Infrastructures for Low-cost Laptop Use in Mexican Schools

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ABSTRACT

In recent years, a number of low-cost laptops have been created for children's education, most notably the XO, developed by One Laptop per Child to embody principles of constructionist learning, and the ClassmatePC, designed by Intel to fit within and improve traditional education. We report on a series of field studies in Mexican elementary schools that deployed the XO or ClassmatePC. Although both devices are promoted as valuable for improving education in developing countries, our studies suggest that creating the social and technical infrastructures needed to sustain school laptop use is far more complex than what technology designers assume.

Author Keywords

Low-cost laptops, infrastructures, developing countries, OLPC, XO, ClassmatePC, education, Mexico, ICT4D

ACM Classification Keywords

K.3.1. Computer uses in education: collaborative learning, computer-assisted instruction. K.4.2. Computers and society: social issues. H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human factors.

INTRODUCTION

In the last five years, there has been a strong push to create low-cost laptops for children in developing countries. These efforts—from the computer industry, non-governmental organizations, and governments—were triggered by the One Laptop per Child (OLPC) project [15], which sought to create radical educational change by massively distributing its XO laptop to developing countries. Envisioned as a response to the problems of educational systems in the developing world, including shortage of teachers and lack of material resources, the XO laptop purportedly embodied the principles of constructionist pedagogy to empower students to learn on their own, without support from teachers [6,7]. Constructionism [25] departs from traditional education by emphasizing students' construction of their own artifacts and knowledge. The XO's most prominent competitor is the ClassmatePC, created by Intel. Unlike the XO approach, the ClassmatePC was designed to be compatible with and integrated into traditional educational systems [33]. Large sales deals recently secured by Intel in Brazil and Argentina [1] are signaling a growing market preference for the ClassmatePC.

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To further understand the role of laptops in elementary education in developing regions, we conducted case study research on laptop programs in a select group of Mexican schools. From research conducted in developed countries (e.g., [35]), we know that successful school laptop programs need supporting socio-technical infrastructures, such as electricity, networks and tech-support infrastructures, as well as trained teachers, staff, and pedagogical materials. HCI research has started to look at educational ICTs in developing countries (e.g., [16]), but the laptop as an educational tool is yet to be investigated. A body of research is needed to design educational technologies that can be supported in resource-constrained environments.

The objective of our research was to understand which resources constituted the socio-technical infrastructures that supported the use of laptops in elementary education in a developing country, the specific functions of these infrastructures, and how these infrastructures were created in resource-constrained environments. We found an ecology of socio-technical infrastructures supporting the laptop programs in schools. These infrastructures included the laptops; physical infrastructures, such as the electrical system, buildings, and furniture; and social and organizational infrastructures, such as management, technical support, pedagogical support, and parental involvement. The educational impact of laptops did not solely depend on the economic resources of the school or on the type of laptops used. Although the socio-economic status (SES) of the schools affected their ability to build infrastructures, we found that the enthusiasm, commitment, and training of teachers, staff, parents, and students, along with the support of external organizations, helped create support infrastructures for laptops, despite limited resources. We found that what laptops can achieve depends heavily on school context, including factors such as teacher preferences, organizational values, and existing norms.

In this paper, we discuss how school communities achieved, or did not achieve, the support infrastructures for these laptops. Our study explains the mundane tasks by which people created complex socio-technical support infrastructures when resources were constrained. Finally, we articulate some of the opportunities for ICT designers in supporting technology-enabled educational change, such as leveraging the assets of school communities implementing laptop programs, empowering the community to create the support infrastructures for laptop usage, and considering implementation models other than one-to-one computing.

RELATED WORK AND THEORETICAL MOTIVATIONS

Several low-cost computers aimed for the developing world have failed to be adopted, as designers overlooked users' contexts [24]. Analyses of educational ICTs in developing countries have studied the different actors and entities necessary to create support infrastructures [8,24,27,34,35], and how the relationships are negotiated [20]. These analyses are useful for aiding policy-making but lack the detail required for technology design. Recent work in HCI has started to cover this gap; Kumar et al. [16] identified educational opportunities for out-of-school mobile learning in India, concluding that learning will increase according to the availability of appropriate sociotechnical infrastructures.

We need accounts of how laptop infrastructures are constituted in practice to better understand how relationships between material resources and communities create these infrastructures [32]. Infrastructures are broad underlying frameworks encompassing physical, social, and cultural resources that enable groups, organizations, or societies to function in certain ways [19]. Given the centrality of social resources in educational activities, we focus on the role of the social to study laptop infrastructures. The question for us is not only *what* resources make up laptop infrastructures, but also *when* those resources make an infrastructure [32], i.e., what kinds of interactions between things and people help develop an infrastructure. Star and Ruhleder found that infrastructures are built on an installed base of inherited strengths and limitations, reach beyond a single event or site, are embedded into other structures and social arrangements, are learned as part of membership with incoming members having to learn them, are linked with conventions of practice as they shape and are shaped by communities, are transparent until they break down, and take time and negotiation to adjust with other systems with which they are involved [32]. Star and Ruhleder's framework provides us with specific notions to discuss the complexities of creating laptop infrastructures, allowing us to relate our work to the growing body of HCI literature that has looked at the infrastructures sustaining ICTs in different contexts.

Scholars in sociotechnical analysis of computing infrastructures have studied multiple contexts [17,18,14,19,30,32,38], but we are not aware of infrastructure studies of education in the developing world. Social accounts of technological infrastructures used by professionals have documented how the material and social conditions of developing countries constrain interactions [14,38]. Interactions are shaped by a lack of organizational resources [17] and accountabilities across multiple organizational levels [18,30]. We argue that many previously identified constraints are present in laptop infrastructures of resource-constrained schools, such as material infrastructures that are less robust than in high-income countries; concerns of insecurity and theft; underdeveloped staff; and accountabilities at multiple levels including to school boards, districts, and state and federal ministries of education. Our study contributes to the sociotechnical analysis literature by showing how creating support infrastructures is a matter of dealing with multiple socio-technical constraints that interact in complex ways.

