I-Slate, Ethnomathematics and Rural Education

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Abstract— **The crosscutting project described here based on the revolutionary concept of Probabilistic design [17] and of Ethnomathematics [13] aims to improve literacy in developing countries and regions, with an emphasis on India as the first test focussing on grades 1-5. Driving the I-Slate design are the pioneering principles trading off probability for energy, while educational pedagogy and practice drive the software design. Energy and concomitant environmental sustainability are the overarching themes that encompass all aspects of this effort.**

Keywords— **Ethnomathematics, education, low power, probabilistic design.**

I. Introduction

In the recent years, there has been an increasing awareness of the need for education in most of the developing countries. But lack of sufficient resources is severely impeding the success of this mission. As a context, in India there are approximately 104 million students in grades 1-5 who *do not have access to electricity* and about half a million primary schools, each with less than three teachers [21]. Also, the average per capita income of the families of the students attending these schools is less than $500 (USD) per year, making it difficult for them to afford costly educational devices or even the necessary text books.

To respond to this challenge, we propose an interactive and intelligent I-Slate that on one hand is very energy friendly, while enabling support for education in developing economies on the other. The design of the I-Slate will be based in part on the novel concept of probabilistic design and PCMOS, and its associated notion of approximate arithmetic, which was ranked by Technology Review (published by MIT) as one of the "10 technologies that we think are most likely to change the way we live" [17]. The I-Slate will be used as a basis for interactive classroom education. The I-Slate innovation and concept was first publicly unveiled at the IEEE 125th Anniversary "Engineering the Future" roundtable event [22].

While technology can be viewed as helping ameliorate this problem, environmental concerns may arise when proposing new uses. Already, global energy consumption is projected to increase by about 50% from 2005 to 2030 attributed to developing countries which use fossil fuels for generating electricity [20]. Also, the world carbon dioxide emissions are expected to increase to 43 billion metric tonnes by 2030 – an increase of about 50% from 2005 [20]. In addition, in the past century, the earth's climate has warmed between 0.6 - 0.9 degrees and, by some estimates, is to increase by 2 degrees in this century [19].

Focusing on the electronics, results by analyst Gartner in 2007 show that Information and Communication Techology (ICT) is responsible for 2% of global carbon emissions [18]. Now, if similar trends continue in the future, then the ICT sector could be responsible for 5-8% of the global carbon emissions [24], which is significant enough to necessitate an environmentally friendly ICT industry. The I-Slate is a novel innovation to help solve the educational needs of developing countries while not elevating the problem of already increasing the carbon footprint.

An I-Slate will consist of a frame that surrounds an interactive screen with one or more partitions. The user can interact with the I-Slate through a stylus or similar device by touching the screen. Elements of the objects being displayed can be dragged, and the spatial context can determine whether a certain dragging and association is correct or incorrect. A concept diagram of the envisioned I-Slate is shown in Figure 1.

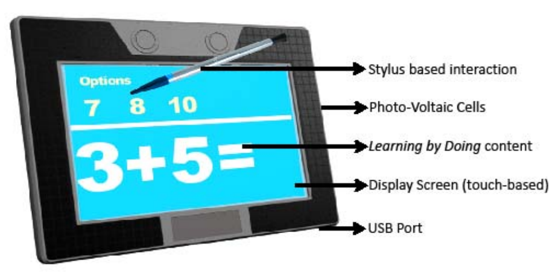

Fig. 1 An envisioned picture of the I-Slate

As shown in Figure 2, the worldwide group involved in this project spans multiple universities and countries. IIIT Hyderabad provides the pedagogy and content. The VISEN center at Rice is leading the core technology, with graphics and related architecture expertise coming from Caltech. ViDAL, a nonprofit organization in Hyderabad, will provide educational delivery to remote villages. The Institute for Sustainable Nanoelectronics (ISNE) at NTU in Singapore will provide integration and electronics prototyping.

