# Education Technology for the Developing World

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**Abstract— This paper identifies constraints that shape the use of learning technologies in the developing world. It provides examples of existing hardware and software teaching environments, including some that personalize teaching material based on inferences about students' knowledge, wearable learning materials that teach within more informal environments and systems that support student collaboration. The paper explores both potential rewards and obvious limitations of each education technology and identifies possible ways to move forward in light of these constraints.**

***Keywords: education; technology; personalization, collaboration, wearable learning.***

## I. Issues and Constraints

Information and communication technologies that are effective for teaching students in the *developed* world will not necessarily work with students in *developing* countries [1]. For example, anecdotal evidence shows that well-intentioned learning technologies in developing countries fail for simple reasons like teachers are not willing to use the technology for fear that they may "break something"[1]. Such constraints cannot be ignored. Rather than blindly importing technologies from the developed world, researchers need to explore education technology constraints within each country. This paper briefly explores such teaching and instructional requirements in different countries and explores areas in which technology can be applied as part of a potential solution. It also discusses economic, social, political and cultural dimensions of the educational problem/opportunity for the developing world.

This discussion is based, in part, on several themes around education technology that offer strong support for teaching and learning in difficult situations, e.g., in the absence of physical schoolhouses or given the lack of good teacher preparation. For example, an international report, entitled *Roadmap For Education Technology*, funded by the U.S. National Science Foundation and Computing Research Association [2] describes a vision for how technology might be used anytime and anyplace, with or without teacher support and in the absence of physical classrooms. Although prepared for the developing world, this report, serves as a good starting point for the discussion of technology for the developing world.

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Researchers seek to understand ways in which computational technology might be fully utilized to achieve the promise of open access to global resources and greatly enhance the larger scale use of technology in teaching and learning.

The first and most obvious constraint in developing countries is *economics*. Thirty-seven countries have a per-capita income below $2000 and sixty-nine countries have one below $5000 [3]. To put things in perspective, a developed country like the United States spends about $10,000 per year on each high-school student in a public school. Therefore, in absolute terms, this spending is more than five times the per-capita income of thirty-seven countries and twice that of per-capita income of sixty-nine countries.

In addition, *critical resources* required for education technology, such as the Internet are prohibitively *more expensive* in many developing countries [4]. For example, in the United States, the cost of broadband is about 1.1 percent of per-capita income, while in a country like Ethiopia, access to similar Internet access is 678 percent of per-capita income [5]. Similarly, in Bangladesh, the annual cost of connection to the Internet is sufficient to feed a family for the whole year and in more than half of the countries in Africa, the cost of Internet access exceeds the per-capita income [6]. Another factor that plays a key role in education technology is the availability of

**Figure 1. Learning companions** in Wayang Outpost express a variety of emotions including excitement (top, middle) and frustration (bottom, left) to help engage students in mathematics problem solving.

*physical infrastructure*, e.g., school buildings, classrooms and availability of electricity, which are taken for granted in most developed countries. However, this is not the case for many developing countries [4]. For example, in four states of India over 50 percent of pupils were in schools with no electricity. In Sri-Lanka and India school heads reported that over 40 percent and 50 percent respectively of pupils were in schools with insufficient writing and sitting places. *Availability of computers* in schools in many developing countries is also lacking. For example, 56.8 percent of students across the world economic indicator (WEI) countries had no access to computers at all. In India, 85 percent of the schools participating in the study did not have any computers [7].

One key component of learning technology is the *ability to connect to the Internet* [4]. Although such connectivity is the norm in the developed world (71 percent of the population is online) only 21 percent of the population in developing countries is online (International Telecommunication Union). Internet user penetration in Africa is 9.6 percent, far behind both the world average (30%) and the developing country average (21%) [8]. As opposed to Internet penetration, *mobile coverage* is quite high all around the world [9]. In developed countries, the mobile market has reached saturation levels with an average of 116 subscriptions per 100 inhabitants at the end of 2010 and a marginal growth of 1.6 percent from 2009-2010 [8]. On the other hand, for the developing world, share of mobile subscriptions has increased from 53 percent per 100 inhabitants of total mobile subscriptions at the end of 2005 to 73 percent at the end of 2010 [8].

One implication of this lack of *critical resources* and *Internet connectivity* is that existing teaching systems designed for desktop computers should possibly be ported to applications on mobile devices and rewritten to rely only on a single local server or rare connection to the Internet.

