SESIM: Linking science and mathematics education to students' reality[1]

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Introduction

Current levels of achievement in science and mathematics in Timor-Leste are extremely low due to various challenges. For four years the Center for the Study of Science and Mathematics, SESIM, has been developing practical teaching activities for science and mathematics at all levels. These activities are created with the goal of supplementing and enriching existing curriculum, and require very few specialty materials beyond what is available in homes and nature. The activities are linked tightly to both the official curriculum and the experience of students and their communities, and whenever possible make use of elements of local culture. By making these links, many educational advantages may be gained, including higher levels of interest, higher levels of achievement, better understanding of the uses of science and mathematics, and increased respect by students for their culture. Currently SESIM is carrying out widespread trainings and gathering data on the effectiveness of this pedagogy.

Today in Timor-Leste many under-qualified teachers continue to teach. Teachers and most current education leaders possess limited experience in education leadership, professional development, and administration (Timor-Leste Ministry of Education 2010). Timor-Leste's population is rising quickly, which puts additional pressure on its education system (Saikia et al 2011).

Despite the lack of sufficient preparation by most science and mathematics teachers, nearly all of them will report the absolute necessity of teaching with "pratika," that is, hands-on methods allowing personal exploration, observation and discovery. In the same breath, they'll confess their inability to carry out this sort of instruction due to a long list of challenges: lack of laboratory or materials, lack of training, lack of time in the curriculum, and lack of support from administrators, among others. The author has encountered few science and mathematics teachers who do any sort of "pratika" on a regular basis.

In addition, often after teachers have been presented with training and teaching materials to facilitate teaching with "pratika," they'll return and carry out a related teaching activity, but fall back on familiar lecture-and-listen techniques and fail to offer the key elements of the instructional experience to their students, for example, waving a single demonstration in front of the class instead of setting up each group to be personally involved. This lack of understanding or ownership of a new pedagogy, even when "mandated" by the Ministry, and carrying forth the symbols of the technique without the substance, is a broader problem seen in various areas of education in Timor-Leste (Shah 2011; Quinn & Shah 2013).

How does a country create a strong, coherent national science and mathematics curriculum and teacher development program and continue to grow its educational capacity in this area, given limited resources, expertise, and infrastructure? It is in this broader political, cultural, geographic context that the first set of learning prototypes, science teaching resources, and instructional design principles were developed.

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Framework and design principles for educational development

In 2009, around sixty local students from the national university, eight teachers and the author, an international consultant and science educator, created a multimedia Encyclopaedia of 83 science and mathematics topics from the daily life and experience of the Timorese. This multimedia Encyclopaedia included reference information (e.g., activity instructions, background science, explanations) and short videos of simple hands-on activities that teachers could carry out in schools using locally found materials to illuminate these topics. For example, marbles are an ever-present artefact used to play different games among children in Timor. One teaching video shows two teachers carrying out a simple energy and momentum experiment by dropping various marbles and measuring the rebound height with a meter stick placed against the classroom wall. This simple quantitative physics experiment helped to make visible the physics behind the game.

Taken as a whole, the Encyclopaedia was designed to provide a starting point for the development of new curricula as well as serve as a teacher's reference resource. The Encyclopaedia served also as a tool for teacher development through a process of participatory design (Schuler & Namioka, 1993). Different stakeholders create together to ensure the work results in a usable end product that is responsive to cultural, emotional, and practical needs. Viewed from a learning and development perspective, the multimedia Encyclopaedia provided a shared focal point and a jointly created artefact to support collaborative knowledge building among members to build a learning community[4]. Knowledge building draws on the collective intelligence of a group engaged in investigating, theorizing, critiquing, making, reflecting, and revising in order to progressively advance a community's shared theories, knowledge, and practices (Scardalalia & Bereiter 1994). Using this design partnership approach to curriculum development, the teachers were more likely to both give recognition and take ownership (and pride) in the lessons developed in the resulting knowledge resource.

As the lead science educator, the author took the role of a facilitator to model the process of inventing activities and bring focus to local topics with high potential for the Encyclopaedia. While he did most of the writing for the Encyclopaedia, the students themselves conceived, developed and tested the activities. The Timorese teachers edited both the content and presentation of materials. The result has been quite popular, with a vast majority of positive evaluations for all trainings carried out using the Encyclopaedia as a resource.