ICT4D and HCI4D literature have informed our views of how infrastructures are built in constrained environments. Studies examining large scale ICT projects for school children (e.g., [8,24]) have found them sustainable only if they address local communities' current practices [10] or if they create opportunities for new practices profiting from existing sociotechnical infrastructures [26]. We are informed by studies critiquing the personal-use private-ownership paradigm in developing countries, where, due to sociotechnical constraints, a shared use model is often more appropriate [24,31], including multiple mice per computer [31]. Ames has studied the country-wide XO deployment in Uruguayan elementary schools [6]. Our work differs from Ames' project by comparing deployments of two different technological platforms—Classmate and XO—and by looking at the Mexican educational system, which has many more social and organizational deficiencies than the Uruguayan educational system. Our study contributes to ICT4D and HCI4D by providing designers with a holistic view of the complexities of creating laptop infrastructures for educational change and by showing how communities can leverage the ecology of tools, policies, and programs to create their self-reliant and sustainable infrastructures. We contribute to HCI4D by studying technology use in Mexico, a high mid-income country facing the challenge of unequal distribution of socio-economic and pedagogical resources.

Our understanding of the human infrastructure in educational ICT has been influenced by the education literature, which has established teachers and pedagogical support as crucial resources for educational ICT projects. Mere access to technology does not automatically enable students to use computers to educate themselves, especially in low-SES environments, if students lack social support at home or school [8,12,22,34,35]. Teachers are a fundamental part of the infrastructure to support laptops, providing the instruction, mentoring, and modeling required for learning. Teachers are also users of the technical and pedagogical infrastructures in the classroom. Although ours is not an education-focused paper, the empirical data presented here serve the educational community in research and policy-making to better understand the challenges that teachers, staff and parents face when creating laptop support infrastructures in resource-constrained environments.

BACKGROUND

Mexico is a mid-income country with strong socio-economic disparities. Since many who can afford it seek education in private institutions [11], the majority of public schools serve less advantaged students. Programs to upgrade infrastructure and introduce ICTs in education have sought to overcome disparities with mixed results [21]. Curriculum reform aiming to prepare students for the 21st century has been difficult to implement due to deficiencies in teacher training [28]. The "Mochila Digital" (Digital Backpack), a large-scale project started in 2008 by the private Telmex Foundation, distributed 50,000 XO laptops in about 1,200 Mexican elementary public schools in cooperation with the Ministry of Education [2,3]. Participating schools received 40 XO laptops to be shared among all students. On a smaller scale, Intel's World Ahead program ran a series of pilot projects in Mexican elementary schools beginning in 2007 to test its ClassmatePCs [13], providing both laptops and substantial administrative and training support [33].

STUDY RATIONALE

Our case study was designed to understand the socio-technical infrastructures that support a laptop program. We selected five different schools in two Mexican cities, segmenting them by SES and by type of laptop deployed, namely Classmate and XO. We segmented the schools by SES into two high-SES and three low-SES schools (see Table 1), which allowed us to contrast how people created laptop support infrastructures in resource-constrained environments and in high-resource environments. Segmenting by type of laptop helped us determine if the support infrastructures were different in each case, and if differences in type of laptop brought changes in their educational function. The schools in our sample had different degrees of internal organizational maturity and of support from parents and external organizations. Contrasting these differences allowed us to understand how organization and support enable, or not, the creation of socio-technical infrastructures. Another dimension against which we compared how infrastructures were formed was the age of the laptop program at each school, varying from a few months to two school years. The final criterion for the design of our study was the use model of the laptop followed at each school. The largest XO implementation in the world, Plan Ceibal in Uruguay [4] follows a one-to-one use model. However the largest XO implementation in Mexico, Mochila Digital, and other smaller implementations, follow a shared use model. Peru's nationwide implementation [36], and a smaller program in Haiti [23], also have moved towards a shared use model. Given the prevalence of the shared use model in Mexico, we selected a majority of sites that followed this practice.

METHODS

We conducted 128 hours of observations (see Table 1) to examine the role of laptops in teaching and learning activities, the resources needed to conduct these activities, and how teachers and staff prepared for these activities. We documented our observations with extensive field notes, photographs of in-class interactions of teachers and students, and collection of samples of work of students and pedagogical materials. We observed classroom activities that did and did not involve laptops, teacher meetings, school assemblies, parent meetings, and social gatherings of teachers and staff. We also observed laptop support activities, such as how laptops were charged, stored, and transported to the classroom.

We conducted 41 semi-structured interviews of 20 to 60 minutes with staff, teachers, parents, and students. In these interviews we asked teachers, staff and parents about their perception of the laptop project, the history and development of the programs, and the process to implement the program, and the social, organizational, pedagogical and technical resources necessary for the program. We asked students, teachers, and staff about the educational uses and practices that involved laptops, and compared their responses against our observations, to be able to understand to what degree the perceived uses corresponded to observed use. We digitally recorded, coded, and transcribed all

	Conocerte	**Del Valle**	**Miguel Hidalgo**	**Independencia**	**Octavio Paz**
Location	Guadalajara	Guadalajara	Puebla	Guadalajara	Guadalajara
SES	High – Private	High – Private	Low – Public	Low – Public	Low – Public
Laptop Type	ClassmatePC-1	ClassmatePC-1	ClassmatePC-1	XO-1	XO-1
Program	Independent	Intel supported pilot	Intel/State govt. pilot	Mochila Digital	Mochila Digital
Active period	2007-2009	2007- date	2007- date	2009-date	2009-date
Laptop ratio	1-to-1	1st yr., 1-to-1. Then shared.	Shared	Shared	Shared
No. laptops	60	40	50	40	40
Observations	N/A.	Nov/09: 10 days. ~40hrs.	Dec/09: 10 days. ~40hrs.	Dec/09-Mar/10: 6 days. ~24hrs.	Dec/09-Mar/10: 6 days. ~24hrs.
Interviews	1 staff member, 2 teachers	7 students, 1 teacher, 2 staff, 2 parents.	8 students, 3 teachers, 1 staff, 4 parents.	5 teachers, 1 staff.	3 teachers, Principal.

