Design and implementation of a low-cost classroom response system for a future classroom in the developing world

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Abstract. Economic considerations and lack of adequate infrastructure impose unique design constraints on future classrooms of the developing world. Thus, future classrooms in underprivileged nations may differ significantly from their counterparts in the developed world. Classroom response systems (CRS) are an emerging technology for the future classroom. CRS are wireless, hand-held devices that help students provide immediate feedback to questions posed by a teacher. In their present form, due to their relatively high cost and high infrastructural requirements, such systems are not sustainable in most developing countries. This paper presents the design and implementation of a CRS based on an open-source, low-cost, and easily manufactured hardware. The CRS design is based on a hybrid wireless/wired platform using Bluetooth with the 1-Wire networking technology. This design significantly reduces the cost, and is consistent with existing conditions in a typical developing country.

Keywords: Classroom Response System, Developing world, Sustainable Design, Arduino, Open-source, 1-Wire

1 Introduction

In addition to personal computers (PC) and the Internet, a variety of technologies like smart phones [1] and even pedometers [2] have found their way into a modern classroom. Future classrooms incorporating embedded computers, digital boards, video cameras, microphones, and multimodal sensors to create a smart learning space have been proposed [3]. The modern "classroom" is also evolving beyond classroom walls towards an ambient intelligent environment instrumented with a host of enabling technologies. For example, technologies like Global Positioning Systems (GPS) and Radio-Frequency Identification (RFID) are being used to augment and track learners where the physical space (a garden, for example) becomes the extended classroom. There is also a promise of using open standards to connect such smart classrooms using web services, and hence enabling novel peer-to-peer pedagogical scenarios across schools [4]. Capturing and incorporating context that includes physical, emotive and information dimensions will allow the future classroom, embedded with a variety of sensors and networking technologies, to deliver unique personalized learning experiences to learners in both space and time.

A recent open-ended survey of elementary students in the developed world revealed that their “likes” included multi-user gaming areas and computers, “dislikes” were creaky windows and hard stairs, and “wishes” consisted of owning a locker, a swimming pool and a football pitch [5]. The vision of a future classroom with embedded computers, digital boards, video cameras, microphones, multi-user gaming areas, GPS and RFID sensors, and providing swimming pools and lockers, for example, is somewhat disconnected from realities of the developing world. Majority of the future learners are in the developing world where circumstances to sustain such classrooms simply do not exist. Hence, there is need to carve out a new vision for a future classroom in the developing world. This vision must be consistent with prevailing conditions in the developing world; conditions like lack of funds and infrastructure, which are not expected to change in the near future.

A classroom response system (CRS) or clickers allows students to provide immediate feedback to their teachers and peers. Such systems are increasingly being used in smart classrooms. This paper presents the design and implementation of a low-cost CRS that can be incorporated into the future classroom of a developing country in a sustainable manner.

The rest of the paper is organized as follows. The next section introduces CRS. This is followed by a discussion of constraints in a typical developing country that may impact the design of a sustainable CRS. The design and implementation of a low-cost CRS built especially for the developing world is presented next, followed by an evaluation and a conclusion.

2 Classroom Response Systems

CRS or clickers are hand-held devices that provide immediate feedback to students and teachers [6]. Clickers have been used extensively in a variety of formal and informal situations, large and small classes, and for various ages ranging from children to post-graduates in a number of fields [7],[8],[9].

Features

Design features of a typical CRS are presented in [10]. One key design feature of a CRS is the keypad; students prefer cheaper keypads, but also prefer keypads that provide feedback that an answer has been registered. Hence, some clickers have small Liquid Crystal Display (LCD) screens in the keypad. Compatibility with presentation software like PowerPoint is also a key feature; most clickers are integrated with PowerPoint to display questions and to show reports of student answers. Most CRS also support some type of data collection and reporting. A number of CRS allow seamless integration with class rosters on learning management systems (LMS) to transfer the grades after each session. Another key feature of wireless CRS is the ability to handle interference; wireless clickers in one class can interfere with clickers in an adjoining class. Such a situation is typically handled by asking students to join a class using their clicker, and by entering a class identifier. Other features of a CRS include deeper integration with online content and textbooks. Efforts are also underway to develop an open, web-based CRS for PC, iPod Touch, iPhone and mobile devices [11]. Finally, a "software only" CRS using Java Remote Method Invocation (RMI) to implement peer feedback over a computer network has also been proposed [12].

