I-Slate, Ethnomathematics and Rural Education

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Abstract— **The project described here based on the revolutionary concept of probabilistic hardware design [17] and of Ethnomathematics [13] aims to improve literacy in developing countries - with an emphasis on India as the first test, focusing on grades 1-5. The pioneering principle of trading accuracy of electronics for energy is at the heart of probabilistic hardware design and drives the design of I-Slate's hardware architecture, 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 recent years, there has been an increasing awareness of the value and importance of education in developing countries. However, 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 of which has 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 and the related educational concepts were 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 significantly to developing countries [20]. As a result, carbon dioxide emissions are expected to increase to 43 billion metric tonnes by 2030 – an increase of about 50% from 2005 [20]. Influenced by these factors, 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 component of this influenced by electronics, results by analyst Gartner in 2007 show that Information and Communication Technology (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 exacerbating the problem of an already increasing 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 dropped, 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.

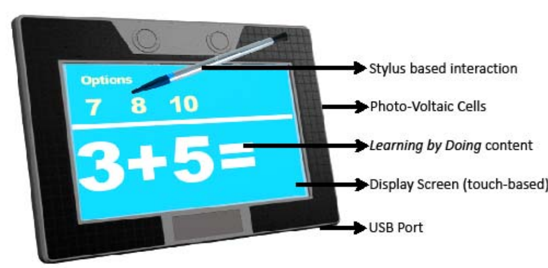

Fig. 1 An envisioned picture of the I-Slate

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

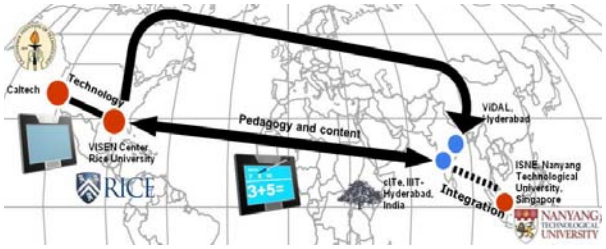

Fig. 2 The worldwide group and the interaction model

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, increased 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 in 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 the "quality" of data being computed by these electronic components is determined by human perception, which can interpret useful information from "noisy" or erroneous data. This has lead to a new design methodology in which the computations are not deterministic but are probabilistic (correct only with a certain probability) or are 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 standard practice, it was shown by Chakrapani et al. in [7] that potentially useful computations 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: unaffordable costs and lack of 'educational guidance' to students from these laptops due to a shortage of qualified teachers. Also, lack of electricity remains a very serious impediment. The I-Slate is intended to overcome all of these impediments.

II. Architecture of the I-Slate

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 without depending on many energy-intensive components. To elaborate, in a conventional architecture, generation of a display usually consists of two processes. The first process called *rendering* creates images in display memory typically requiring high performance graphics processors, thereby causing this step to be energy intensive. The second process moves the image from the display memory to the display device and is not as energy intensive. 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 the 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 using an off-line computer and is stored as individual screenshots. After development, the content is transferred to a storage device (e.g., USB) which can be carried to remote sites (namely, rural schools). The content will then be copied from the storage device into the main memory of the I-Slate.

Following this, the controller will be used to 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 simple logic structure whose functionality supports the transfer of pedagogical content from storage (memory) onto the screen *without* involving (energy) expensive 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 hardware 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 these "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 likely 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 hundreds of Megabytes. Each USB will consist of content related to a specific topic to be taught. When the USB will be plugged into the I-Slate, the whole content or topic to be taught will be transferred into the main memory of the slate by the USB controller. This minimizes the total

monetary cost by enabling the sharing of the USBs between different slates. We note that monetary cost is a significant constraint in this environment.

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 the ability to tolerate extreme environmental conditions such as high heat and humidity. Also, special care would be taken to make it appealing to young students in grades 1-5.

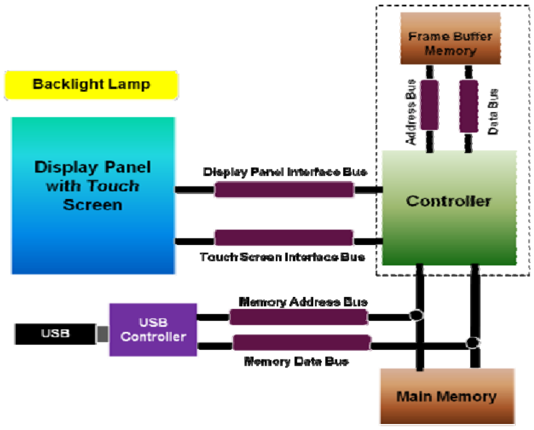

Fig. 3 The proposed architecture of the I-Slate

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 in an examination scenario but does not give them the conceptual understanding of the subject. One of the most important challenges in educational research is the ability to ensure that students learn with understanding.

In contrast, 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 hypotheses, 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 principle of *learning by doing* [25].

This problem of inert knowledge acquisition affects mathematics in particular. 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* [13] as our vehicle for pedagogy.

B. Learning By Doing - Constructing Knowledge

Ethnomathematics 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 the roots of early mathematics are 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 take pride in the achievements of their people and motivates learning.

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 from Zulu culture to teach mathematics.

Paralleling this, our goal is to explore the possibility of teaching elementary yet difficult mathematical concepts based on mathematical ideas intrinsic to 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 teaching mathematics is an effective one, there are some practical challenges with implementing this idea in the classroom. The lack of structure in the process is a first challenge. Mathematically inspired supervision and correction is required when children make jewels or crafts. For example, given a problem, children can come up with multiple patterns. While this is attractive as it encourages creativity, validating every pattern and making the underlying mathematical concept explicit becomes a demanding task for the teacher. The resource requirement is the next challenge. Physical materials need to be provided to every child to apply the craft. The teacher may have to create new sets of materials every time the activity is to be repeated.

Keeping this in mind, the I-Slate will allow the students to make patterns, automatically validate them and explain the underlying mathematics. Furthermore, our resources are virtual and provided as graphical images. Specifically, the ethnomathematics create content 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. We anticipate that 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 a 'mala' – a popular jewel in many subcultures (e.g., Lambada, gypsies in southern India). 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 this and similar concepts using the I-Slate.

IV. ViDAL

Villages in Development and Learning Foundation (ViDAL) is a non-profit organisation that works to promote rural development. The primary approaches 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, or the "3 I's" – *investment*, *infrastructure* and *illiteracy*. ViDAL's award winning project *Computers on Wheels* (COW) for people-centered development [16] is designed to overcome these barriers. 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 manner. 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 and livelihood.

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 leading eventually to improved livelihood and health through literacy. 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 a discussion outlining the value of the learning-by-doing philosophy and its use in the rural *Rajiv Gandhi University of Knowledge Technologies* 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 enable 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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