Table 1: Characteristics of the observed urban elementary schools in Mexico.

interviews, and coded the field notes and pictures. Our coding was bottom-up, and the themes reported in our findings emerged from the data. The field researcher is Mexican and was educated there; all fieldwork was conducted in Spanish. Translations from Spanish are ours. Pseudonyms are used for schools and people.

THE SITES

Low-SES schools

We had three public, low-SES schools in our sample. The Miguel Hidalgo School ClassmatePC program was sponsored by Intel and the Puebla State Ministry of Education. Independencia and Octavio Paz schools were part of the Mochila Digital program and used XO laptops.

The Miguel Hidalgo School, a public elementary school in the city of Puebla, started its ClassmatePC program with 50 laptops in October 2007 [13]. The school had ample prior experience using ICTs. It has had a computer room since 1998. The principal was supportive of technology projects, and the school's technology coordinator was trained in both technology and ICT pedagogy. Both sponsors gave ample technical and pedagogical support to the school, and their pedagogical support personnel frequently visited the school.

The XO schools, Independencia and Octavio Paz, were located in low-SES neighborhoods of Guadalajara. Independencia was a stable older school with veteran teachers. Parents had a seemingly good relationship with the school authorities. Octavio Paz School was relatively new and growing fast. Lower grade classes had close to 50 students each, and classroom space was running out. School administrators indicated that parental participation was low, which they attributed to long working hours of low-income parents. The XO laptops were delivered to Independencia and Octavio Paz in spring 2009. Technical training was provided only to two staff or teachers per school, and not until October of that year. Those trained were expected to replicate the training to their peers. The XO schools faced numerous technical problems, as discussed below.

High-SES schools

The two high-SES schools were located in wealthy neighborhoods of Guadalajara. Both were running ClassmatePC laptop programs. These private schools had well-trained teachers and a good relationship with parents. Both schools have had well-equipped computer rooms for at least 10 years. Most classrooms in these schools had LCD projectors and a computer for the teacher. The Del Valle school program was also initiated as an Intel sponsored pilot project in 2007. During the first year, the school's 40 ClassmatePCs were allocated on a one laptop per student basis to all sixth grade students. After the first year, laptops were used on a shared basis among grade four-to-six students. The other private school, Conocerte, independently acquired ClassmatePCs in 2007, to implement a one-to-one laptop program in grades 5 and 6. The program lasted until spring 2009 (see discussion below). Students' parents covered the cost of purchase of laptops, and laptops were managed by the school's technology coordinator. After several months, students were allowed to take the laptops home. As Conocerte had the longest running one-to-one laptop program in Mexico that we were aware of, we decided to include the school in our sample, even though the program was no longer active at the time of our visit. We interviewed extensively the two teachers who had used the laptops with their classes and a technical support staff member.

FINDINGS

More than the laptop, it was the support infrastructures that made an educational difference. In low-SES schools, both using XOs and ClassmatePCs, much effort was expended to build infrastructures to enable students to access learning environments that they had no access to otherwise. Schools that solved the access issue—all high-SES schools and one low-SES—built infrastructures to capitalize on students' enthusiasm for technology to motivate them to be more independent learners. Schools changed their teaching and learning practices, only after their infrastructure was solid, and teachers had enough technical and pedagogical support to change their practices. How laptops were used to transform educational practices was determined by the skills and interests of the teachers, the motivation of students, and the values of the schools, rather than the affordances of the laptops alone.

Learning environments are laptops plus teachers

Most of the low-SES students' previous experience with technology was restricted by either limited physical access or limited social support. According to teachers, between a half and one-third of students in the observed schools had computers and Internet access at home. Though cybercafés were ubiquitous, few low-SES parents felt comfortable letting their elementary school children attend them or could afford the costs. Low-SES students who did find outside access to computers often lacked mentors. Only some students had parents, older siblings, or other relatives with extensive computer experience. Many had to learn computer skills on their own.

Laptop programs provided the opportunity to access educational resources because students could use laptops with the guidance of a teacher or technology coordinator in an environment conducive for learning. The use of XOs by two 3rd grade groups at Independencia illustrates how laptops plus teachers made the difference to create a productive learning environment. In "3-A", students used the XO without teacher supervision, as their teacher was not trained to use the XO. When the teacher handed out the laptops, she told students that they could "chat." Some students started communicating using the Chat program, but others were not able to figure it out, leaving them frustrated. Students of "3-B" conducted an educational activity which consisted of playing the popular song "Brother John" using TamTam, an XO music creation program. Their teacher printed the activity handout from the Mochila Digital's support site. Using the handout and their teacher's assistance, students could play the song on their own. The activity of 3-A had little educational value, as many students had chatted before at cybercafés and those who were not able to chat did not receive guidance to use the program. In contrast, the activity of 3-B allowed many students to create music on the computer for their first time.