Pedagogical Effectiveness

Clickers attract student's attention at three levels [13]. First, clickers create novelty and fun. Second, clickers increase student participation through anonymity and thirdly, clickers improve interaction through peer discussion. For example, student participation and engagement improved as a result of using clickers in a biochemistry class [14]. In addition, use of clickers also increased responses from students with behavioral problems [15]. While use of clickers activated the learning experience, and improved class dynamics, such usage did not necessarily help build critical thinking skills in certain situations [16]. However, when combined with meta-cognitive conceptual feedback strategies, the use of clickers was found to improve performance at higher levels of understanding as well [17]. Anonymous use of clickers also helped engage students in discussions that invoked significant reflection [18].

Use of clickers does not always lead to performance differences in learning, but helps support the learning process. For example, while no performance difference were detected among control and treatment groups, clickers kept student more actively involved, increased their attentiveness and made lectures more enjoyable [19]. A similar increase in communications and participation, but not in performance, was also reported by [20]. While no statistical differences were found in performance, students using clickers were found to be more engaged in large classes as well [21]. Use of clickers also increased chances of a student reading before a class, and also helped students engage and learn from peers in a small classroom setting [22]. Students exposed to clickers also wanted clickers to be used in other classes as well [23]. Finally, use of clickers in a second language learning class also increased student motivation and interest, and promoted self-assessment [24].

Without appropriate pedagogical support, use of clickers can also have an unintended negative impact on performance. For example, [25] found that while use of clickers increased student engagement, in some cases, it actually reduced performance. Similarly, [26] also reported that clickers tended to decrease performance in certain classes. In another study, no performance effects due to the use of clickers in a library setting were observed, and this was attributed to the need for an appropriate pedagogical shift [27]. Consequently, specialized pedagogical approaches like TEFA [28] and SCCQ [29], designed specifically for clickers, have begun to emerge. Indeed, use of clickers actually may help teachers shift from a teacher-centric to a student-centric perspective [30].

Background of learners also mediates the role of clickers. For example, adults with lower English language proficiency levels perceived anonymity to be more beneficial as opposed to learners with beginning to intermediate levels of English, who perceived clickers to be more valuable for communications [31]. Similarly, [32] noticed a significant relationship between when the students registered their clickers and performance; higher performing students registering their clickers earlier. The application of a technology acceptance model to clicker usage found that ‘perceived usefulness’ was a key variable affecting student’s intention to use a clicker system [33].

In summary, while the usage of clickers has been wide-spread and they generally increase student engagement and enjoyment, a direct impact on performance is more elusive calling for an improved coupling with appropriate pedagogical approaches. The use of clickers, however, does generally seem to have an impact on important learning parameters like better communication, peer engagement and meta-reflection.

3 Challenges and Opportunities

This section discusses challenges and opportunities related to the design of a CRS for future classrooms in the developing world.

3.1 Challenges

The key challenges facing the deployment of CRS in a typical developing country include lack of physical infrastructure, funds, computers and Internet connectivity, and trained teachers [34]. Each challenge is discussed below.

Physical Infrastructure

Unlike the developed world, physical infrastructure like proper classrooms and electricity are not available in many developing countries. Fig. 1 shows a typical classroom in a semi-rural setting of a developing country. A typical classroom, like the one shown in Fig. 1, can hold up to one hundred children, bunched together on hard wooden desks, in a room with no air-conditioning and heating, no computers and often no electricity. For example, in four states of India that participated in the UNESCO WEI survey [35], over 50% of pupils were in schools with no electricity. In addition, schools in countries like Pakistan face frequent “load shedding” which means that electricity is not available despite the connectivity. And while students in the developing world worry about issues like “hardness of stairs,” the fore-mentioned WEI survey also showed that in Sri-Lanka and India, school heads reported that over 40 and 50 percent respectively of pupils were in schools with insufficient writing and sitting places.