A different solution is provided by One Laptop per Child (OLPC),[1] a non-profit organization whose mission is to help provide every child in the world access to modern education. This group distributes connected, power-efficient and robust laptops, called XO, to children in several countries. For example, every primary school student in the 1st to 6th grade in Uruguay has an XO, and 98 percent of all students have Internet connectivity at home, provided through Plan Ceibal, a national project of the Uruguayan President, Tabaré Vázquez.

Another constraint in terms of education in developing countries is *poverty* and *educational disparity,* which take on an increasingly important role in characterizing students in the developing world [4]. For example, as compared with Vietnam (that has the same per-capita income), Pakistan has three times the level of *education poverty*, reflecting disparities linked to wealth, gender and region that go beyond the per-capita income [10]. Wide variability in the *number of hours* a student is expected to spend in school also contributes to this problem [4]. For example, a 9-year old in Chile is expected to receive 1,140 hours of teaching, compared to only 729 hours in Argentina [11]. *Life-long learning* also takes on different dimensions in the context of developing countries. 72 million children were out of school in 2007 and not engaged in any formal learning activities. If things remain the same, 56 million children are expected to be out of school in 2015 [3]. The Middle-East also suffers from high *youth unemployment*; about 20 percent of youths are out of work calling for training or vocational education [10].

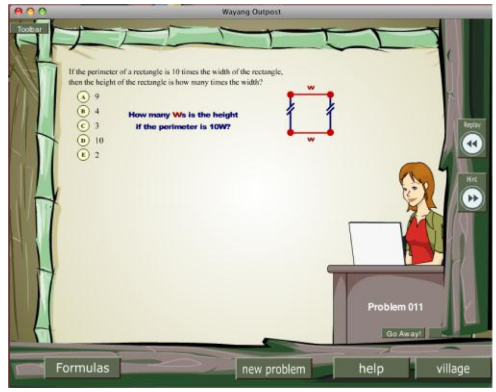


**Figure 2. Mathematics problems** in Wayang Outpost provide clues specific to the student and problem.

One implication for future teaching systems of this *poverty* and *educational disparity* constraint is recognition of the large influence of cultural issues on the educational enterprise. Any solution must involve cultural, social and technical components. We would be naïve to think that technology alone can solve education's problems and the failure of technological determinism is well documented.

One unique solution is found in Afghanistan where half of the computers supplied by OLPC in the country are found in schools for girls. The Afghan government has digitized school texts and produced new materials for the XOs. These laptops have a dual Dari-Latin keyboard and all software is localized into Dari and some is in Pashto as well.

Solutions like this can fill some gaps between detailed qualitative case accounts (providing insight into single accomplishments) and quantitative methods (finding patterns in aggregate data) that might otherwise separate researchers from the processes by which schools and country appropriate the technology. Cultural, social and technological solutions are needed to address complex learning situations, both in the context of formal education (traditional class settings) and in informal learning (outside of classrooms).

Because of the unique characteristics of education technology environments, numerous *documented* failures have also been recorded [4]. For example, in Ethiopia, introduction of the OLPC XO computer continues to face challenges such as lack of content and teacher training in addition to a lack of integration in schools because children are mostly using these computers at home [12]. Traditional, paper-based means of distance learning continue to be more reliable, sustainable, and

[1] One Laptop per Child is described at http://one.laptop.org/

widely used than online and Web-based methods of learning in sub-Saharan Africa [13].

However, many *success stories* have also emerged [14]. For example, Telesecundria in Mexico was a pioneer in successfully using television as a medium of distance education. More recently in Pakistan, the mixed model of satellite television, tutors and the Internet has been a success at the Virtual University of Pakistan (VUP) with enrolment reaching over 60,000 students. A survey of 387 students in their final undergraduate year at the VUP showed that over 90 percent of the students found learning over the Internet and via satellite TV beneficial [14]. In addition many innovative and practical approaches like using a $38 Korean multi-media player called "pocket school" for indigenous children in South America [14] are being explored. Introducing cheap learning gadgets in improvised schools in Malawi that have a GPN[2] of $280 (one of the poorest nations) has had a positive impact on both students and teachers [12].

Other success stories include Madagascar, where OLPC schools have started with the youngest children, who learn to read and type with their XOs. They also learn how to use and maintain their machines with their own laptop hospital. Young boys work together at home on their XOs in Kathmandu, Nepal and spend as much time with their XOs as they do at school. Parents embrace the change. Peru's education system is built in part on project-based learning. The Education Ministry developed dozens of longer projects and activities that could be accomplished only on a XO. Paraguayan software developers and educators have collaboratively developed localized software and class materials that they use today. Students in Takaungu, Kenya have an XO study hall with seats rearranged in groups, to explore what interests them. Students work on recording video, programming in Turtle Art, and playing favorite Sugar activities.