It is pretty but not practical

Making the laptops "practical" to use, and easy to integrate into teaching and learning practices, was a function of the organizational capacity of the school, and not necessarily linked to its SES. Miguel Hidalgo had a solid internal organization, support from parents, and good relations with the Ministry of Education. With the advice of the Ministry of Education, the school built a "charging center" to charge and store all laptops. Its cost of nearly $700 US was paid for by parents. In contrast, the electrical infrastructure at Octavio Paz was unreliable. The principal bought some power-strips to charge the laptops at the single electrical outlet of each classroom, making laptop charging labor-intensive. This inconvenience made Octavio Paz's teachers characterize the XO laptops as "pretty" but not "practical". The lack of engagement between Octavio Paz staff and the parents made it impossible to raise funds for a reliable electrical infrastructure.

In high-SES schools, where providing laptops and physical infrastructures was not a problem, social organization was still crucial for using laptops reliably. When the technology coordinator at Conocerte, a high-SES school, resigned, the laptop program was officially ended. Still, many parents continued to buy netbooks for their children, and these students regularly brought their netbooks to school. However, teachers had reservations about using the netbooks in class, as some students had "inappropriate" material on their netbooks, such as violent videos, and teachers were also worried about computer viruses. Conocerte teachers told us they had felt much more confident in the laptops when the technology coordinator used to manage the program and help ensure that the machines were used for educational purposes.

Elsewhere, lack of local knowledge of its SugarOS made the XO difficult to maintain. Between a half and a third of XO machines of the Mochila Digital schools were received with a software-lock, as the security layer of SugarOS, called "BitFrost," had no activation key. Loading the keys on the computers was relatively complex for a non-technical user. Also, the laptops were not configured to access the Internet. Technical support was provided mainly over the phone, with no in-person support. Technical support of Mochila Digital was slow to respond, and schools could not use local technical expertise since SugarOS was virtually unknown.

Insecurity and robbery are a reality in Mexico, and it was a concern in all schools, directly impacting access to computing. At the high-SES Del Valle School, all of the laptops were stolen from a locked room a few weeks before our arrival. To carry on with their activities, and also to allow us to perform the study, the school borrowed laptops used at a sister campus for a few weeks. Staff explained to us that it would take months to replace the stolen laptops. The robbery made evident the vulnerability of computing infrastructures to the larger social context of a country where even low-cost laptops are valuable items.

One-to-one is aspired to, but sharing is more practical

One-to-one laptop programs were practically achievable in only one school. Even if a one-to-one laptop program was an aspiration for most teachers and staff, the laptops' cost and lack of requisite socio-technical support made this goal infeasible. Only Conocerte, the most privileged school, was able to sustain a one-to-one program for a prolonged period. For the technology coordinator of Del Valle, a high-SES school, a sustainable one-to-one program was achievable in two years, after lobbying with school authorities, building a school network, and working out financing with parents.

Low-SES schools shared laptops, given the lower capacity of their social and physical infrastructures, and the perceived benefit of giving access to all schools students as opposed to a single class with a one-to-one program. At the Miguel Hidalgo School, the principal chose to share their 50 ClassmatesPCs laptops among the twelve groups of the school, over having a single group in a one-to-one program. The principal considered that sharing was better, as all students would have a "chance to open [their] minds" to new ways of learning using the laptops under the guidance of their teachers. The value of using laptops was in increasing the access to technology for all students, beyond making teaching and learning more efficient.

Sharing laptops entailed practical problems, as neither laptop was designed for multiple users. First, transporting laptops between classrooms was an issue. Schools established weekly schedules to allocate a couple of hours per group. And moving laptops from classroom to classroom required coordination and time. For instance, at the Miguel Hidalgo school, each group picked up the laptops from the media room and took them to their classroom (see figure 1). This routine was time-consuming; it would have been more efficient to set up the laptops permanently at the media room. But taking "the technology inside the classroom", the technology coordinator explained, was something that students "liked and were excited about" as it made students feel closer to technology, especially to those with no computer at home. The second

Figure 1: Students transporting the laptops to their classroom.

issue was storing students' work. Miguel Hidalgo's laptops were labeled so each student would work on the same machine every time, storing their work in a folder with their name. In schools using XOs, students were not able to save their work on the laptop, as it had limited memory and the OS had no folders. At the Independencia School, some teachers asked students to buy USB flash drives, but only one third of parents were able to buy them. Students shared their drives with others who did not have one, but the practice was ineffective and many times the work was lost.

Improving the low-SES schools' infrastructures for implementing schoolwide one-to-one laptop programs requires a holistic approach. Nation-state support is required as few parents can pay for laptops or requisite infrastructure upgrades. Electrical installations for most classrooms were inferior. Storage arrangements would have to be made in many overpopulated classrooms, and schoolwide wireless networks would need to be established. Outside of a few schools, more attention to building the social infrastructure in support of laptop use is required. However, the technology coordinator of Miguel Hidalgo felt that at well-organized low-SES schools such as hers, with "good teachers and staff," a one-to-one laptop program would be implemented with positive educational results.

Building the community that builds the infrastructure

For low-SES schools, creating organizations that build reliable infrastructures in a context prone to breakdowns was crucial, and required great effort. Some community-building practices were mediated by the use of the laptops themselves. To increase the involvement of parents at Miguel Hidalgo school, they would be regularly invited to educational events to use the laptops with their children. We observed an event where parents worked with their children creating a Word document about the most important values of their family. These kinds of events allowed parents—with little experience with computers—to experience first-hand the power of laptops at school.