A common tendency when creating national educational resources is to assume a deficit model and consequently impose fully published science and math curricula from another nation that has been found to promote achievement. Here, intellectual resources viewed as "funds of knowledge" (Moll & González, 2004) from the Timorese were used to promote learning and engagement. The collective Timorese experience served as the context for generating the activities in the Encyclopaedia. The Timorese brought knowledge from their craft skills, common observation of earth and life systems, and every-day practices centred on work and the improvement of life through greater understanding of the world around themselves.

Common questions were often related to engineering a design that required learning and applying knowledge of mathematics and science to solve community-oriented and culturally relevant problems. The driving questions were timeless ones from real life, such as, "How can we farm more productively?", "How can I make a traditional gun to shoot birds more effectively?", "How might we weave a beautiful new rice dumpling katupa for the feast?", and "How can my family make a house using the materials that we already have here?" The contents of the Encyclopaedia are based on these kinds of questions as well as the philosophy that people from any locale learn and do, and have done science and mathematics naturally through their own experiences since time immemorial (George and Lubben 2002).

[4] While not a curriculum per se, the Encyclopaedia was distributed to Timor's teachers, and in the following year, SESIM provided training for a group of pre-secondary and secondary teachers on how to use the Encyclopaedia to teach experiential, locally based lessons.

Scientific inquiry skills may serve as a useful instructional tool for formal science education to pose investigable questions, propose multiple alternative explanations, and collect data to verify and support one's conclusions (NSF 1999). In contrast to using magic or religion, science and mathematical reasoning through a process of guided inquiry often leads Timorese to useful effective, repeatable results. This kind of reasoning can be readily found in the development of traditional agriculture techniques, architecture, hunting and fishing methods, and the making of many indigenous health remedies. Thus, when students can be led down the same paths their ancestors trod to discover for themselves how their world works, the result is a powerfully motivating and engaging set of activities that can be included in a national curriculum. This stance on science learning is consistent with learning and development viewed as cultural processes that embrace and use community-derived knowledge as an asset to learning academic science content (Bang & Medin 2010; Nasir et al. 2006; Rogoff 2003).

During the process of creating this Encyclopaedia, the teachers formalized their meetings to form a group called SESIM, an acronym from Tetum, Timor's lingua franca, for "Centre for the Study of Science and Mathematics." SESIM's mission is to promote and improve science and mathematics education in Timor. Since the launch of the Encyclopaedia in late 2009, SESIM has continued to develop and write new topics for a second volume, while carrying out periodic trainings of teachers and students, and attempting to find an institutional home for itself within Timor's educational establishment. Trainings have received overwhelmingly positive feedback from teacher participants; a common response is that never have they participated in such relevant and useful training, and that they want it continued (SESIM 2010 – 2013).

Example activities

In the table below, three activities from the Encyclopaedia are details, showing how the core principles are articulated within each topic and how they were derived from the key design principles: locally rooted, experiential, and locally sustainable. These three principles illustrate how a community-designed curriculum approach can produce both robust curricula and culturally relevant learning environments for both learners and teachers.

Activity Name	**Description**	**Materials Used**	**Disciplines + Topics, Big Ideas**	**Principle #1 Locally Rooted**	**Principle #2 Experiential**	**Principle #3 Locally Sustainable**
Chicken foot and **Arm model**	A chicken's foot is dissected; muscles, bones, ligaments and tendons are identified and explored. An anatomically correct model of the human arm is built.	Chicken feet, razor blades, kabob sticks, rubber bands, string and tape	**Biology**: anatomy, kinesiology, structure and function of muscles, bones, joints **Physics**: force and motion, simple machines, levers	Most Timorese own chickens, familiar with body structure. Feet are easily accessible, as are materials for constructing model.	Each small group will touch the chicken foot, pull on the tendon, witness the resulting movement. Each will construct a model that behaves like their own arm, then examine their arm.	Activity is easily possible for every student in Timor. Extremely low cost.
Basketry with rhombus weave	Various types of baskets that employ the 60º/30º rhombus weave are analyzed. Simple	Common baskets from students' homes, pencils, palm leaves	**Mathematics**: geometry, angles, shapes, patterns, transformations, area and volume, factors and	All families in Timor have and use these baskets on a daily basis. Most families have members that can weave	Baskets are in hands being scrutinized for mathematics. Each student personally uncovers submerged	Basket materials are available for free from the jungle; students can each bring baskets to

