 Player's identifying symbol: The icon in zone 4 (Fig 2) serves two purposes: it identifies the child's work area and at the same time, works as a button that must be pressed to enter the answer.
5 Feedback zone: Once the child enters his answer, feedback to his actions is displayed in the middle of his cell. There are four types of feedback: correct answer (Fig 1, column 2, row 4); incorrect answer (Fig 1, column 1, row 2); correct answer and pass to the next level (Fig 1, column 3, row 5); and if the child does not move his mouse within 60 s, a sleeping symbol is displayed (Fig 1, column 2, row 1). If inactivity persists after 120 s, the background of his cell becomes the same colour as the sleeping symbol (Fig 1, column 2, row 3).

Pedagogic rules

Each child is shown an equation determined by the teacher, or according to the student's level, which in turn corresponds to a specific pedagogic rule. The child must solve the said equation and enter the answer in the specified zone. If the answer is correct, a new equation will appear, according to the pedagogic rule system; if it is incorrect, the same equation will be displayed until the child solves it correctly.

This application is designed to support the teaching of math in the classroom, which is why it has a set of rules that increases in difficulty. These rules are aligned with the math contents set out by Chile's Ministry of Education (MINEDUC 2011) for grades 1 to 4. In the Appendix, we show the rules used in this experience, i.e. for addition (18, Appendix A) and subtraction (18, Appendix B). The total number of rules for the system is 65; the 36 addition and subtraction levels we already mentioned, plus 13 for multiplication and 16 for division.

For each level, children must carry out at least ten exercises that are randomly generated according to the rule. If the student correctly answers all ten exercises, he moves on to the next level. If he makes a mistake in the first ten exercises, he must solve five more in order to pass. If at the end of these 15 exercises he has solved at least eight with no mistakes, he may move on to the next level. If he has not, the system will keep generating a new exercise from the same level until the above criterion is met. The objective in having a variable number of exercises is for the children to reinforce the levels where their performance is insufficient, as well as to show certain abilities in managing the mathematical activity they were exposed to when they pass a level.

The teacher's role

In Fig 1, a ranking is displayed outside of the students' work space (on the right side), which graphically sums up each child's information, listing them according to their placement in the application in terms of level achieved, number of exercises solved and progress. This is shown as feedback for the students, so they can know how they are doing with regard to their classmates. Because the list is in order of results, it adds a competitive-ludic element among participants. This ranking, along with the icons regarding inactivity, allows the teacher to see the groups' progress as well as know which students are lagging behind or have low results and need his attention and mediation.

Once the teacher ends the session, the students' data are saved so the children can work on the same level during the next session. The data corresponding to each session can be displayed at the teacher's request.

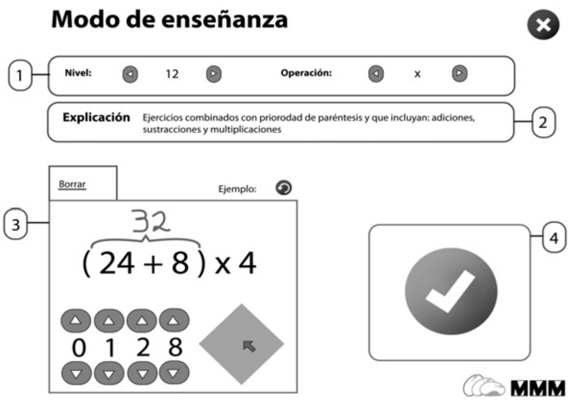

Fig 3 Teaching mode.

The teacher's cursor is different from the students' because it is red and is the only one not limited in its movement. It can freely move throughout the screen to intervene in a student's work if he so wishes. The teacher can identify any student's name and go into a given child's work space to work with him inside his area.

