Emergent Design and learning environments: Building on indigenous knowledge

by D. Cavallo

The empirical basis of this paper is a two-year project to bring new learning environments and methodologies to rural Thailand. Pilot projects were mounted outside of the education system, with the specific purpose of breaking "educational mind-sets" that have been identified as blocks to educational reform. A salient example of such a mind-set is the assumption that the population and teachers of rural areas lack the cognitive foundations for modern technological education. The work required a flexible approach to the design of digitally based educational interventions. Analysis of design issues led to a theoretical framework,* Emergent Design, *for investigating how choice of design methodology contributes to the success or failure of education reforms. A practice of "applied epistemological anthropology," which consists of probing for skills and knowledge resident in a community and using these as bridges to new content, was developed. Analysis of learning behaviors led to the identification of an "engine culture" in rural Thailand as an unrecognized source of "latent learning potential." This discovery has begun to spawn a theoretical inquiry with significant promise for assessment of the learning potential of developing countries.

The central thrust of this paper is the presentation of a new strategy, which I call *Emergent Design*. The paper describes an approach used for educational intervention; the claim is a more general one, however, in that the strategy is appropriate in settings for technologically enabled paradigmatic change. I claim that the more traditional approaches to systems design, implementation, and deployment have not produced desired results in situations where the goals and needs are for systematic change. When the desired changes cannot be reliably foreseen, and particularly when the target domain is computationally too complex for automation and thus relies on the understanding and development of the people involved, then top-down, preplanned approaches have intrinsic shortcomings and an emergent approach is required.

Educational environments definitely possess these characteristics. However, in the emerging business and cultural environment, many other domains do as well. I have utilized this approach previously in the design and implementation of enterprise architectures and process re-engineering. The most notable example[1] is a health care delivery environment where the Emergent Design of the architecture and applications of the systems for health care delivery, administration, and patient use enabled a broad change in medical practice. The approach to the design of the educational intervention I describe here resembles that of architecture, not only in the diversity of the sources of knowledge it uses but in another aspect as well—the practice of letting the design emerge from an interaction with the client. The outcome is determined by the interplay between the understanding and goals of the client, the expertise, experience, and aesthetics of the architect, and the environmental and situational constraints of the design space. Unlike architecture, where the outcome

0018-8670/00/$5.00 © 2000 IBM

is complete with the artifact, the design of educational interventions is strengthened when it is applied iteratively. The basis for action and outcome is through the construction of understanding by the participants.

The technological ramifications are immense. We often build inappropriate technology because the domain changes too quickly, or the designers' understandings and aesthetics vary too much from the users' understandings, needs, and goals. At other times projects fail because, even though the technology might be appropriate, the deployment is flawed. Design cycles that cannot adapt to rapidly changing conditions miss emergent phenomena that either need correction because they are undesirable, or need capitalization if desirable. A resultant long-term problem is lack of belief in the true possibilities for technology because it did not live up to expectations. This is certainly the case in education, although business uses also share this outlook, as evidenced by complaints about lack of productivity gains through technology.

Perhaps more importantly, traditional approaches to learning of and through technology have not mobilized the indigenous knowledge and expertise among many people. The growing "digital divide"—concerns about the potential of a widening gap between rich and poor in the new, knowledge-based global economy due to a lack of modern, technological skills among people in lower social-economic strata, and a growing concern about the potential of educational systems to ameliorate this situation—all point to a serious problem becoming seemingly permanently intractable.

This paper describes an approach to technology design and use that provides hope for a different, more positive outcome. The same technology that can be a primary factor in widening the divide, may be the best hope for eliminating the divide. The Emergent Design approach enabled the discovery and utilization of latent, engineering expertise and creativity among people in rural Thailand. Rather than being bereft of social capital necessary to succeed in the new economy, *these traditionally poor, rural people are conceivably better situated for success so long as the technology and methodology used is expressive, appropriable, and constructionist*.