Involving and supporting teachers was fundamental for the continuity and success of the program. Technology coordinators and support staff were key to supporting teachers' involvement. Ms. Alejandra, a teacher at Miguel Hidalgo School explained that "the teacher" was the most important resource for a laptop program. Ms. Marian, the technology coordinator at Miguel Hidalgo, explained that her responsibility was "to guide the teacher so he or she can effectively see the laptop as something positive". For this, Marian had the support of personnel from Intel and the Ministry of Education. Marian invited teachers with poor computer literacy skills to follow the computer literacy lessons imparted to students. Sometimes students would help teachers in their learning process (see figure 2). This strategy helped to train teachers and integrate them to the laptop program by making teachers feel comfortable as technology learners, without losing face with their students. This way, Marian was able to "change the culture of the teachers," to become lifelong learners of technology.

Building a social network of teachers beyond the school was viewed as important. At Independencia, the laptop program coordinator explained that one of the challenges for program continuity was sustaining teacher motivation. She believed that enabling teachers to acquire continuous ICT training would be the key. As part of the solution, she pictured a network of teachers who could share their uses of technology in the classroom, creating a sense of belonging and support. But this network was difficult to bring about, as the Mochila Digital schools were spread out around the city. Online networks could be a solution, but those take time to build well and had not been developed.

Motivating students with their laptop enthusiasm

Schools with more stable laptop infrastructures, namely Del Valle, Conocerte, and Miguel Hidalgo, were able to use students' enthusiasm for laptops to motivate them to work independently. Teachers could capitalize on students' enthusiasm by continuously creating activities in which students experienced a new way of learning that was more enjoyable, more dynamic, and closer to their interests. Laptops became an auxiliary tool to capture students' attention, create supporting material for difficult subjects, and help students produce higher quality work.

Developing students' motivation was a blend of laptop affordances and social practices. Students enjoyed using laptops as they were perceived as aesthetically pleasing. Students of lower grades (1^{st} through 4^{th}) liked the small size of the laptops and keyboard, though the keyboard size started to bother some 5^{th} and 6^{th} graders. Beyond the affordances of laptops, their major value was in the social practices they allowed. Teachers were able to include multimedia resources that captured students' attention and supported their understanding of complicated material. Using laptops created opportunities to include students' technology interests, such as computer gaming, or using social networking sites. For instance, an English teacher encouraged students to use the Facebook game "Pet Society" to increase their vocabulary. Furthermore, teachers perceived that any activity done at the computer more easily caught students' attention. A Del Valle teacher suggested that students felt more compelled to work when using laptops, as technology was "part of them [...] they were born with it".

Since few schools had laptops, owning these devices became an occasion to interact with outsiders interested in

Figure 2: Student teaching her teacher how to use the laptop.

the programs. These interactions furthered the sense of teachers and students participating in something special. Miguel Hidalgo, for example, was featured in the local media, closely observed by another research team besides ours, presented in state government meetings as a model for ICT integration, and participated in contests and special activities. The laptop program there allowed some students to gain recognition, such as two 2nd grade students who received a public award in an inter-school writing contest for student using ClassmatePCs. Their laptop program also gave students the opportunity to interact with people from outside of the country; one project coordinated by Intel pedagogical support staff brought selected students into online discussion with students in Germany to discuss girls' rights in their respective countries.

At Independencia, and Octavio Paz, unstable infrastructures made it difficult to use laptops as a motivational device. At Octavio Paz, with little pedagogical support and difficulties in setting up the laptops, a teacher tried using the XOs as a recompense for her students' discipline, exchanging students' attention during class for letting them play with the XOs using any games such as Mazes for a few hours a week. The strategy only worked a few times, given the difficulties to charge the XOs and the lack students' interest to play with the machines without an objective.

The use of laptops depends on the infrastructure

The two high-SES schools were able to consistently integrate the laptops into their teaching and learning practices. How laptops were used was greatly influenced by teachers' preferences and skills. Both teachers who had used the laptops at Conocerte were highly competent and ready for change, but with different preferences. Adolfo, passionate about electronic music composition, implemented many multimedia production activities. Students in his class made electronic music to represent aspects of the city's geography. To help them, he learned how to use free sound editing software, installed it on each of the machines, and taught students how to use it. Alicia, who was more inclined towards mathematical and analytical aspects, took advantage of Excel and PowerPoint to teach students to create conceptual maps to visualize different perspectives on complex issues.

The school's values were another subtle but powerful influence on how laptop affordances transformed teaching and learning, as seen in differences between the two high-SES schools deploying ClassmatePCs. Conocerte School focused on cultivating students' creativity and autonomy through project work; this was reflected in how laptops were used as described above. Del Valle, which took a more traditional approach to academic achievement, emphasized more structured learning activities under careful teacher supervision. The efficiency of laptops helped students at Del Valle worry less about their work presentation and focus more on the quality of their answers, yet students adhered closely to teacher instructions per the overall values of the school.

We observed that the capacity to change teaching and learning practices increased when certain preconditions were met, including consistent access to technology, a prepared and committed teaching staff, and support from external organizations, district authorities, and parents. Creating the infrastructures for transformative uses was not only dependent on economic resources. While higher economic resources at high-SES schools helped to create physical infrastructures, a strong social organization was most important. At the wealthiest school in our study, Conocerte, the laptop program was completely halted once the technology coordinator resigned. And the low-SES Miguel Hidalgo school successfully leveraged its strong organizational capacity and external support to transform educational practices. Constant dialogue between teachers and technology coordinators at the school greatly facilitated educational change there. Concrete methods for using laptops were worked out during the teachers' weekly lesson planning time, as the technology coordinator worked together with the teachers to plan their their classroom activities. The dialogue also gave the technology coordinator an appropriate perspective of the laptops, as "one more tool", albeit a powerful one, for education.