When the teacher wishes to explain something in greater detail to the entire class, he can go from practice mode to teaching mode (Fig 3), where only the teacher interacts with the system. In teaching mode, the teacher has his own work space (component 3, Fig 3), which will help him choose and show the pedagogic rule he needs (component 1, Fig 3) with a short description (component 2, Fig 3). The teacher's work space (component 3, Fig 3) works exactly the same as the students', except feedback is displayed at the right side (component 4, Fig 3). Within the work space (component 3, Fig 3), the teacher can write and underline.

Comparative analysis in different cultures: usability analysis

Objective

A multicultural exploratory study was performed to prove whether students could adequately use the technology, regardless of differences in knowledge and technological abilities, considering they came from such distanced socio-economic realities as Chile and India. It did not seek to measure the pedagogic value of the system (analysis performed in the following section) but its usability.

The two schools studied in Chile and India are representatives of government-run or supported schools in each country. Yet, both countries have wide variation in the quality of their schools' infrastructure; teaching style, teacher qualifications and student backgrounds vary significantly from school to school. Specific results may have differed had the assessment been carried out in different schools from the same countries. Thus, in the ensuing analysis, while the schools are referred as being in Chile or India, this should not be taken as a generalized expectation across the two countries, just as an illustration of the variation that can occur when using the analysed tool.

Experimental design

The tests in India were carried out in an average school in Bangalore, financed with state support as well as voluntary donations. The students come from a low socio-economic background, where most fathers are employed as labourers and most mothers are domestic workers. The school gives out two meals a day, which is one of the main factors for parents to send their children to school instead of making them do fieldwork. The school has a computer lab with nine computers, one of which has Internet access. Teachers normally take their classes to the computers because they value the importance of learning to use them, especially learning to type. The computers are open for students to use freely, but access to them is difficult, as they are in the principal's office. Most students do not have computers at home and have limited access to them in general.

In Chile, the tests were carried out in a school corresponding to the middle socio-economic class, with state subsidy. Most parents have 14 or 15 years of schooling. The school has a computer lab with about ten computers, all of them with Internet access. They also have technology such as projectors and a screen. The computers are open for students and teachers to use, as wanted and needed. Their primary use is for work assigned in class. Most students have access to a computer at home or at a neighbour's house.

In India, the tests were carried out with a sample of 30 students, ranging between 9 and 10 years of age, in a multipurpose room (smaller classroom), with the students sitting on the floor, in rows of seven. In Chile, the experience was carried out with 20 students from the same age group in a computer lab. In both groups, the equipment was similar: a laptop, a projector, plus the necessary mice and hubs.

In both cases, four experimental sessions were carried out, each lasting approximately 90 min in India and 30 min in Chile because of time restrictions imposed by the school. During that time, the students carried out the exercises indicated by the system.

At the beginning of the sessions, we explained how to use the system with slides. This introduction was sometimes omitted, according to the students' requirements.

In India, the teachers in charge of the participating students were present at the intervention, as well as some other teachers who expressed interest, while in Chile, only the research team was present during most of the sessions because the teacher had to take care of the students who were not participating in the experience. In India, teachers and those in charge of the experiment took note of students' questions, so they could help with language issues. Videos were recorded in both countries to document the qualitative study. Additionally, surveys were carried out among students and teachers.

The system described in the previous section already considers some of the usability findings of this study. Therefore, for the intercultural usability study, we used an earlier version of that system. The differences include minor changes in the graphics and the teacher's tools. Data were not saved between sessions. Two or three-digit addition exercises were randomly generated (at the teacher's discretion).

Comparative analysis

Table 2 reports the statistics of use of the experience performed in Chile and India, for the first and last sessions, to illustrate the corresponding evolution. In each case, we define the parameter and also report the differences observed. This data, plus the qualitative observations, are used as input for the usability analysis in the next section.

Usability study

System usability is characterized by *learnability, memorability, efficiency, errors*, and *satisfaction* (Nielsen 1994).

Learnability

Regarding learnability, we observed that the number of activities carried out per session was very different between the first and final sessions in India, where students went from not completing any activities to completing six. In Chile, on the other hand, we can see an increase in the number of completed activities, from one to three. However, the available time was greater in India (90 min against 30 min in Chile). This shows that students managed to overcome the technical and system-related difficulties they had at the beginning of the experience in both countries.