In summary, a CRS design that presumes that availability of basic infrastructure like electricity in classrooms is not viable for most developing contexts.

Fig. 1. A typical classroom in the developing world

Funds

Schools in developed nations like the United States spend upwards of US$10,000 per pupil per year. This is more than twice the per-capita income of the poorest 69 countries [36]. Spending on education also varies widely within the developing nations. For example, educational expenditure per primary school pupil was highest in Chile (PPP$[1] 2,120), followed by Argentina (PPP$ 1,605), Malaysia (PPP$ 1,552), Brazil (PPP$ 1,159) and Uruguay (PPP$ 1,063) [35]. In contrast, expenditure per primary school pupil was less than PPP$ 700 in India, Paraguay, Peru and the Philippines. This situation has been exacerbated by the current financial crisis which has had an adverse impact on current levels of spending on education. For example, countries in sub-Saharan Africa will lose about 10% spending per primary school pupil in 2009 and 2010 [37].

In United States, a $30 expense on one clicker represents a $30/$10,000 = 0.3% of total spending per pupil per year. In a developing country like India, however, such an expense is a whopping 4% (13 times that of the U.S.) of the total yearly educational expenditure on a pupil and certainly difficult to sustain. Therefore, significantly reduced cost is a key constraint on the design of a CRS for the developing world.

[1] PPP represents purchasing power parity between two countries to adjust for actual buying power in a country.

Computers and Internet Connectivity

Many schools in developing countries have very few or no computers. For example, 56.8% of students across the WEI countries had no access to computers at all. In India, 85% of the schools participating in the study did not have any computers [35].

In addition to a lack of computers, Internet access is much more expensive in many developing countries than the developed world. For example, in 2009, an entry-level fixed (wired) broadband connection cost on average 190 PPP$ per month in developing countries, compared to only 28 PPP$ per month in the developed world [38]. Similarly, in the United States, the cost of broadband is about 1.1 % of per-capita income, while in a country like Ethiopia, access to similar Internet access is 678% of per-capita income [39]. In fact, in more than half of the countries in Africa, the cost of Internet access exceeds the per-capita income [40].

While the Internet access in developing countries has increased from 503 Million users in 2006 to 1.5 Billion users in 2011, the Internet access still lags behind the developing world; only 26.3% of the population in developing countries is online as opposed 73.8% in the developed world. In 2011, Africa had an Internet penetration of only 12.8%. Similarly, fixed-line broad-band Internet penetration is lower in developing countries and expected to reach 4.8 subscriptions per 100 people in 2011 as compared to 25.6 subscriptions per 100 people in developed countries [38]. Consequently, in South American cities, Internet cafes are often the primary source of accessing the Internet [41]. However, some developing countries like Pakistan only have five Internet cafes for every 10,000 people [42].

Clearly a CRS design that presumes the availability of a PC in each classroom or wide-spread and low-cost Internet access is not a sustainable option in the developing world.

Trained Teachers

Availability and competency of trained teachers is another important constraint in designing any learning technology for the developing world. For example, [30] showed that teachers need significant pedagogical and technological support in successful implementation of CRS. Most of the 67 countries with moderate to severe teacher gaps were developing countries [43]. While some countries have reasonable gap percentages, others like Zambia (6.6%), Côte d'Ivoire (8.5%) and Mali (8.8%), Burkina Faso (12.5%), Niger (13.8), Chad (13.9%), Eritrea (17.8%) and the Central African Republic (19.4%) have a large primary teacher deficit. In addition, there is a wide variation in the level of training required to become a teacher in the developing world, putting into question the competency of many trained teachers. For example, total number of years of schooling required of teachers to teach fourth grade children varied from 11 to 19 years [35]. Similarly, in India and Tunisia, the pre-service teacher training was 1.1 years as opposed to 3.7 years for Chile and Uruguay [35].

The lack of trained teachers implies that a CRS design needs to provide additional functionality that will enable school administration to monitor and augment the use of such devices in an educational setting in the developing world.