"Core to our mission is providing the world's most isolated and vulnerable children access to modern forms of education and the opportunities that follow," said Nicholas Negroponte, chairman and founder of One Laptop per Child. "With the XO, the children can continue to stay connected and gain the skills and knowledge required to participate fully and thrive in the 21st century – even when getting to school is impossible."

## II. Software Solutions for Instruction

The previous section described constraints for use of educational technology in developing countries and cited examples of hardware success. This section describes software solutions that arise from the distinct need to introduce instructional content and to build teacher training on hardware platforms, such as the XO. Several broad themes about how software might be built for instruction were explored in the *Roadmap for Education Technology* [2]. We present three of those themes and explore their potential: *personalization* of instruction for individual students, *re-examination of educational boundaries*, especially those that limit a student's engagement, and *social learning* to support students who work together collaboratively.

### A. Personalization

Learning systems can be adapted for each student's traits (prior knowledge, learning style, and culture) and states (emotions, level of frustration) [2]. Such systems show great promise of succeeding in the developing world as they address the lack of qualified teachers and consistent learning venues [4]. Issues such as gender disparity, poverty and first language provide additional reasons to personalize education in the developing world. Yet, the non-availability of one computer per child in many environments and general lack of hardware and software raise additional challenges.

As one example of personalized tutoring systems, we describe Wayang Outpost, a mathematics tutor developed at UMass that uses real-time multimedia and reasoning about individual cognitive characteristics to train middle and high school students in mathematics, see Figure 2 [15,16]. The tutor is situated in a fictitious orangutan research laboratory in Borneo, which provides rich real world content for mathematics problem solving. For example, students might calculate the amount of roofing material needed to rebuild an orangutan nursery destroyed by a fire or calculate whether a jeep can safely ride across a broken bridge, assuming that it can withstand a fall from a certain height.

Learning companions with three ethnicities (White, Hispanic and African), see Figure 1, use gestures to reflect student emotion and deliver messages that emphasize the importance of effort and perseverance, e.g., "Remember, the mind is like a muscle; it improves when used." If students have difficulty solving math problems, a simple analogue problem is presented to remind them of basic principles. Multimedia explanations provide step-by step instruction and guidance in the form of animations, videos, explanations, etc. For example, on a geometry problem, a student might see a line crossing two parallel lines, and angle with a known value on one parallel line might then rotate, showing the corresponding


**Figure 3. Wearable learning shirts** ("hoodie") provide electronic scaffolding for learning through children's games, e.g., hide and seek and tag.

angle on the other parallel line and emphasizing the principle of correspondence. Explanations and hints resemble what a human teacher might provide, e.g., by drawing, pointing, highlighting, and talking, rather than by relying on screen-based text.

Such software personalizes instruction based on each student's cognitive profile, gender, spatial ability, and speed [17]. It identifies a student's skills and then adapts its presentation of comments and subsequent problems. Like a human tutor, it provides sustained engagement and structured practice using information about each student's cognitive skills. Machine learning and statistical models predict student's skills, knowledge, interest and emotions, and vary the amount of challenge or feedback provided by pedagogical characters. Semantic rules and models of students, domain knowledge, and teaching strategies reason about how to tailor the curriculum to individual needs.

Students who use Wayang show improved learning gains (an average of 12 percent from pretest to posttest) after only 2 classroom periods. In addition, they pass standardized exams at a higher rate. These tutors are freely available on the Internet[2] and can serve poor students or students who have no schools. In view of the constraints described in Section I for developing countries, such personalized tutors will be very effective for individual students who learn at different rates, or who may be forced to learn without the benefit of formal classes or trained teachers. However, other constraints suggest that such systems need to be available on mobile devices and not depend on instantaneous connection to the Internet.

### *B. Re-examination of education boundaries*

A second theme discussed in the *Roadmap* is re-examination of educational boundaries, which is appropriate for the developing world. This theme focuses on educational labels that keep students from fully engaging in learning, specifically labels that fix students by levels of education (elementary, middle, high school, and colleges), personal ability (special and typical students), place of study (home, work, institutions) or type of learning (formal and informal).