A second observation regarding learnability is the analysis of the mean of correct answers during the experience. In India, between the first and second sessions, it increases considerably (from 0.59 to 5.00), stabilizing itself from then on, until reaching an average of 5.55 correct answers. This indicates that students reached the techno-educational threshold as early as the second session. The techno-educational threshold is the point where the results of the mathematical exercises stabilize between sessions (average of correct and incorrect answers). This shows that the difficulties in improving no longer have to do with using the technology but rather with the complexity of the mathematical exercise. The mean of incorrect answers also maintains a slight decrease, which corresponds to an increase in the number of correct and total answers, showing an improvement in learning mainly in the technological aspect. In the Chilean experience, there is not a significant increase in the mean of correct answers (7.05 to 7.63), which indicates students had little technological difficulty at the beginning, reaching a quick balance when faced with the difficulty of the mathematical exercises. The mean of incorrect answers increases slightly between the first and last sessions (1.76 to 1.89), but it is less than the increase in the mean number of total answers (7.5 to 9.05) due to better use of the technology.

A final aspect of learnability was observing the need for culture-independent graphic elements. This made us rethink the feedback and symbol systems, originating the version seen in the previous section.

Memorability

Concerning memorability, we observed that both in India and Chile, students did not need an introduction to the activity as of the third session. In both countries,

Table 2. Comparative analysis.

	India		Chile	
	Initial session	Final session	Initial session	Final session
Initiation time. Time it took the children to settle in their seats and be ready to begin (shows the logistic challenges to starting a session). Differences are due to the number of children in each group and the different physical infrastructure.	7 min	7 min	5 min	4 min
Session length. The available time in India was much longer.	90 min	90 min	30 min	30 min
Introduction. Necessity of explanation at the beginning of the session. In both countries, this was only so at first.	Yes	No	Yes	No
Number of activities completed in the session. In Chile, activities were completed within the first session, which was not possible in India because of the children's distance from the use of technology. During the last session in India, the activities carried out were twice as many as in Chile as much more time was available.	0	6	1	3
Type of addition. Number of digits (2 or 3) involved. In Chile, because of initial knowledge, it began and ended with three digits.	2 digits	3 digits	3 digits	3 digits
Mean number of total answers. Sum of all correct and incorrect answers normalized by the number of participating children. Similar at the beginning in both countries but increased more in India than in Chile.	7.96	11.53	7.5	9.05
Mean number of correct answers. Sum of all correct answers normalized by the number of participating children. The initial state of correct answers in Chile was much greater than in India, which showed a notable increase, less visible in Chile.	0.59	5.55	7.05	7.63
Mean number of incorrect answers. Sum of all incorrect answers normalized by the number of participating children. The initial low number of correct answers in India was not only due to lack of knowledge but also to poor handling of the technology.	8.25	6.38	1.76	1.89
Mean number of questions regarding position on screen. The average student's difficulty in identifying his or her personal work space on the screen. Similar values can be observed in both countries.	0.4	0	0.2	0.05
Mean number of questions regarding use of the mouse. The average of how many times children asked how to use the mouse or how to use it to enter their answer correctly. Initial difficulties were greater in India than in Chile, but at the end, both were similar.	1.56	0.13	0.2	0.45
Mean number of conceptual questions. The average number of questions about the exercise being presented to the student. Similar values can be observed in both cases.	0.43	0.8	0.65	0.45
Mean number of recognition comments. Students raised their hands as if they had a question, but when the teacher approached, the student was actually expecting recognition for the solved exercise. Similar behaviour in time in India. This aspect was not observed in Chile.	0.7	0.56	0	0
Student interest. Before, during and after the activity, students were questioned about their interest in the activity and if they would like to play it again. Interest was always lower in Chile than in India, in fact decreasing over time, as the activity was always the same because there was not a self-regulated system of rules.	100%	100%	>90%	>80%
Teacher interest. Before, during and after the activity, teachers were asked if they were interested in the OMPC concept and the software itself and if they would use it in other subjects; interest was very high in both countries.	100%	100%	100%	100%

OMPC, One Mouse per Child.

many students expressed not needing an introduction as early as the second session.