While the claims here are broad, I choose to focus on one concrete example, that of an effort in educational reform. Educational institutions, although relatively young, have proven extremely resistant to change.[2] Moreover, schools for the most part have not used new computational technology in innovative ways. This, despite a lot of hype for the possibilities of technology in education, has caused many to doubt the potential in the technology. The problem, though, is not with the technology per se, but rather with the design, deployment, and uses of the technology.

Technology and the reform of educational environments

Educational reform efforts, over a long period of time, have offered many different blueprints. Yet none has had the substantial effect for which it was designed. Why is this the case?

We need to look at the way in which education reforms are usually carried out. Some set of individuals decide there is a problem needing addressing (such as low math and science scores) or a change deserving implementation (such as the introduction of a new item like ethics to the curriculum). A group convenes. They call in the various experts, stakeholders, practitioners, and other usual suspects. They design a blueprint for their reform. The blueprint contains a curriculum, materials, texts, assessment, teacher training, and so on.

This paper presents the view that these blueprints have failed simply because they are blueprints. Many analysts researching this situation, most recently David Tyack and Larry Cuban,[2] have shown how the process fails. Whatever blueprint is proposed, it is inevitably going to be transformed in the course of appropriation, ending more in conformance with what the designers originally hoped to reform. The institution tends to reform the reform, perhaps retaining the rhetoric but rendering it toothless. Tyack and Cuban brilliantly term[3] the overriding mindset the "grammar of school." Like a grammar, they describe a deeply held organizing system that allows only certain expressions (or actions) as legitimate and renders some expressions nonsensical if they deviate from the underlying system.

Tyack and Cuban made clear that whether reforms are big or small, from the "right" or from the "left," national or local in scope, they do not work. Some might deserve to fail because of the nature of their content. But while content may or may not be a limiting factor, they fail because of the form in which they were designed.

What is needed is an alternative approach that is not a blueprint. This naturally raises the question of whether having no blueprint means the abrogation of all design and planning so that "anything goes." In the same way that a jazz group can improvise within the structure of a piece while remaining coordinated and within the theoretical principles of the genre, so too can an emergent design remain consistent within a core set of principles.[4]

This paper describes a form of intervention in learning that is very different from the model of reform studied by Tyack and Cuban. It offers hope for addressing the great educational needs created by the digital age by drawing on two of its important innovations: (1) digital technology and (2) the approach to management of organization and of organizational change that has come in the wake of the technology.

More precisely, this work draws on the combination of these two innovations. A distinction must be made because, as I show, the temptation to use either of them alone has led to failure. It is the combination that offers an optimistic vision for the future of learning—the combination of these two products of the digital age along with a theoretical framework based on the work of pre-digital-age thinkers who knew what to do but did not have the means to do it. Among these the most central is Paulo Freire,[5] but also represented are John Dewey[6] and, although he did not focus on education per se, Jean Piaget.[7]

Limitations of a single focus. A focus solely on technology leads to technocentrism, that is, a view that it is the technology and not what we do with it that has impact.[8] Such a focus also leads to a narrowness of vision. In other words, we simply place the technology into the existing structure and thus are not able to see the possibilities that extend beyond the existing organization. Merely adding technology reinforces an experimental paradigm out of place. This paradigm tries to modify one element at a time, holding the others constant. When using such an approach when introducing technology, what one holds constant—rather than maintaining experimental purity—merely serves to neuter the potential for educational change catalyzed by the technology. Thus, an erroneous view of the technological and learning potential results.

In his book *The Productive Edge*,[9] Richard Lester describes mistakes made within conventional mind-sets about business, productivity, and change that resonate with conventional mind-sets of education and school reform. Lester describes how many companies, in an attempt to improve productivity, quality, or some other often highly quantifiable attribute, would attempt to apply a seemingly scientific method by researching a new methodology or so-called best practice; they then attempted to test whether adding this method to their own operation would generate positive results, holding all other things constant. In a vast majority of cases such applications of new methods failed to produce positive results. This not only called into question whether the new methodologies truly had value, but also led to an *experimental fatigue* from being repeatedly forced to adapt to the change program of the month.

Adoption and implementation of new methodologies needs to be based in, and grow from, the existing culture.