	versions are weaved.		factorization, size and scale	them, most often women elders, usually without formal education.	mathematical concepts with guidance by teacher. Many major concepts from canon are discovered, observed.	school for analysis. Ongoing investigation is easily facilitated.
Leaf tensile testing	Four types of palm leaves are tested for tensile strength using simple gravitational arrangement.	Palm leaves, cargo basket from students' homes, water bottles, rocks,	**Engineering and Physics**: data taking, data analysis force, gravity, tension, density, weight and mass, **Biology**: structure of plants and plant tissue, cells, moisture content,	Name of one of these palms is synonymous with "string;" its leaves are routinely used for tying things such as animals and roofing. The strength of this palm leaf is well-known, so to make a methodical test to compare the strength of the others is illuminating.	"Common knowledge" (hypothesis) is put to the test with the scientific method in front of all to witness. Hard data is taken in the course of a legitimate, student-conducted experiment.	Lab activity is completely cost free. No special, foreign materials are necessary. Even weight can be calculated by measuring volume of water if a scale is not available.

Pedagogical design principles

The three example activities presented here from the Encyclopaedia embody key design principles that the SESIM partnership used to teach science and mathematics concepts grounded in local traditions, familiar objects, and everyday inquiry practices resulting in the development of rich science and mathematics curricular materials especially rooted in non-Western traditions. These principles also inform SESIM's other activities, such as teacher development and teacher mentoring. Here they are explained in detail:

Design Principle #1: Content, examples and activities must be locally rooted

In a community that continues to strive to feed and rebuild itself, students and their families can be understood to have little patience for learning abstractions, theories, and "inert knowledge" (Whitehead 1929). The concepts focused upon in instruction needed to be both pertinent and relevant to life in Timor, socially, culturally and economically. The concepts we chose for elaboration are based on Timorese experiences, daily, common practices and objects such as those found in cooking or toys or special noteworthy events (e.g., lightning, drought, and earthquakes). All scientific phenomena that can actually be observed at school or in the immediate surroundings of the school are given priority since teachers can accompany students in the process of inquiry. Scientific inquiry is offered as an addition to a repertoire of approaches to understand and explain one's surroundings with care not to discredit existing tools or ways of knowing. In this way, students can then begin to find value in scientific inquiry, which is important for longer-term engagement in science and mathematics.

The design principle of being locally rooted also refers to collective knowledge held by the elders in the community who possess culturally relevant knowledge and practices from their ancestors. Concepts of science and mathematics found within traditional activities or artefacts are given great value at the same time respect and recognition is given to elders and ancestors. Unlike Western science teaching standards in industrialized nations that are more top-down, requiring instruction to cover topics and standards established by states, these curriculum elements are being derived from the ground up, using local examples, materials, and practices to teach key scientific concepts and ideas found in the disciplines. In this approach, similar to the practices followed in the African Primary School Program, teachers learn by doing while taking ownership and pride over the activities and curricula. Individual teachers direct the design, fitting, and adaptation of activities for local circumstances (Carlisle 1973; Duckworth 1978).

Design Principle #2: Content must be presented in an experiential and observable manner

Learning from direct experiences is important to allow students to witness, observe and describe concepts based on their own interactions and firsthand knowledge of a shared experience with others in the community. This is especially important when designing activities for groups that possess inaccurate conceptions of science including ancestral or indigenous beliefs such as explanations for what causes illnesses, rainbows and changes in weather. Thus, teaching, discussion and concepts to be learned are grounded and based on observable phenomena or linked to real examples common to students. This will help bridge the worldview of students to that of Western science (see Bang & Medin, 2010), and allow access to the knowledge and techniques of science by constructivist means. Students' questions, sometimes around existing beliefs, are given recognition in discussion, recorded and addressed to the extent possible, even if no satisfying answer can be achieved. The teacher conveys no information verbally if students can make the discovery personally. Complete honesty is the rule in discussing what can and can't be observed or proved, and what information needs to be taken on faith from the textbook. Students use authentic scientific methods in investigating phenomena whenever possible.