Efficiency

Regarding efficiency, on-site observations, as well as the audiovisual material, indicate that students in Chile had minimal problems in understanding how to use the technology, specifically the mice. In India, many of the students had never used a mouse before and could not handle it properly in the beginning, presenting problems with movement sensibility (they could not click where they wanted to, and thus got many wrong answers by mistake), or clicking the right button (when the activity required clicking the left button). However, we can see from the number of questions regarding the use of the mouse (which decreased progressively between sessions) that most of the students developed the ability to use the mouse. Likewise, their ability to identify themselves based on the symbol on the screen also progressed as they dominated the technology and understood the activity.

A second aspect pertaining to efficiency is the initiation time for the activity. When there is a reduced available time, as in Chile (just half an hour), initiation time can be a considerable 15% of the session. This is mainly because of the complexity of managing a massive number of mice with cables. This problem can be solved in a lab wired to meet these needs. Another solution is the use of wireless mice; however, this is much more expensive.

Errors

Concerning errors, we observed that the superior technological abilities shown by the students in Chile also meant more demands towards the system and its proper functioning. When there was a problem (involuntary disconnection of one or more mice), the students showed explicit dissatisfaction and their motivation towards the activity decreased. A clear example could be observed during the third session in Chile, where we had a major technical problem, which notably diminished enthusiasm not only during that session but also during the one that followed. In contrast, Indian students showed great tolerance towards software errors that interrupted the normal flow of the activity. In spite of the fact that said tolerance decreased as the sessions went on, enthusiasm towards using the technology was always absolute. In addition to possible cultural differences, we believe that because of greater previous exposure to PC use, the Chilean students were more sophisticated in their expectations and therefore demanded better software; the Indian students were perhaps more forgiving because they had little other experience for comparison.

Satisfaction

We observed that students in India constantly showed great satisfaction in using the technology, with most of them wanting to keep using it past the duration of the session. Teachers had no problem with carrying on with the work, considering the students' enthusiasm. This also happened in Chile, where some students used the free time they had between classes to take advantage of the activity, though that was a small group. We concluded that the technology generated great interest in both countries, both in students and in teachers, because of the opportunity it presented to the students. This was especially so in India. We hypothesize that the novelty of interacting with a computing system explains the different responses. The Chilean students were accustomed to using PCs; the Indian students were enthralled by the interaction. It is not clear that this difference would continue after sustained use.

Achievement and conduct assessment in a second study in Chile

Design of the intervention

As indicated at the end of the section on experimental design, a second version of the software, the one shown in section 'One Mouse per Child for Basic Math', was used to do a qualitative and quantitative assessment of achievement and conduct.

An exploratory study was designed to be carried out in a state-subsidized school located in a low-income neighbourhood of Santiago de Chile. The school was next to a land illegally occupied by families with lightly constructed housing, without adequate living conditions. According to official data, 57.51% to 82.5% of these students are socially vulnerable, which means both their well-being and quality of life is at risk. The children only went to school in the afternoon.

The sample was taken from the third grade (boys and girls ranging between the ages of 8 and 10). The class was made up of 43 students, 40 of which actually participated. The school has a computer lab with 20 computers, which is used regularly by different classes. Because of the characteristics of this intervention, the activity was carried out in two regular, adjoining classrooms, randomly dividing the children into two groups of 20. Each room was equipped with a notebook, a projector, and the number of mice required for the children present. Each room was led by a person from the research team, and the class' teacher alternated between both classrooms.

Seven 30-min sessions were carried out twice a week. The first and last were dedicated to pre- and post-tests to assess abilities in solving basic equations similar to those featured in the studied system. Therefore, the children were exposed to the system five times. The children only worked with addition and subtraction because of their school level. The exercises were automatically generated by the system.