What Lester demonstrated was that there are not typically such things as decontextualized best practices that can be grafted onto existing organizations and thereby produce results. Rather, each company has its own complex culture, full of subtleties, and successful companies are the ones that can innovate, cultivate, adapt, and use methods that can thrive in their particular environment. The successful approaches fit more with the Emergent Design concept advocated here than with the more traditional top-down, change-one-variable-at-a-time approaches thought to be more in the line of scientific management. Digital technology enabled the customization of process to culture rather than forcing culture to be responsive to management dictates and "the one best method."[10] The critical point is that adoption and implementation of new methodologies needs to be based in, and grow from, the existing culture, and typically fails when it is merely imposed from above without such cultural considerations. Interestingly, incremental approaches to educational reform closely resemble the less successful methods that Lester describes.

The reform of educational management, usually in the form of administrative decentralization, does not

break the stranglehold of the grammar and ends up with reversion to type. By themselves, ideas such as decentralization of control and decision-making, or intradistrict competition, do not generate new content and methods. On the contrary, they merely push the same practices down the hierarchy without fundamentally changing practice. Thus, the only substantial change is in administration, not innovation in the learning environment.

The need for new principles. Saying one needs to base new methodologies and the change process to resonate with, and build upon, existing culture does not mean that deep change is not intended, nor that any type of change is desired. In the case of learning environments, the primary principles we brought were: constructionism, technological fluency, immersive environments, long-term projects, applied epistemological anthropology, critical inquiry, and Emergent Design.

Constructionism builds[11–13] upon principles in constructivism. While constructivism holds that the learner constructs new knowledge based on the existing knowledge he or she has, constructionism builds on this idea by maintaining that this process happens particularly well when the learner is in the process of constructing something. For example, in our work with LEGO**-Logo[14,15] we witnessed many children, including those who had previously done extremely poorly in school, understand complex ideas in mechanics, physics, and mathematics through constructing LEGO robots to accomplish various tasks.

The idea of building *technological fluency* draws on the image of being fluent in a language.[16,17] When one is fluent in a natural language one can think, express, communicate, imagine, and create with that language. In the same way, we like to develop fluency through the construction of, and with technology as a means of, personal and group expression. We try to develop fluency with technology in order to help people become more eloquent and effective in their expression. Just as fluency changes the focus to a more holistic use of natural language, this also changes the focus of learning with technology.

Just as the idea of fluency is adopted from language, so too is the concept of *immersive environments*. Being immersed in the culture and environment facilitates learning a foreign language. So too does working with others in a culture where the knowledge of technology and construction is deeply embedded facilitate the development of technological fluency.

Building artifacts of interest to learners aids the construction and the development of fluency. In order to delve deeply enough to unearth the underlying concepts and principles, we enable students to work on projects over a *long period of time*. Rather than rushing through a broad curriculum in a shallow manner, we prefer to encourage diving deeply into the projects. This takes time. This also differentiates our practice from other project-oriented approaches in education, where the project is preplanned by the curriculum designers and not emergent from the interests of the learners, and where it lasts only a short period of time in order to fit the traditional classroom situation.

Applied epistemological anthropology is a term I have given to the practice of unearthing the meaning learners attribute. This applies on both a cultural and individual basis. In order to facilitate the construction of new knowledge on the existing knowledge of the learners, one must first help discover the existing frameworks as best one can. This practice itself is facilitated through the construction of objects of interest to the learner, where the learner has as much freedom of expression as possible. When the freedom of expression exists, then the learner has the space in which to express himself or herself in a manner faithful to the learner's thoughts. This is a key element in the design of technologies for learning. Through the construction, and mediated by discussion, the underlying thoughts become more evident. This enables the teacher or facilitator to better design and implement learning interactions. This leads to the necessity of a more emergent approach.

Critical inquiry is the process of engaging in a conversation with one's world in order to understand and act upon it.[5] Through critical inquiry we collaboratively determine upon which projects to work. Also through critical inquiry we try to understand the phenomena of study in sufficient detail so as to construct artifacts modeling the phenomena or designed to ameliorate the situation, as well as to understand and debug the artifacts of construction.