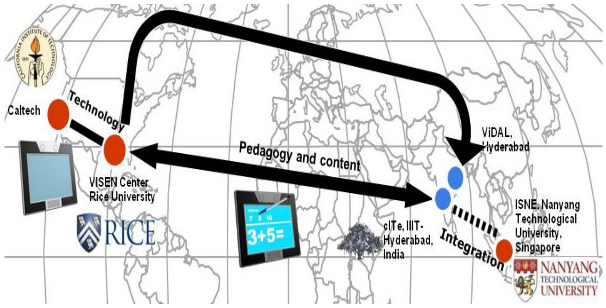

Fig. 2 The worldwide group and the interaction model

A. *Probabilistic/Approximate Design for Ultra-Low Energy Computing*

The miniaturization of computing devices through technology scaling referred to as Moore's Law [1] is posing a serious hindrance to reliable computing with hurdles including thermal noise, parametric variations and other device perturbations [2], [3], [4]. The conventional method for increasing reliability through redundancy results in an increased component count and, hence, the energy consumption for the same amount of information computed [5]. Thus, traditional approaches aimed at solving one of the (twin) hurdles of unreliable computing and high energy consumption tend to come at the expense of our ability to solve the other.

However, using an approach pioneered by Palem [23], George et. al. [6] showed that the domain of electronics dealing with multimedia audio and video signal processing, *error can be tolerated* in the datapath of the hardware engine, while gleaning energy savings. The reason this is possible is because "quality" of these electronics is determined by human perception, which can interpret useful information from erroneous data. This leads to a new design methodology in which the computations are not deterministic but are probabilistic (correct only with a certain probability) or approximately correct [7]. Thus, rather than being an impediment, error quantified probabilistically has been shown to be a resource that can be traded during the design of the hardware, in return for energy savings.

Building on this idea and in a radical departure from this universally accepted approach, it was shown by Chakrapani et al. in [7] that potentially useful computation can be realized even when the associated circuits are operating at frequencies that violate the critical path imposed delays. Using novel mathematical abstractions and models, they show that circuit designs realizing a form of approximate arithmetic afford energy and speed advantages over designs that adhere to the hitherto canonical approach of always respecting the critical path delay. In contrast and in conventional digital circuit design, the critical path and its associated delay play a critical role in that the circuit is not operated at a speed (or clock frequency) that violates this delay.

B. *Other Solutions and Relationship*

Several projects have been initiated in the past targeting the education in developing countries such as the widely known One Laptop Per Child (OLPC) and Intel's Classmate PC to name a few. Even with these proposals, the following challenges and impediments remain: non-affordable costs and lack of 'educational guidance' to students from these laptops. Also, lack of electricity remains a very serious impediment. In contrast, the I-Slate is intended to overcome these impediments.

II. The I-Slate Architecture

A. *An Approximate Graphics Controller*

In the quest for an ultra low power architecture, we have designed the I-Slate to be minimal in its hardware complexity and have removed the necessity of many energy-intensive components. In a conventional architecture, generation of a display usually consists of two processes. The first process called *rendering* draws images into display memory typically requiring high performance graphics processors, thereby causing this step to be highly energy intensive. The second process moves the image from the display memory to the display device, and is not an energy intensive process. In the proposed I-Slate, we completely avoid the computationally intensive rendering process, thereby eliminating the need for a processor. Hence, the envisioned I-Slate will not have any processor, and I-Slate's operation will be completely controlled by a graphics controller which can be regarded as the "brain" of the I-Slate.

The architecture of the controller in the proposed I-Slate and the controller's interface with the other components is shown in Figure 3. The content is completely developed off-line using a fixed computer, and stored as individual screenshots. After development, the content is transferred to a USB device which can be carried to remote sites (e.g., rural schools). The content will then be copied from the USB device into the main memory of the I-Slate. The controller will transfer the required screenshots into the frame buffer memory; the screenshots are displayed on the LCD panel and can be interactively controlled by input from the user. In short, the controller of the I-Slate will be a primitive logic structure whose functionality is to transfer the pedagogical content from a USB drive onto the screen *without* involving graphics computations.

In order to further reduce the power consumption of the I-Slate, some other techniques well known in the literature such as frame buffer compression, dynamic backlight control, lower display refresh rate switching and others are envisioned to be implemented.

B. *Putting it all Together and the I-Slate Hardware Architecture*

While significant effort will be spent on designing the most critical component of the I-Slate – the controller – the other components which are necessary to construct the slate will be based on off-the-shelf designs with appropriate modifications to fit the I-Slate design objectives. A brief description of the other envisioned components of the I-slate such as the display screen, USB, solar cells and chassis is given below.