To evaluate the experience, the following aspects were considered:

1 Management of the system by the students and the teacher.
2 Children's explicit conduct (verbal comments), as well as implicit conduct (gestures, body language) towards working with the system.
3 Achievement in solving exercises similar to those included in the system.

Aspects 1 and 2 were observed by applying an open-ended observation checklist designed by the research team. Students were observed during three sessions (sessions 2, 3, and 5). Aspect 3 was evaluated with a written open-answer test, made up of exercises with the same structure as those found in the software. Exercises were chosen from the system, so they would correspond to a third-grade level as far as the numeric aspect, abilities, and difficulty. The test was applied twice: before and after the intervention. Each correct answer was assigned 1 point, while each incorrect answer got 0 point; the entire test had 16 points. The software log was also considered to analyse each student's achieved level and performance. We report only the results for addition exercises as these accounts for 96.3% of the exercises performed.

Qualitative observations

Students had few requests in the technological aspect of the intervention, although they initially had difficulties identifying themselves on the screen and, to a lesser degree, using the mouse.

As far as the pedagogic aspects of the exercise, during the first session with the system, students asked for help on solving equations because many of them had deficiencies in basic addition and subtraction operations. In spite of the fact that these weaknesses were present throughout the remaining classes, the students progressively asked for less help.

Disruptions were observed on the second and fifth session with the system. In general, there were always some students who said they did not want to participate, showing lack of concentration and restlessness. For instance, they asked to go to the bathroom, or got distracted and played with their adjacent peers. This was because of a number of factors, mainly, disruptive conducts present in some students prior to the intervention, difficulty in understanding and carrying out the exercises, frustration, and fatigue. The teacher reported that the children that showed low level of engagement in the activity recurrently showed a lack of motivation in other subjects too. On the third session, system disruptions increased significantly as there were technical problems at the beginning of the session; this caused annoyance among the students and lack of motivation, which resulted in more fatigue conducts being observed in this session.

Both competitive and cooperative behaviours were observed, though competition was slightly greater. We observed that the children that were more engaged with the activity were more interested in reaching a new level than interacting with their peers.

Quantitative analysis

The quantitative design was quasi-experimental, with pre- and post-tests. The obtained data were subjected to frequency analysis, difference of means tests (repeated measures ANOVA) and effect size tests (Cohen's d).

There is a 17.86% of improvement ($P < 0.001$) between the pre- and post-test in the addition exercises, achieving a medium effect size (Cohen's $d = 0.768$). If we analyse the software's log, we discover that the percentage of correct answers obtained by the students when solving exercises with the system between the first and last session increases in 14.75% ($P < 0.001$), with a large effect size (Cohen's $d = 0.855$). This shows us that, though the exercises' difficulty increases, the quality of the work improves.

To analyse the impact of the work according to the children's achievement, the class was split into two groups according to their achievement on the initial test. Achievement was measured by obtaining the maximum level each child reached at the end of the experience and then, in the pre- and post-tests, only considering questions up to that level. The results of both groups on the tests were compared (Table 3), observing greater improvement (25.53%) in the students with the lowest

Table 3. Achievement percentage on the test, separating the class according to their results on the initial evaluation.

Achievement percentage on the test	Initial	Final	Improvement	Significance	Cohen's *d*
Group with the highest results on the initial test	66.52	69.64	4.69%	0.457	0.255
Group with the lowest results on the initial test	39.17	49.17	25.53%	0.008*	0.775

*means statistically significant.

initial results. This progress is statistically significant, with a medium effect size.

When comparing the percentage of correct answers obtained by students when solving exercises with the system, there is also greater improvement (20.96%) for students who had the lowest initial results (Table 4). This progress is statistically significant with a large effect size for both groups.