Emergent Design is what manages the overall process. Due to the emphasis on approaching learning by building on the existing knowledge of the learners through their expressive construction of projects of their own choosing, this process by definition has strong emergent tendencies. However, design is also emphasized as the others in the community who work with learners—be they teachers, parents, or other community members—also play an active role in as-

sisting to assist and guide the learner in the process. The idea of design extended to a "grassroots" level enters because, just as Emergent Design is practiced to facilitate organizational change, so too is Emergent Design practiced in the interaction between teachers and learners.

There is no claim that the methodology described in this paper is the only way to achieve the desired results. What this does serve as is an existence proof of *a* way. That this way at least initially demonstrates interesting, unexpected, and quite positive results among populations that previously did not exhibit such results in traditional settings should serve to question the existing school grammar as well as to facilitate other such experiments. I close this section with a story that illustrates the prevailing educational mind-set as well as effective informal methods that can be leveraged.

DOS commands and flower gardens. On my first visit to Thailand my hosts took me to a nonformal education (NFE) site in a Buddhist temple. I saw a computer class held at the NFE temple school. A child was being taught DOS commands. The logic behind such an introduction to computers, following the typical school curriculum grammar of using sequential building blocks of knowledge, is that it provides the requisite basis for later, more difficult learning. However, the useful learning never comes! And in the meantime, the formalistic nature of the beginning work confuses and frustrates the novice.

The student's teacher assigned four commands for him to learn and practice. The first was *dir*, to get a listing of files in his directory. The second was *copy*, to copy a file from one location to another. The third was *format*, to format his A drive (fortunately, it was not the C drive). I do not remember the fourth but it was made irrelevant by the reformatting of his disk.

This confounding situation led the student to stop me with a plaintive question, "What is the problem here? It worked before but now it no longer works. I am following my teacher's instructions, but this is not working properly." On the first iteration of practicing his commands by rote, everything was fine. Subsequently, however, none of the commands was giving the specified results. His directory was now empty. He could not copy his file. I explained to him that the result of using the format command is that it reformats the entire disk, meaning it wipes clean what was on it and sets it for the computer's operating system. Thus, there were no more files in his directory to list or to copy.

Despite several attempts at various ways of explaining it, including recreating the example on the computer and showing how *dir*, *copy*, and *format* work with a newly created set of files, I am not sure he understood my explanations. One reason for this is that my explanations meant that what his teacher had said, done, and assigned no longer made sense, which would be quite disorienting. Another possibility is that no matter what the explanations and examples, learning commands this way is too decontextualized to make sense. One is merely learning by rote what someone else says is important without any conception of why or how it might be used.

I suggested that we create environments for learning computational ideas in the same manner that monks learn gardening.

The split between conventional "School thinking"[18] and cultural learning was shown vividly in the contrast between the computer class at the temple and how the monks themselves teach flower gardening. Beautiful flowers are grown and displayed at all the Buddhist temples in Thailand. They are impressive, colorful, and fragrant. After my visit and the experience with DOS teaching run amok, I inquired about how people learned to cultivate such gorgeous gardens. A monk explained that when initiate monks enter the temple, they work alongside more experienced ones and learn by demonstration, by asking questions, in the best sense of learning by doing. I mischievously asked whether any classroom instruction was involved. The monk looked at me askance, but politely answered no, they felt there was no need. I tried to explain that this was the approach we also preferred for learning computational ideas. That is, that new learners work on projects of their own, are in an environment with others working on similar, but perhaps more complex, projects, and can observe and ask others questions—in essence they are immersed in a culture of computing just as the monks are immersed in their culture.