1) *Display:* The display will be the most expensive component in an I-Slate and the most energy intensive component as well. Taking into consideration the energy consumption and the size of a normal slate, the proposed I-Slate will have a 7-8" display screen with integrated touch screen functionality. The display screens from Pixel Qi will be our primary candidates as they are claimed to consume about half to a quarter of the amount of energy of current displays present in the market.

2) *USB:* The I-Slate will receive the content through a USB device of size up to a few hundred Megabytes. Each USB will consist of content related to a specific topic. When the USB will be plugged into the I-Slate, the whole content will be transferred into the main memory of the slate by the USB controller. This minimizes the total cost by enabling the sharing of the USBs between different slates.

3) *Solar Cells:* By being ultra-low energy and by being based on probabilistic and approximate hardware design, one significant aspect of this invention is the ability to operate it using solar energy exclusively; a photo-voltaic device or battery using solar energy can be used to provide energy to an I-slate.

4) *Chassis:* The I-Slate chassis will be built of light and durable material. It will be designed with the real world in mind, including extreme environmental conditions such as high heat and humidity. Also, special care would be taken to make it appealing to the young students in grades 1-5.

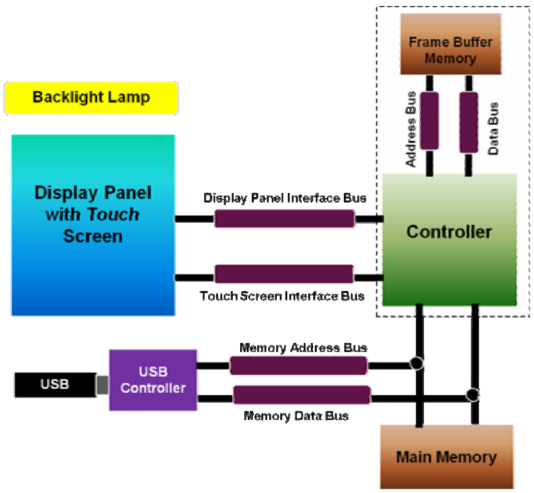

Fig. 3 The proposed architecture of the I-Slate

III. Learning by Doing and Ethnomathematics

A. *Learning By Doing - Constructing Knowledge*

Education serves its purpose only when it enables students to transfer the knowledge they acquire in classroom to real world problems. Unfortunately, in our current educational system many students acquire only inert knowledge [8]. This knowledge helps them pass examinations but does not give them the conceptual understanding of subject matter. One of the most important questions in educational research is how to ensure that students learn with understanding.

The constructivist philosophy [9] of cognitive learning and development contends that children create their own knowledge. They experiment and explore the world around them and in this process form hypothesis, acquire information and refine their ideas. This is how knowledge is constructed – by active participation and not by passive listening. It follows that for students to gain deeper knowledge they should be given opportunities where they can experiment and hence construct knowledge. This leads us to the premises of learning by doing.

The problem of inert knowledge acquisition affects mathematics most. Students view mathematics as a set of procedures to be applied on a set of symbols and hence fail to acquire its real value. In our work, we wanted to develop an alternate method of teaching mathematics so that students could appreciate the subject more and relate it to real life. This method should also resonate with the constructivist philosophy, enhance their creativity and make the whole learning process enjoyable. This led us to choosing *ethnomathematics* as the pedagogy.

B. *Learning By Doing - Constructing Knowledge*

Ethnomathematics [13] is the study of mathematics that is present in various cultures around the world. Researchers have discovered that there are many mathematical concepts that go into the cultural forms of an ethnic group such as its architecture, arts, crafts and jewels. For example one can find Graph theory in Indian Kolams [10], fractals in African Settlements [11] and tessellations in Native American patterns [12].

The use of ethnomathematics to teach mathematics in schools has been motivated by the following ideas [14]:

a) a lot of mathematics has originated in Africa and Asia,

b) students should realize that mathematics arises out of real needs and interests,

c) a multicultural and interdisciplinary approach to mathematics education can be pedagogically beneficial, and

d) students from different backgrounds should take pride in the achievements of their people.

The idea of using Ethnomathematics to teach mathematical concepts is being successfully carried out in Africa through the Africa meets Africa project [11]. They use works of arts and craft of Zulu culture to teach mathematics.

Paralleling this, our goal is to explore the possibility of teaching difficult mathematical concepts based on mathematical ideas imbibed in Indian culture. Children would be given activities in which they would make some jewel or craft. Then they would explain the mathematical concept behind it. This approach to teaching mathematics has the advantage that children relate mathematics to the world around them, rather than just learning and repeating a procedure.