As an example of inexpensive technology that helps diminish these boundaries, we describe *wearable learning*, or clothing that has been embedded with electronics and cognitive tools to support student's active learning in physical games. Children's games have a cross-cultural appeal and children intrinsically connect with them cross-culturally [18]. This makes games an excellent motivational device for learning. Often this research is referred to as *embodied cognition* (EC), to distinguish it from work on stationary computer games. In EC games, learners construct new knowledge while engaging their neuromuscular system and interacting with the world visually, aurally, and kinesthetically [19].

We describe physical embodied games developed at UMass based on the childhood game of hide-and-seek or peek-a-boo (for younger children). This social game involves two groups, people who are and those who are hidding. One joy comes from mutual reaffirmation, an ability to communicate one's intentions to others [20]. The world becomes suddenly smaller, guided by the new rules (someone is seeking, someone is hiding). The satisfaction of feeling autonomous and independent to go hide "on my own" follows until, suddenly, the tension emerges: "Will I be searched for? Am I important enough in your eyes to be sought?" Another joy comes in the positive response from the seeker, who supports the intentions of the child to be found.

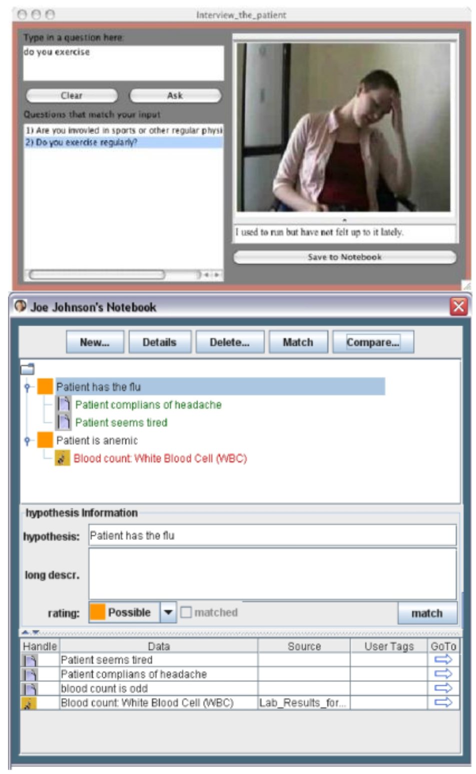


**Figure 4. Students collaborate** around medical diagnosis of a virtual patient (top) in the Rashi system. They "interview" patients and record their hypotheses in the notebook (bottom) along with evidence supporting and refuting that evidence.

Let's assume we teach mathematics through hide-and-seek. Given a timing component, where students hide in a limited amount of time, the game lends itself to measurement *estimations* and *number sense* kinds of mathematics problems, where exact computations are not necessary, but a good approximation is enough. The following examples are of issues for hiding places, in which both hider and seeker will become aware. Students hide inside or behind something that has a volume greater than 50 cubic feet. Or they hide in any place at a distance less than $\sqrt{1000}$ feet from the base or outside a circle with a certain area.

We developed technology to support teachers in the game of hide-and-seek, see Figure 3. The back of the hoodie includes the Lilypad ATMEL 328-based Microcontroller [18], connected to a Zigbee-based wireless module and powered by a 1000 mAh Lithium battery. These three components have been

[2] The Wayang tutors are available at http://wayangoutpost.com/

modularized in the form of the PAP+ patch as shown on the hoodie and include all internal connections between the three components. This patch can be easily removed for washing. The hoodie also includes a 7 X 21 bright LED display to show the various hints to each child.

The teacher leads children who will hide into the learning environment that contains objects and asks each child to select a hiding place and then to create a hint related to the particular object they are hiding behind. Each hiding child swipes their forearm against the barrel, which conveys their position to a central computer. After all the children have hidden themselves, the seeking child is led into the learning environment and receives a sequence of clues, one from each hidden child, which are displayed on an LCD on the seeking child's shirt.

After the teacher hits a key in a central server, all students receive a message displayed in the LCD displays of their hoodies that represents one of the math issues identified earlier. When all lights are off, the seeker starts searching, and continues to play in the traditional way. Teachers both enter new math issues for hiding places and set the timing of the LED lights, in the teacher panel. They adjust the time that students have to decode the message on the LCD and figure out the hiding places.

The seeking child has a limited amount of time to decode this clue about the hiding place (LED lights on the shirt again show the passing of time) and find the child hiding behind the object associated with the hint. From a physical perspective, hiding and being seen increases bodily awareness; it is the body that goes away to hide. This helps young children develop the perspective that someone is not seeing you, even though you can see yourself.