3.2 Opportunities

As opposed to Internet penetration, mobile phone coverage is quite high all around the world [44]. While in developing countries the mobile phone market was expected to reach an average of 117 subscriptions per 100 inhabitants by the end of 2011, share of mobile subscriptions in the developing world was expected to increase from 53% at the end of 2005, to 78.8% at the end of 2011[38]. Africa has the worst mobile telephony adoption rate, and was expected to reach mobile penetration of 53% by the end of 2011[38]. Mobile broadband, however, has much low penetration in developing countries. For example, while mobile broadband in Europe was expected to reach 50.4% by the end of 2011, by contrast, the penetration is expected to reach only 3.79% in Africa and 13.79% in the Arab States. Thus, the use of mobile networks in the developing world is primarily restricted to low-bandwidth and low-cost devices. The prevalence of cheap mobile devices has also developed a small cottage industry in most developing countries which is involved in repair of mobile phones. Since even the cheapest mobile phones are typically based on latest advances in semi-conductor packaging techniques, an explosion of mobile phones has had an unintended effect of developing technical skills like hand soldering of "surface mount" devices in developing countries. Such skills can be utilized to manufacture low-cost hardware devices for the developing world as well.

The pervasive availability of cheap mobile infrastructure suggests that a CRS design for the developing world must exploit this new modality in an intelligent and sustainable manner.

4. Design of a CRS System for Developing Countries

As the previous section shows, key design challenges for an CRS in a developing country include lack of physical infrastructure, cost, lack of computers and Internet connectivity and untrained teachers. The primary design opportunity is the wide-spread availability of mobile phones and the related repair technologies and the mobile infrastructure. All of these challenges and opportunities are exploited in the design of a specialized CRS for developing countries as described below.

4.1 Hardware/Software Design

Fig. 2 shows the conceptual design of a CRS for developing countries. As Fig. 2 shows, a traditional CRS typically requires a computer and one Receiver module for each teacher. Receiver module is connected to the computer using a Universal Serial Bus (USB) or a similar wired connection. Each student needs to have a wireless CRS end-device with a keypad. This end-device typically costs around US$30. An end-device communicates with the Receiver module using some form of wireless technology. For example, legacy CRS used Infrared (IR) for communicating between an end-device and the Receiver, while most current CRS have adopted some form of Radio of Frequency (RF) wireless technology, with some systems using highly sophisticated spread spectrum techniques to support thousands of end-devices simultaneously. In addition to RF, using WIFI or GPRS wireless technologies with mobile phones acting as end-devices, has also been proposed. Finally, more exotic network wireless technologies like the IEEE 802.15.14 or Zigbee are also good candidates for establishing communications between wireless end-devices and the Receiver.