C. *Need for Technology*

While the culture-based approach to teach mathematics is an effective one, there are some practical challenges with incorporating the idea in the classroom. The lack of structure in the process is a first challenge. Supervision and correction is required when children make jewels or crafts. Given a problem, children can come up with multiple patterns. While this is attractive as it encourages creativity, validating every pattern and making explicit the underlying mathematical concept becomes a demanding task for the teacher. The resource requirement is the next challenge. A set of materials needs to be provided to every child to make the craft. The teacher may have to create new set of materials every time the activity is to be repeated.

Keeping this in mind, we have created a software tool, which would allow the students to make patterns, automatically validate them and explain the underlying mathematics. This tool will be used to create content which can be manipulated through the touchscreen display of the I-Slate, permitting a student to create these patterns via touch, just as they would draw/write on a 7-8" slate that is widely used in schools in India. Thus, an electronic version of the slate, the "I-Slate," should be easy to use and appealing to students.

D. *Teaching Fractions using Ethnomathematics*

Currently we have developed a set of activities to teach fractions using ethnomathematics. The concept of fractions was chosen because it is considered to be the most complex mathematical concept encountered by a child in the primary school years [15].

The first activity requires the child to make a bead necklace locally known as 'mala' – a popular jewel in many subcultures (e.g. Lambada, gypsies). The next activity requires the tiling of an area using different motifs. Some rules are given to the children when they perform these activities. This ensures that the activity is structured. It is always ensured that there are multiple solutions given the set of rules so that the children appreciate that there is always more than one solution to a problem in a real-world setting.

The child is given a toolbox with beads of four different colours or tiles of four different patterns. Once the activity is completed, the child is asked to report the number of beads or tiles of each type they used, to complete the activity. Then they are shown that when they say, 'I used 4 red coloured beads in my mala of 10 beads,' they are actually using the concept of fractions, where fractions quantify a larger quantity divided into parts.

The above tool has been evaluated by a group of children who have not been introduced to fractions as a part of their curriculum. This early evaluation testing has shown encouraging results, and we plan to expand this idea to teach more concepts using the I-Slate.

IV. VIDAL

Villages in Development and Learning Foundation (ViDAL) is a not for profit organisation that works for the cause of rural development. The primary approach ViDAL uses include innovation, incubation and access to knowledge for transforming villages, thus enabling rural wealth creation. Rural development through technology use – the I-Slate based ethnomathematics pedagogy in our case – in a country like India requires cutting across three key barriers, "3 I's" – namely, investment, infrastructure and illiteracy. ViDAL's award winning project "Computers on Wheels" (COW) for people-centered development [16] is designed using the same principles. COW uses innovative mobile technologies in remote tribal habitations and villages to take education, health and agricultural support information services to their doorstep.

Education and health services developed as a part of the COW program have been found to be successful due to their usefulness, and the project's ability to match the user's perceptions in a culturally aligned way. Experience with the COW project led to an understanding of the cultural fabric of people across social and tribal configurations.

In rural India, ViDAL is the grass roots partner for the I-Slate project and proposes to put the gadget to use across regions and tribal habitations for creating culturally sensitive mechanisms for learning and creating skills and knowledge. This in turn, enables the students to harness sustainable means to livelihoods for themselves and their families.

V. Conclusion

In conclusion, we have described the concept and vision for a new approach to providing technology and pedagogy to assist in rural education. We are optimistic that the I-Slate project will enable a generation of future learners as well as teachers.

VI. Acknowledgement

Krishna Palem would like to thank Professor Raj Reddy for discussion outlining the value of the learning-by-doing philosophy and its use in the rural AP-IIIT program in Andhra Pradesh, India, that he pioneered. This conversation prompted Palem to conceive the I-Slate concept based on probabilistic design with its socio-economic implications and to assemble a world-wide team of experts to contribute to the technical design of the I-Slate and its pedagogical content. Jayanthi Sivaswamy is championing the approach using Ethnomathematics in this context and wishes to acknowledge S. Sathya who developed the prototype of the Ethnomathematics software tool. We would also like to acknowledge two IIIT-Hyderabad students, Sumit Raj and Rishabh Ranjan, who put together a prototype I-Slate at NTU in the summer of 2009.

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