DISCUSSION

In each of the five schools, socio-technical infrastructures shaped the use and educational value of laptops. These findings are in line with other reports [12,20,22,34,36,37] on how the "social envelope" surrounding ICTs influences the educational benefits of these technologies. To develop support infrastructures, the entire school community had to work in concert, making use of local and global resources. We can summarize several features related to infrastructures for learning with laptops, as follows.

Achieving educational change was not a product of the principles embodied by the laptops. OLPC believed that as the XO embodied the principles of constructionism it would function as a "Trojan Horse…a backdoor into overhauling the entire education system" of countries [9,6], making education more creative and student centered. In contrast, Intel described the ClassmatePC as a tool more centered in teachers and traditional learning, which could "easily integrate into their curriculum," that could be "locally appropriated, easily deployed" [5]. But, in spite of different intentions of the two laptops designs, in this small sample, the Classmate was being used for constructivist purposes more than the XO, showing that the way a device is used depends greatly on its adoption by a community in local context, according to its sociotechnical infrastructure, rather than just the intent of the designers.

Developing a strong human infrastructure allowed schools to use laptops to deliver educational value. Even with its material constraints, the low-SES Miguel Hidalgo school was able to use laptops to educate and motivate its students as it had well-trained staff and teachers. As ICTs only become useful when meaningful social practices are created around using these technologies [34], strong community support becomes crucial for effective use of laptops. Practices are learned from peers, parents, teachers and other role models. In low-SES schools, children often lack home access to knowledgeable computer users. But the organization and community support at Miguel Hidalgo allowed creating these social practices. The training and technical support programs were key for the success of the Intel sponsored pilots of our sample, showing the importance to develop social infrastructures. But the results of these ClassmatePC pilots, especially of the observed low-SES school cannot be immediately replicated. Miguel Hidalgo was a school out of the norm when compared with the other low-SES schools of our sample, as it had strong internal organization and efficient support from Intel and the government. The Mochila Digital schools we visited needed time and support to develop their social infrastructures: much stronger technical support, teacher training, and community support was need at these schools to get educational value out of the laptops. Scaling up programs to support the development of schools' social infrastructures remains a challenge. Comparing to another development effort, even India's Hole in the Wall project, which began by giving children unfettered access to kiosk computers without mediation by adults or organizations, has evolved to focus more on building ties with schools, teachers, and local communities as mediators of learning [8]. Walter Bender, former OLPC president of software and content, recently suggested that OLPC should also strive for building sociotechnical support infrastructures [34].

Building strong infrastructures supporting the laptops was dependent on the social conditions of each school. Creating an appropriate physical infrastructure was, especially in low-SES schools, dependent on the ability of the school to organize the community. Miguel Hidalgo, which had an efficient organization, was able to create a charging center, whereas the Octavio Paz School, which had problems with its parents' association, was not. Also, the ability to develop the human infrastructure through teacher training was affected by the wage structure. Many teachers had no free time to attend training sessions as they held multiple jobs to supplement their income. These dependencies between infrastructures ran across multiple organizational and social levels, further increasing their complexity. To take full advantage of the capabilities of the laptop infrastructure, educational plans and standardized tests created at federal and state levels have to be updated. Servicing laptops, in response for example to the Bitfrost locking of the XOs, depended both on the Mochila Digital tech support team and the school's technology coordinator.

Working out how laptops could fit into existing practices of school communities was fundamental to adoption. Miguel Hidalgo's teachers and technology coordinator could visualize new uses of laptops only when working together in the teachers' weekly planning sessions, an existing practice. When infrastructures have matured, they are learned as part of the membership of a community of practice. But the teachers' community had no precedent for how to use the laptop infrastructures. So the technology coordinator and teachers had to work out new uses of the laptop infrastructures. Technology coordinators were central in integrating laptop infrastructures into daily practices, and thus assumed the role of what Nardi and O'Day termed a "keystone species" [22].

But achieving the adoption of laptops needs dialogue at multiple levels, from curriculum reform at a national level, to the practicalities of each teacher's weekly lesson planning. Schools running laptop programs for a longer time had developed more stable infrastructures, as they had had greater opportunity to negotiate appropriate changes. The Miguel Hidalgo School had experience in both building relationships with its local community and in developing training and curriculum reforms with Intel pedagogical support staff and Puebla state Ministry of Education officials. This gave Miguel Hidalgo much more stable laptop infrastructures than those of the newly implemented Mochila Digital's schools, in which these dialogues and processes had not occurred.

Laptops had to be shared to work within the schools' existing infrastructural capacity. The initial designs of the XO (explicitly) and ClassmatePC (implicitly) assuming a one-to-one model of student use were out of synch with the infrastructures of the resource-constrained schools in our study. None of the laptop implementations at low-SES schools had a one-to-one program. Only Conocerte, the wealthiest school in our sample, was able to sustain a one-to-one laptop program for a prolonged period, and that later collapsed as well. The inability to move to a one-to-one program was not only due to the cost of laptops, but also due to the insufficient physical and social infrastructure to maintain, deploy, and effectively use a large number of laptops. In contrast, a shared use model at low-SES schools allowed all students a chance to meaningfully use computers, while not straining infrastructures. This observation is consistent with the case of the large XO implementation in Peru, first launched as a one-to-one program but then expanded as a shared use program to better match the country's infrastructural capacity [36].