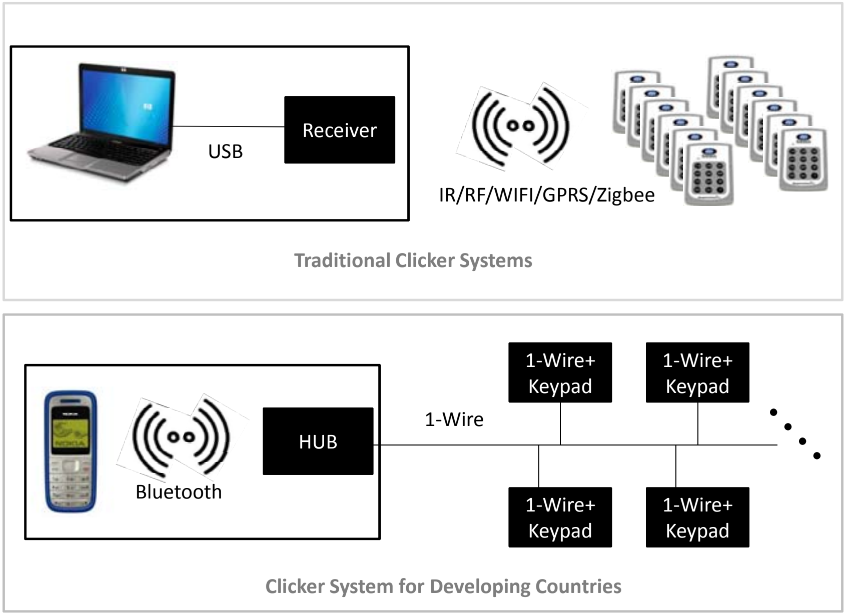

Fig. 2. A CRS for developing countries

As Fig. 2 shows, the proposed design of a CRS for the developing countries replaces teacher's computer with a cheap Bluetooth and J2ME-enabled mobile phone. As Fig. 2 shows, the teacher's mobile phone wirelessly communicates with a HUB using Bluetooth. HUB is a piece of hardware that plays the same role as the Receiver in traditional CRS systems. However, unlike the conventional CRS systems employing expensive wireless technologies, the HUB uses a wired connection to communicate with end-devices via a 1-Wire network [45]. A 1-Wire network uses a single wire to establish communications between a master on the HUB and a large number of slave or end-devices where each end-device has a unique 64-bit address. The master can supports speeds of up to 15.3 kbits/second and wires can be extended up to 100 meters without any additional hardware. This means that one HUB and a large number of wired devices can be easily deployed in a typical classroom in the developing world. The 1-Wire network does not require special wires and can be built using the locally available wires in a particular developing country.

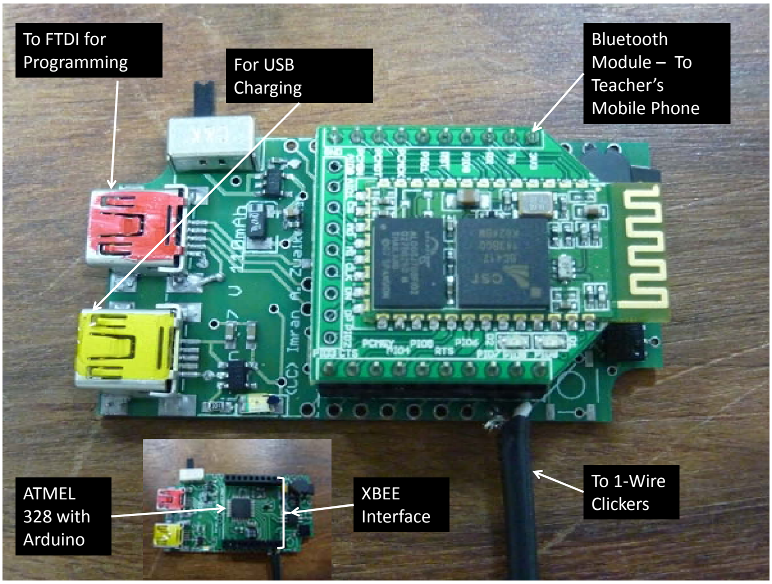

Fig. 3. The HUB based on open source hardware

The HUB

Fig. 3 shows hardware design of the HUB. One key consideration in hardware design for this CRS was to not use any proprietary technology that added licensing costs. Consequently, the hardware design is based on Creative Commons License and is designed around the inexpensive, and readily available, 8-bit RISC-based ATMEL-328 microcontroller [46]. This microcontroller is connected to a Bluetooth unit using the XBEE hardware interface. The advantage of using the XBEE hardware interface is that various types of alternative wireless modules like Zigbee, WIFI or even GPRS can be substituted for future applications. The ATMEL microcontroller runs Arduino software which is open-source and conveniently supports libraries for interfacing with various types of hardware and sensors [47]. The simplicity of Arduino programming was another important consideration in the overall design. The HUB can be programmed by using freely available development tools on a PC using a serial-to-USB converter and a USB cable. The HUB also implements a charging circuit for a rechargeable Lithium-Ion battery. Finally, the HUB hardware provides a wired interface to a 1-Wire network through a serial to 1-Wire line driver [45].

The Printed Circuit Board (PCB) for the HUB was deliberately designed to have only two layers. This ensures that this PCB can be easily manufactured locally in most developing countries. Even though the board uses surface-mount technologies, the board shown in Fig. 3 was successfully assembled using hand soldering in a developing country. This level of skill is widely available in developing countries in the cottage industry that caters to hardware repair of mobile phones. The approximate cost of each HUB module in prototype quantities with a Bluetooth option is about US$75. This price is expected to drop significantly in high volumes of production.