We can conclude, from the results in Tables 3 and 4, that the software proved most beneficial for the students with the lowest initial results. However, both groups improved their learning level when we consider individual advancement with the software. This happens because the system adapts to the students' needs, reinforcing the content they most need to work on, thus generating a personalized learning process, adapted to the needs of each student. This was also observed with the software's log data. For example, in levels 12 and 13, which are the final levels reached by close to 40% of the class, there are differences of up to 122 exercises between the student who solved the most and the one who solved the least exercises, on a single level (where both students had the same number of sessions with the system). This illustrates the difference in difficulty that a single level can represent for different children.

Conclusions

Our first research question was if interpersonal computers, which are an alternative that maximizes resource utilization in schools, can be used in different cultural classroom settings.

We showed how, with minimal equipment (i.e. a computer, a projector, and one mouse per student), we can allow all students in a class to participate simultaneously at their own pace. If we take into consideration that this equipment is used daily by the students, that up to ten different groups can share it per day and that the equipment has a useful life of at least 2 years, the cost per student – considering a class of 45 – is close to one dollar per student per year (World Bank 2010). This technology relies on just one computer for a whole classroom, which makes it a critical resource in case it fails; although in a similar way, all technical support can focus on just one device. We followed standard design principles for SDG applications including goal-based progression, personal reinforcement and scoring, and colour and shape-coded mouse pointers (Jain *et al.* 2009).

The very different environmental conditions where the activity was carried out in India and Chile (students sitting on the floor or at desks, lighting conditions, and the quality of the technical equipment) showed us that it is possible to implement massive interactive technology in very diverse conditions. We empirically showed that the children in both cultures had no problem in identifying their personal work space on the common display. We also showed that the Indian children, who – in contrast to the Chileans – had no previous computer knowledge, were able to control the mouse much like the Chilean students in just a few sessions. The software was mastered at a similar pace in both countries, even though for the Indian children, this was their first encounter with a computer program. The

Table 4. Achievement percentage in the SW, separating the class according to their results on the initial evaluation.

Achievement percentage in the SW	Initial	Final	Improvement	Significance	Cohen's *d*
Group with the highest results on the initial test	87.23	95.21	9.15%	0.044*	0.960
Group with the lowest results on the initial test	73.25	88.60	20.96%	0.004*	0.940

*means statistically significant.
SW, software.

Indian students showed more interest, which was reflected in the mean number of exercises answered, enormously increasing their rate of correct answers between the four sessions but not reaching the rate attained in Chile.

Teacher enthusiasm in both countries was due to the fact that teachers feel that technology has an important role in the general context and that they see in it an economically viable opportunity to support their students' learning. Additionally, bringing participatory activities into the classroom is seen as an attractive incentive to come to class. Regarding the software itself, teachers valued its ability to effectively develop mental calculations.

Our second research question was if it is possible for all the students in a class to work simultaneously on their individual basic math problems at a shared display on just one computer and still achieve personalized learning with individual feedback.

We have to understand that the benefits of technology can be realized only through an effective learning and teaching strategy; the problem to focus on is not technological but pedagogical. We do not see the OMPC approach as a general tool but a curriculum-oriented one, in the sense that the presented application covers basic math; we are working on a second application on fractions and a third on reading/writing. Our application can be compared to Mischief (Moraveji *et al*. 2009), which is a SDG general tool for up to 30 kids; however, it has a different pedagogical approach, characterized by collective feedback. In our application, feedback is individual as we manage the identity of each child. This allows us to have *N* simultaneous intelligent tutoring systems, where each child advances at his own pace in a lecture and throughout curricular units. While in Mischief, reports are focused on classroom behaviour, our approach is student oriented, providing the teacher with tools to mediate the different kids that need it.

We established statistically relevant results, with medium- and large-effect sizes in the mean individual performance, in learning addition. We also empirically observed that though the exercises' difficulty increased between levels, the quality of the work improved (percentage of correct answers in a level). An especially interesting result is the greater improvement in achievement (pre- and post-test) and quality of the work of students who began the intervention with lower results. The presented system adapts to the needs of the students, reinforcing the contents they most need to work on, thus generating personalized learning.