In consideration of the constraints described in Section 1, inexpensive technology such as wearable learning shirts provide an exciting opportunity to engage students in learning through informal and playful methods, while providing a mobile system that does not require connection to the Internet. Technology provides learning materials that help students move between formal and informal learning situations thus supplying ubiquitous learning, available everywhere and anytime. Networks and electronic games help diminish artificial boundaries, yet other characteristics of a country, such as culture and finance add additional constraints. For example, informal education that employs LEGO may be too expensive for most countries and might face cultural resistance. The *Roadmap* document [2] also suggests developing alternative teaching methods, such as inquiry, collaboration and discourse and social learning. Availability of cheap mobile devices in addition to high penetration present novel opportunities for such alternative teaching methods in the developing world.

### *C. Social learning*

The third and final theme about using technology within developing countries applies to the importance of social learning. Social learning is important for citizens an information society, since modern problems often require real-time responses over lengthy periods of time, not solutions by single individuals over short and finite lengths of time. Students need to learn *within* communities, and communities need to *construct* knowledge, and learn from one another. This makes collaboration tools more important to the future of education [21].

Mobile and wireless devices enable social interactions among students that take place anytime and anywhere and provide remote access to information. Such technologies support a variety of activities, such as *discussions* (with peers), *exploration* and *investigations* (of physical environments), *recording* of data (sounds, images, videos, text, locations) and *sharing* (of captured data) [21]. Mobile tools are 'fun,' in that they make learning easier and more effective in part because they support '*learning-in-context'* and '*continuity between contexts,*' aspects of learner ownership and control that empower learners. Mobile learning is also important because it results in communication among peers, student access, personalization and engagement [14].

However, in many cultures, resistance and characteristics of the country may thwart the success of technologies for social learning. For example, a key component of teaching collaboration is teacher training which may be limited in some countries. In addition, large class sizes and the lack of Internet access present great challenges to development of collaborative activities. Yet cheap and pervasive mobile devices present novel opportunities.

We describe one such social tutor that engages students in peer-to-peer collaboration within undergraduate biology classes. Rashi is an inquiry learning system developed at UMass and grounded in medical diagnosis, problem based learning and real-world problems [22]. The tutor provides medical case descriptions for students to diagnose, along with information about how to approach each problem, see Figure 4 [22, 23]. Students evaluate virtual patients and generate hypotheses about their medical condition. They begin by studying patients' complaints, conducting patient interviews, performing physical examinations, and running lab tests. During collaboration, students view each others' notebooks and drag and drop both data and hypotheses from others' notebooks into their own. This supports a variety of collaborative activities ranging from students working in tightly knit groups, to students working mostly independently but sharing ideas and thoughts when reaching an impasse. The system also provides a chat facility to enable students to discuss issues with members of their group. Within the chat feature group members click on subjects and are quickly taken to related work in a group member's notebook.

In order to facilitate collaboration, Rashi recognizes the topics that students discuss within the chat window and make comments to help students maintain proper focus. It recognizes students dialogue y using an expert system to match student chat topics with the expert system's encoded statements of the correct solutions. This has been done with 88 percent success rate) [23].

In addition to recognizing student topics, Rashi identifies situations where students might be helpful to each other [24] and intelligently encourages collaboration, providing a list of other students working on similar topics and, at crucial points, provides "suggested topics" for individual students. The system also detects specific moments at which interventions might be given and reasons about which opportunities are appropriate for which students.

Such social tutors, especially ones that exploit mobile and wireless devices, provide effective and enjoyable learning for many students and help to develop students' social and communication skills. On the other hand, such systems can't rely on rapid connections to servers or the Internet to store and evaluate large student and collaboration databases.

## III. Discussion

Education technology, as described in Section II, addresses many broad issues that remain stumbling blocks for education in the developing world, including lack of infrastructure, poor resources and poorly trained teachers. Computational systems can help those students who are most isolated and vulnerable, especially when these systems provide personalization, address educational boundaries and support social learning.

However, much work remains to be done. Software needs to be ported to appropriate hardware, and can't depend on rapid and consistent connection to the Internet. For example, Wayang and Rashi, described in Section II, currently reside on desktop systems and rely on the Internet to store and reason about student records and individual collaboration skills. However, to be effective in the developing world, these and other systems should be on mobile systems and their Internet-dependent tasks moved to a single local machine that utilizes only limited connectivity (e.g., only the teacher has the connection). Instructional software and hardware provide a perfect combination to support students in situations where schools, resources and teachers might not exist. With innovative thinking and a rationalized approach, it is hoped that researchers might set a solid foundation for addressing such problems in developing nations so that technology might play a fruitful role in education.

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