The 1-Wire End-Device

Fig. 4 shows the 1-Wire end-device hardware incorporating a 1-Wire client based on an 8-channel, 1-Wire Addressable Switch that can read eight inputs from a simple keypad [48]. The end-device can either use parasitic power from the HUB or can be powered using a commonly available 1.5 volt battery; the option is jumper-selectable. Consequently, the end-device hardware includes a 1.5 volt to 5 volt converter circuit because 1-Wire operates at 5 volts.

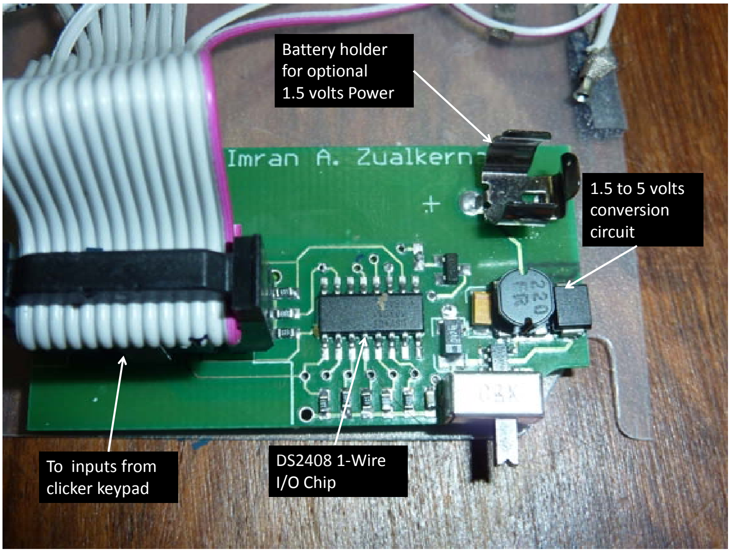

Fig. 4. The 1-Wire CRS end-device

The clicker keypad can either be a cheap membrane type, or alternatively, pupils can design and maintain their own keypads. Fig. 5 shows one such keypad. This keypad uses commonly available items like paper, aluminum foil and a plastic file folder to build a clicker that can easily be reconstructed or repaired as required in any developing country. The only requirement is the eight input connections and one 5 volt connection to 1-Wire clicker hardware. The 1-Wire clicker communicates with the HUB using two wires; one wire for the 1-Wire signal and the other for ground (GND).

The hardware is not restricted to using only one keypad per 1-Wire end-device. Rather, as Fig. 6 shows, a variety of configurations can be easily constructed. For example, a simple configuration like Fig. 6 (a) provides eight buttons per keypad. In this case, the total cost of a 1-Wire end-device is not more than $10 per pupil in prototype quantities. However, configurations Fig. 6 (b) and Fig. 6 (c) use only four or two buttons (true or false, for example) on a keypad and hence drop the cost to be at most $5 per pupil, or $2.5 per pupil respectively. The hardware design is also flexible and easily incorporates configurations like Fig. 6 (d) which shows how two end-devices are used to build a 16-button keypad. Such keypads can be used, for example, to create pedagogical scenarios including teams of students working together to provide feedback on complex questions. A key feature of the design is that heterogeneous networks including any number of any of the configurations shown in Fig. 6 can be easily constructed by simple changes to the software.