Most of those we interviewed understood that schools had to upgrade their physical and organizational infrastructures before venturing into one-to-one programs. This belief was against OLPC's "saturation" principle of immediate one-to-one implementation. This principle downplays the need for a physical and social infrastructure to sustain a large-scale laptop deployment, whether to charge, maintain, and repair laptops or to ensure that they are used effectively. This downplaying of the critical role of community support—from technology coordinators, teachers, parents and others—has had negative consequences in OLPC deployments around the world [36]. For example in Uruguay, more than a quarter of the country's 400,000 XOs are non-functioning due to hardware of software problems [29]. In Alabama, after the Mayor and City Council launched a program despite opposition from teachers and the school district, laptops were seldom used in schools, large numbers become unusable due to hardware or software problems, and funding for the program was eventually discontinued [36].

Technology designers should understand that the nature and development of infrastructures depends on context. What was taken for granted in high-SES schools, such as adequate electrical systems or physical space, became a major obstacle for some low-SES schools. Simple schemes for distributing technology do not work if a suitable sociotechnical infrastructure is lacking. We saw how the laptop program in the highest SES school collapsed when the technology coordinator resigned, even as parents continued buying laptops for their children. Furthermore, the opportunities to change educational practices depended on the context: the skills and preferences of teachers and students, the values of the school, and the values of the larger educational systems in Mexico all determine what is practical to change. In the cases of the Del Valle and Conocerte schools, similar laptop affordances were used very differently, suggesting that laptop infrastructures are shaped by school values. It is not possible to introduce new educational models, as OLPC sought to do with constructionism, without a comprehensive approach to change the culture and practices of schools and teachers. The only way to transform education is to engage the whole community in a dialogue for creating change, as was being done at Miguel Hidalgo. The involvement of teachers is vital, as it is their role to facilitate learning practices in classroom. As teaching and learning practices with laptops were new in these schools, it was necessary to create an environment where teachers could be seen as learners of technology and experiment with new ways of working.

OPPORTUNITIES FOR LAPTOPS IN EDUCATION

We face the challenge of creating sociotechnical infrastructures that support large-scale educational change. The design of XO and Classmate assume a one-to-one use model. However, this model for personal use and private ownership makes assumptions based on the conditions of developed countries [31]. In most of our cases, laptops had to be shared to increase reach, lower costs, and be sustained within limited physical and social infrastructures. "One laptop per child" obscures the complexity of supporting laptop usage. The whole school community contributes to laptop infrastructures and use.

An ecology of technologies, community programs, and policies is needed to make effective use of laptops in education. Support technologies include hardware and software to share, maintain, and secure laptops, and to facilitate interactions among teachers, students, and parents. Programs to build technical and pedagogical capacities, motivate, and engage the school community can help ensure the sustainability the laptop infrastructures. To take advantage of laptops, educational systems in developing countries have to engage in comprehensive reforms to update their curricula, transform student testing, and promote the professional development of teachers. These ecologies must operate within educational systems with chronic organizational deficiencies and within the socio-economic problems of developing nations. Actors from all levels (policy makers, technology developers, educational authorities, school staff, teachers, and parents) have to participate in these ecologies. Monolithic approaches for change through injection of a new device will not work. Schools need building blocks that can be shaped according to their particular context, to cultivate the conditions in which educational change can emerge.

The designers of these ecologies can take advantage of a number of assets school communities have to create laptop infrastructures. Enthusiasm for technology can be capitalized on to build the motivation of both students and adults, as laptop activities with parents and pupils at Miguel Hidalgo School showed. A motivated community will have the creativity and perseverance needed to build a laptop infrastructure. Changing certain community rules can positively impact individuals' abilities to contribute towards the laptop infrastructures. For example, providing norms and structures for teachers to be learners of technology in their own groups can encourage teachers to update their skills and practices and strengthen the human component of infrastructures for laptop use. Dialogue is central to expand the construction and use of laptop infrastructures. Spaces for dialogue have to be created within existing practices. We saw how, if members of the community are questioned at the right moment, new uses for the infrastructures become clear, as shown when the technology coordinator talked to teachers during their weekly planning.

Each school should cultivate the "keystone species" [22] of teachers and technology coordinators. Mentor teachers will require support in the educational system, for example, through extra paid professional development time. While paid technology coordinators require extra resources, they can have an enormous impact on helping teachers integrate laptops with school practices. Socio-technical infrastructures supporting laptops cannot be immediately implemented, as communities take time to mature.

We agree with Pal et al. [24] on the appropriateness of the shared laptop use model for most of the schools in the developing world. In low-income countries, sharing a limited number of laptops puts much less stress on fragile school infrastructures, both physical and social, than providing one laptop to every child. In mid- and high-income countries, it is possible to transition to a one-to-one model, as the infrastructures of the whole educational system and each school strengthen, as demonstrated by the evolution of many laptop programs in US schools [35]. Software for laptop infrastructures should be suitable for a shared use model. Rollout strategies for large laptop programs should follow a staged implementation in certain grade levels or subject areas first, so that requisite physical and social infrastructures can be developed over time.

CONCLUSION

In the near future we will likely see more governments and institutions investing in laptops for basic education. The emphasis of these projects should be on building the basic sociotechnical infrastructures that will enable students to engage in meaningful learning with laptops. Given the complex environment of schools in developing countries, introducing new technologies is not easy. Support infrastructures for laptops are dependent on the context of each community, and it is only with full community participation that laptop infrastructures can be developed. As designers of technology, we should understand that laptops for education are not devices for individuals, but rather are part of a large sociotechnical infrastructure created by the whole school community. Designs should take a holistic approach, thinking about the ecology of tools, policies, and programs that each community will mix and match to create their own laptop infrastructure. Low-cost laptops can be used to promote educational change in developing countries, if the enthusiasm that these devices evoke is leveraged to promote the growth of organizational capacities, upgrade teachers' skills, and create a better overall educational environment for students.