Future work considers introducing collaboration within an SDG environment. Open questions are the collaborative mechanisms that have to be developed in such environments where students are not necessarily adjacent, and the working models that support it. We are also working on how to introduce ludic language to the OMPC method to improve children's appropriation and involvement. The key research question is how to achieve immersion and challenge in such an environment.

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Appendix: System rules

Appendix A. Pedagogic rules for addition.

Addition		
Level	Description	Examples
1	Additions with 2 addends, without carrying	*3 + 4*
2	Additions with 3 or more addends, without carrying	*2 + 3 + 2*
3	Additions with 2 addends, without carrying, up to the tens	*20 + 7*
4	Additions with 3 or more addends, with tens in each one, without carrying	*30 + 40 + 20*
5	Additions with 2 addends, each one with two digits, without carrying	*25 + 33*
6	Additions with 2 identical addends, one digit each, with or without carrying	*4 + 4, 6 + 6*
7	Additions with 2 addends, without carrying	*3 + 4, 30 + 40, 300 + 400*
8	Additions with 3 addends, without carrying	*200 + 50 + 10*
9	Additions with 2 identical addends, one and two digits, with or without carrying in the ones	*32 + 32*
10	Additions with 3 identical addends, one and two digits, with or without carrying in the ones	*450 + 30, 354 + 231*
11	Additions with 2 addends and carrying in the ones	*14 + 18, 135 + 325*
12	Additions with 2 addends, multiples of 10 and carrying in the tens	*80 + 30, 140 + 270*
13	Additions with 2 addends and carrying in the tens and ones	*38 + 73, 156 + 266*
14	Additions with 2 addends, without carrying	*3.200 + 54, 3.271 + 2716*
15	Additions with 2 addends, carrying only once, in one position (tens or ones)	*28.146 + 37, 26.734 + 139*
16	Additions with 2 addends, carrying only once, in one position, except in the tens of thousands	*28.146 + 1.337, 37.235 + 51.337*
17	Combined addition and subtraction exercises, with parentheses	*(36 + 24) − 15, (364 + 24) − 15*
18	Combined addition and subtraction exercises, without parentheses with numbers	*36 + 24 − 15, 364 + 24 − 15*

Appendix B. Pedagogic rules for subtraction.

Subtraction		
Level	Description	Examples
1	Additions with 2 addends, where an addend is missing, without carrying	*6 +__ = 9, 63 +__ = 96*
2	Simple subtraction, without carrying	*6–3, 60–30*
3	Intermediate subtraction, without carrying	*63–20, 63–23*
4	Successive subtractions with 3 terms, with only one digit	*9–2–1*
5	Advanced subtractions, without carrying	*7–3, 70–30, 700–300*
6	Subtractions with carrying in the units, and one-digit subtrahend	*50–2, 150–2*
7	Subtractions with carrying in the units, and one-digit results	*45–36, 345–338*
8	Subtractions with carrying in the units, and two-digit results	*45–18*
9	Subtractions with carrying in the tens	*451–61, 451–161*
10	Subtractions with carrying in the units and the tens, and one-digit subtrahend	*500–2, 700–9*
11	Open numeric subtraction phrases that involve adding or subtracting, without carrying, to be solved	*__–5 = 43, __–215 = 143*
12	Subtractions with carrying in the units and the tens, and two-digit subtrahend	*451–62, 374–96*
13	Subtractions with carrying in the units in the tens, and three-digit subtrahend	*451–162, 374–196*
14	Subtractions with 5-digit minuend, without carrying	*13.427–426, 13.437–13.426*
15	Subtractions with carrying in only one position	*28.146–147, 24.257–9.023*
16	Subtractions that require carrying twice, in any position	*28.146–17.247, 2.678–1.849*
17	Open numeric subtraction and addition phrases that involve adding or subtracting, to be solved. Operations may or may not require carrying	*__–145 = 1.893, 5.806–__= 522*
18	Combined addition and subtraction exercises, without parentheses with numbers	*(36 + 24) − 15, 364 + 24 − 15*

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