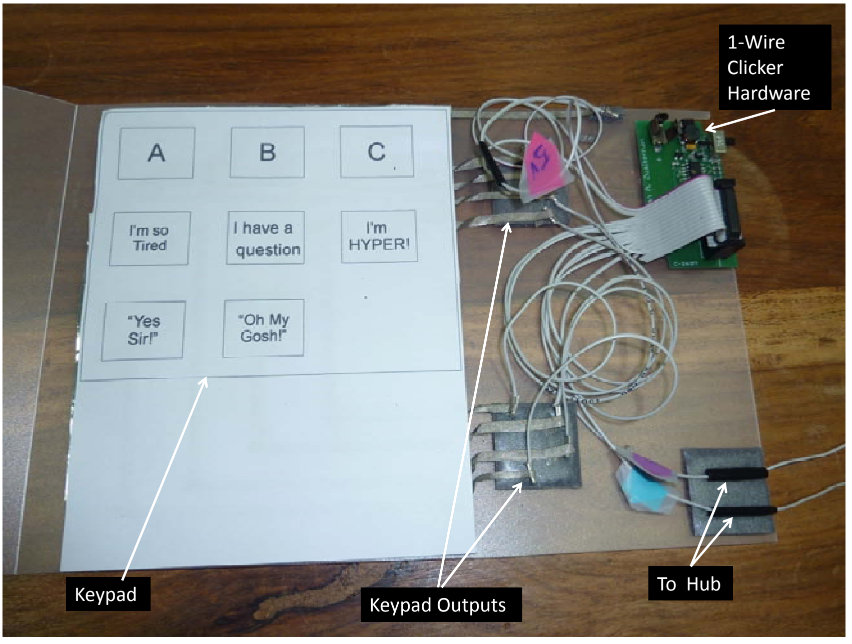

Fig. 6. A homemade keypad for the 1-Wire clicker

4.2 Usage Scenario

Fig. 7 shows a complete scenario for using the 1-Wire clickers. As Fig. 7 (a) shows, a school administrator using a PC and an attached (Simple Messaging Service) SMS modem can broadcast a question or a set of questions to various remote schools. These questions can, for example, be hosted on a learning management system (LMS) and grouped according to the curriculum of a particular grade. As Figure 7 (b) shows, each question is transmitted to various remote schools using the publically available mobile infrastructure. Upon reception, each teacher in the remote school verbally asks the questions of their students or writes down the question on a blackboard (if available). In response, each student uses the keypad of a 1-Wire end-device to answer the questions. These answers are transmitted to teacher's mobile phone using the Bluetooth wireless technology. The teacher's mobile phone displays the results using a simple J2ME or a similar application. Not only does the teacher get an immediate response, but the student's responses are also instantly transferred to the administrator's computers via SMS. These answers can be saved to create daily or weekly reports on the performance of pupils in each class in each remote school.

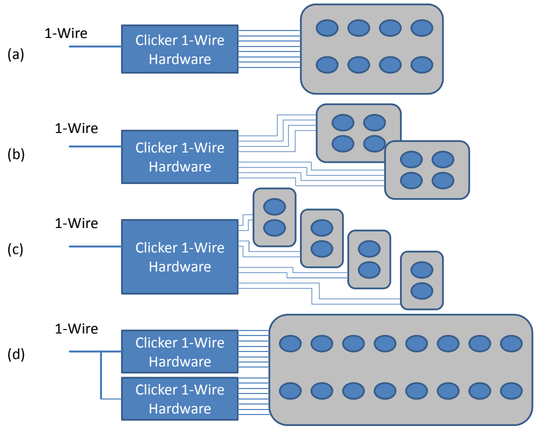

Fig. 6. Various configurations for the 1-Wire clicker end-device

As Fig. 7 (c) shows, the use of 1-Wire clickers does not assume the availability of extensive infrastructure like a physical building or even electricity. Portable versions of the clicker systems can be built and "rolled out" in the field. Clearly, each teacher is also free to formulate and ask their own questions and to collect immediate responses from students. The system also allows for implementation of unique gaming scenarios where, for example, students from one school can pose questions for students in another school. The questions from a classroom in one school are transmitted via SMS to the teacher in the other school who asks the question to their students and their responses are collected and sent back. This allows for the implementation of unique school to school peer-learning pedagogical scenarios.

4.3 Evaluation

Cost is an important, but not the only factor in determining future classroom modalities for the developing world. In addition to cost, various other factors like sustainability also play a key role. Table 1 shows a comparison between the CRS proposed in this paper and traditional commercial CRS available in the market today. As Table 1 shows, the proposed system is clearly much cheaper when compared with the currently available clickers; $30 per end-device versus $5 per end-device, for example. In specific, the proposed system also obviates the need for a PC required to record the