Design Principle #3: Curricula, teaching techniques, training plans, and teaching materials must all be made locally accessible and sustainable for the long-term future

To avoid the waste of developing a curriculum that is out of reach, inappropriate, or irrelevant to the local community, the third design principle espouses the idea that all instructional frameworks and materials are created and authored in partnership with teachers using firmly achievable strategies and locally accessible materials if at all possible. This allows the curriculum to be more sustainable economically and less reliant on external sources for specialty equipment, tools, and materials. If necessary, imported materials are to be strictly supplemental. If local teachers create and adapt their own lessons, there is a stronger likelihood that they will be valued, used, and adopted by other local teachers. A goal is to have locally created texts, guides and references, while still addressing key concepts and topics that form a recognized coherence in engineering and science curricula internationally. Sustainability as a design principle addresses concurrently the environmental sustainability of the materials used, as well as the economic sustainability of materials acquisition, available non-monetary resources, and the willingness of the community to contribute resources to education.

Teaching strategies and professional development of teachers

Most teachers in Timor today limit their practice to one-way lecturing, and demonstration of learning is shown on written tests of memorization and recall, which stand as the gatekeepers to pursuing higher education. As Quinn notes in her 2009 work, "Evident in all settings observed was the high proportion of teacher talk in contrast to student talk… it was rare to observe students using more than one word/one noun answers" (Quinn 2009). The opportunities within schools for group discussions and practicum experiences based on real, inquiry-based knowledge construction are few and far between.

To affect change in this challenging area, during trainings SESIM utilizes participatory, active-learning, student-centred pedagogic principles. For example, students (and teachers in teacher trainings) work together in groups, share common tools, discuss findings and communicate with their teacher, instead of receiving a lecture. In line with the approach taken by the Exploratorium's Teacher Institute[5], each teacher is given many opportunities to learn using the methods described here so as to have personal experience in addition to the theoretical knowledge (Bezin & Tamez 2002). Teachers get considerable support in understanding the basics of these principles with many examples to reflect upon. Such methods are more common in Western schooling, but often brand new in Timor. This is a significant challenge for trainer and teacher alike, and a risk exists of teachers taking away only superficial understanding of the deeper pedagogy (Quinn & Shah 2013). Though there is yet no empirical data available on the effectiveness of these initial efforts, all indications are positive: teachers are excited about using these methods, and they are popular among students. SESIM and the authors welcome further research and foresee favourable data in the future.

Discussion, conclusions and implications for science education

From the three examples and design principles, we have provided an introduction to a participatory, experiential approach to developing science and mathematics curriculum elements and carrying out teacher training emerging from a group of dedicated teachers in Timor-Leste. Local teachers with the help of a Western-trained science teacher developed and instructed with activities that made use of local expertise, folk knowledge, and readily accessible local resources.

This work relied heavily on an inquiry-based, learning-by-doing-together approach to develop curricula elements as well as teach students and train teachers. This pedagogical approach is also consistent with collaborative knowledge building, and is necessarily grounded in everyday practices, truth-seeking, and forming systems of rationality, giving students the basic tools to conduct their own investigations and pose investigable questions in experimentation and dialogue with others. All students regardless of prior formal schooling possess knowledge of the natural world as well as a set of guiding beliefs (diSessa 1988; Hammer 1996). The students and teachers in Timor-Leste are no different.

SESIM's approach to creating more contextualized education and the idea that science learning should be more closely tied to students' existing knowledge and experiences is not a new concept, but is often forgotten in modern science education, especially in the remote, resource-limited communities that could make the best use of it. Our design principles offer some starting points and guidelines for supporting the design of culturally relevant curricula and inquiry-based instructional practices.

Culturally relevant curriculum is just one aspect of providing a contextually relevant education, which is much needed in a rapidly evolving nation. Organizing and establishing professional development to ensure teacher quality is also a necessary part of this evolving education system to establish an important foundation through means of an accepted certification process (Earnest, 2003). From our experiences, the design-based approach we have been using with great success addresses concurrently the development of teachers and the development of a meaningful curriculum that can they can implement. Future studies that make use of design-based research approaches as well as examine issues related to local context and practices can be helpful to refine locally valuable innovations while also developing more globally usable knowledge for the field (DBRC, 2003; Sandoval & Bell, 2004).

In summary, Timor-Leste offers a unique contextually rich environment to conduct cross-cultural studies to further explore the localized context for science and mathematics curricula, teacher development, contrasting and converging views of Western science and worldview of students. Our work so far has simply generated working design principles for education development at the local and regional levels. We are optimistic that this approach and these design principles can have a national impact when a participatory development approach is taken as a first step to engaging all stakeholders.

[5] Exploratorium Teacher Institute - the professional development home for middle-and high-school science teachers since 1984, where the first author apprenticed and has taught others since 1992.
http://www.exploratorium.edu/teacher_institute/

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