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REFERENCES

1. Brazilian Ministry of Education plan large deployment with Mandriva Linux on Intel-powered classmate PCs. http://www2.mandriva.com/en/news/?p=145&s=0.
2. Mochila Digital. www.mochiladigitaltelmex.com.mx/.
3. OLPC Mexico. wiki.laptop.org/go/OLPC_Mexico.
4. Plan Ceibal. www.ceibal.edu.uy/.
5. Intel's Vision for Low Cost Netbook Laptops for Children and Schools Worldwide. www.classmatepc.com/vision/.
6. Ames, M. Hacker Learning? The Social Meanings of One Laptop Per Child. 2008.
7. Ananny, M. and Winters, N. Designing for Development: Understanding One Laptop Per Child in its Historical Context. *ICTD* (2007).
8. Arora, P. Hope-in-the-Wall? A digital promise for free learning. *British Journal of Educ. Technology 41*, 5 (2010).
9. Bender, W. Radio Open Source interview. 2007. olpctalks. com/walter_bender/bender_radio_open_source.html.
10. Best, M.L. and Kumar, R. Sustainability failures of rural telecenters: Challenges from the sustainable access in rural india (sari) project. *ITID 4*, 4 (2008).
11. Bracho, T. Desigualdad educativa. Un tema recurrente. *Revista Mexicana de investigación educativa 7*, (2002).
12. Giacquinta, J.B., Bauer, J.A., and Levin, J.E. *Beyond technology's promise: an examination of children's educational computing at home*. Cambridge Univ. Press, 1993.
13. Heredia Escorza, Y. and Lozano Rodríguez, A. El uso de computadoras ClassmatePC en una escuela primaria del estado de Puebla: un estudio descriptivo. 2008.
14. Irani, L., Dourish, P., and Mazmanian, M. Shopping for sharpies in Seattle: mundane infrastructures of transnational design. *ICIC* (2010).
15. Kraemer, K., Dedrick, J., and Sharma, P. One laptop per child: vision vs. reality. *Commun. ACM 52*, (2009).
16. Kumar, A., Tewari, A., Shroff, G., Chittamuru, D., Kam, M., and Canny, J. An exploratory study of unsupervised mobile learning in rural India. *CHI* (2010).
17. LeDantec, C. and Edwards, K. The view from the trenches: organization, power, and technology at two nonprofit homeless outreach centers. *CSCW* (2008).
18. LeDantec, C. and Edwards, K. Across boundaries of influence and accountability: the multiple scales of public sector information systems. *CHI* (2010).
19. Lee, C.P., Dourish, P., and Mark, G. The human infrastructure of cyberinfrastructure. *CSCW* (2006).
20. Luyt, B. The One Laptop Per Child Project and the negotiation of technological meaning. *First Monday 13*, (2008).
21. Muñoz-Izquierdo, C. and Magaña Rodriguez, R. Un acercamiento a la eficacia de los Programas del gobierno federal orientados a mejorar la calidad de la educación básica. *Revista Mexicana de Investigación Educativa 13*, (2008).
22. Nardi, B. and O'Day, V. *Information Ecologies: Using Technology with Heart*. MIT Press, 2000.
23. Näslund-Hadley, E., Kipp, S., Cruz, J., Ibarrarán, P., and Steiner-Khamsi, G. *OLPC Pre-Pilot Evaluation Report (Haiti)*. Inter-American Bank Education Division.
24. Pal, J., Patra, R., Nedevschi, S., Plauche, M., and Pawar, U.S. The Case of the Occasionally Cheap Computer. *ITID 5*, (2009).
25. Papert, S. *Mindstorms: Children, computers, and powerful ideas*. Basic Books, 1993.
26. Patel, N., Chittamuru, D., Jain, A., Dave, P., and Parikh, T.S. Avaaj Otalo: a field study of an interactive voice forum for small farmers in rural India. *CHI*, (2010).
27. Peña-Lopez, I. From Laptops to Competences: Bridging the Digital Divide in Education. *Revista de Universidad y Sociedad del Conocimiento 7*, (2010).
28. Pineda Pineda, I. Compentencias para el desarrollo del trabajo docente en la escuela primaria. *Congreso Nacional de Investigación Educativa*, (2010).
29. Plan Ceibal. Síntesis del informe de monitoreo del estado del parque de XO a abril de 2010. http://www.ceibal.org.uy/.
30. Ribes, D. and Finholt, T. Tensions across the scales: planning infrastructure for the long-term. *GROUP*, (2007).
31. Sambasivan, N., Cutrell, E., Toyama, K., and Nardi, B. Intermediated technology use in developing communities. *CHI* (2010), 2583-2592.
32. Star, S.L. and Ruhleder, K. Steps toward an ecology of infrastructure: Design and access for large information spaces. In J. Yates and J. Van Maanen, eds., *Information technology and organizational transformation: history, rhetoric, and practice*. SAGE, 2001.
33. Vota, W., Derndorfer, C., and Berry, B. One laptop per child overview. 2009. www.olpcnews.com/files/ One_Laptop_Per_Child_Overview_2009.pdf.
34. Warschauer, M. *Technology and social inclusion: rethinking the digital divide*. MIT Press, 2004.
35. Warschauer, M. *Laptops And Literacy: Learning in the Wireless Classroom*. Teachers College Press, 2006.
36. Warschauer, M. and Ames, M. Can One Laptop per Child Save the World's Poor? *Journal of Intl. Affairs*, (2010).
37. Warschauer, M., Cotten, S., and Morgan, A. One Laptop Per Child Birmingham: Case Study of a Radical Experiment. manuscript submitted for publication.
38. Wyche, S.P., Smyth, T.N., Chetty, M., Aoki, P.M., and Grinter, R.E. Deliberate interactions: characterizing technology use in Nairobi, Kenya. *CHI*, ACM (2010)