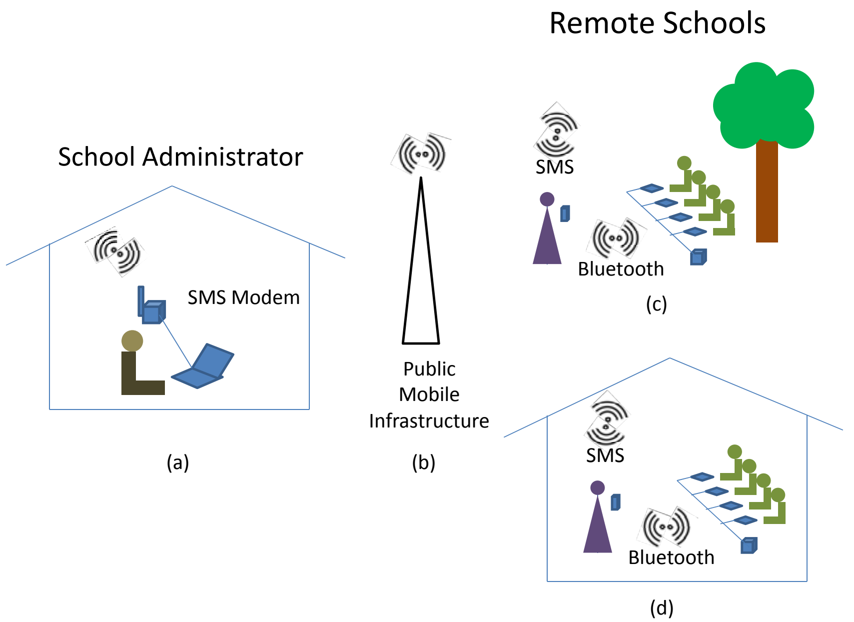

Fig. 7. Usage scenarios for the 1-Wire clicker

results of a CRS. In addition, the proposed CRS is designed to not require the availability of elaborate physical infrastructure (e.g., a physical classroom) or electricity. Rather than using proprietary technology, whose maintenance is tied to expensive maintenance contracts, the proposed CRS also relies on locally repairable hardware and software. It is also expected that teacher adoption of such a system will be higher because of its simplicity, and because in many instances, teachers in developing countries are afraid to use a learning technology because they are afraid that if they break it, then they may have to pay for it. One important component of the proposed CRS is the real-time connection to school administrators. This is particularly important because teachers are not always well-trained in the developing world. This real-time connectivity allows school administrators to easily monitor the performance of pupils and teachers in remote schools even on a daily basis. Finally, the mobility of the proposed CRS is much higher compared to a conventional CRS because the 1-Wire devices can be moved much more easily than a PC in a classroom.

5 Conclusion

Prevailing conditions in developing world create unique affordances for design and deployment of learning technologies. Consequently, a sustainable future classroom in the developing world will perhaps be very different from its developed world counterparts. This paper has presented the design and implementation of a CRS specifically designed by taking into account the various constraints of the developing world. Clearly, such a CRS is one small component of the future classroom in the developing world, and needs to be tested in real-life scenarios with appropriate pedagogical support. However, it is hoped that introduction of such solutions starts an informed discussion on other aspects of future classrooms for the developing world that looks beyond the obvious trend of dedicating valuable and scarce resources to build physical school buildings, or indeed even computer laboratories, that are often abandoned or not used because of unavailability of appropriate infrastructure and well-trained teachers in the developing world.

Table 1. A comparison of 1-Wire CRS with conventional clickers

Criterion	Traditional Clickers	1-Wire CRS
Cost per child	High	Low
Cost per teacher	Expensive, PC is required	Uses a low-cost mobile phone already owned by most teachers
Infrastructure needs	Requires electricity or expensive uninterrupted power supply to run the PC	Runs on locally available batteries
Maintainability	High cost	Low cost - Locally maintainable
Local manufacturing	No – Typically Based on proprietary technology	Yes – Simple open source design can be manufactured locally in most developing countries
Technology	Proprietary	Open-source
Teacher adoption	Potentially lower because teachers may not use for “fear or breaking”	Potentially high because teacher is using their own mobile phone
Real-time connectivity to school administration	Expensive - Will require a GSM/GPRS modem for each PC of the teacher	Inexpensive – Can use SMS or GPRS readily available on the phone
Mobility	Low – because the PC needs to be moved	High – only need to move the 1-Wire end-devices and HUB

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