The depth of resistance to these ideas was illustrated by the way the teacher who was translating my remarks into Thai misrepresented the explanation, creating an initial misunderstanding between the monk and me. After listening to my translator, the monk politely responded that they would never do what I suggested. Considering that I had just suggested that we create environments for learning computational ideas in the same manner that the monks learn gardening, I could not understand how he disagreed. So I inquired again about what was said. The teacher told me that she told the monk I had suggested that they teach gardening in a classroom just as we teach computers in a classroom. When I re-explained what I had really intended, the teacher could not believe I meant it. Rather than immediately retranslating, she passionately protested. Surely classrooms were the modern and most effective means of teaching. How could I, from a modern western university, suggest that the monk's method could be better? It took quite a while to get her to tell the monk what I thought. In retrospect, this was a powerful learning moment for my translator, although thoroughly and necessarily unplanned.

Scenes from Project Lighthouse

The context of this paper is Project Lighthouse, a bold intervention to initiate radical change in the educational processes in Thailand. As its name suggests, Project Lighthouse is not a blueprint for education or education reform. Rather, it attempts to highlight actual possibilities for powerful learning environments in Thailand, particularly in settings where traditional education has not succeeded. A primary goal is to *break mind-sets* about what education must be by providing concrete examples. The following are samples of activities from Project Lighthouse over a 17-month period. The scenes provide a concrete basis for the discussion that follows.

Bangkok, March 1997. In the first scene, Seymour Papert and I, from the MIT Media Lab, were meeting with leaders of the Suksapattana Foundation.[19] We were designing a proposed intervention intended to provoke a radical reform of the educational system in Thailand. The meeting came about because a group of industry leaders and government officials had come to believe that, unless they achieved a total transformation of their educational system, Thailand would not merely stagnate economically, but also that they would lose all the gains of the previous decade. More critically, the leaders worried that there was a growing and more intractable divide between rich and poor that would destroy the fabric of Thai society. They further believed that in the absence of an educated, thoughtful, literate populace, it would be impossible to support their nascent democracy and prevent a return to autocratic, and corrupt, military rule.

The Thai leaders believed that the existing school was not a hospitable medium for developing alternative forms of learning. Moreover, they felt that to change it directly would cost too much and take too long. They believed the existing schools to be too rigid, too reliant on rote instruction, and staffed by too many teachers who were barely educated themselves.

They had set bold and ambitious goals for their educational system. They had developed a new national education plan as an essential part of their national development plan. This education plan, combined with a special commission from the Office of the Prime Minister devoted to education reform (ONEC), specified the new goals.[20] The goals were thoughtful and admirable. They included:

- Becoming learner-centered
- Developing critical-thinking ability
- Fostering innovation and creativity
- Developing collaborative spirit and skills
- Learning how to learn
- Providing familiarity, ability, and comfort in working with technology
- Developing "happy" learning, that is, a joy for learning

However, none of the plans specified how to achieve such a system. They did not discuss how to operate in this new paradigm or how to make the transformation. Thus, while the goals were lofty, the implementation of both the new system and the method of reforming the current one, were mired in the existing, undesirable paradigm.

The goal behind our endeavor, Project Lighthouse, was to break mind-sets by creating technologically rich learning environments that would demonstrate the "out-of-the-box," yet practical, possibilities for children in Thailand.

However, it was not clear what to do. Moreover, there was little agreement on, or acceptance of, our proposal. Some believed that we should focus on gaining the acceptance of the national curriculum developers as the current system moved only through

the curriculum. Others believed we from MIT should train the trainers who would then train the teachers who would then work with the students. Others felt we should place computer labs in more schools and train teachers to work there. Finally, there was near unanimous agreement that the existing teacher corps was incapable of working in a new, learner-centered, project-based, technologically rich environment. Virtually everyone told us that the teachers were barely educated themselves and might not be able to learn to use the technology, let alone teach with it.

We proposed creating four pilot projects where we could quickly demonstrate significant results in some of the most critical areas of need.[21] These were:

- Alternative learning environments within nonformal education
- Rural village learning centers
- Teacher development
- Alternative learning environments for at-risk youth such as street children in urban areas and girls at risk for or exiting prostitution

There were two major objections to our proposal. First, commentators argued that our proposal did not fit the prototype five-year plan, which spells out all activities over that time period. How could people know what to do if we did not provide such a plan? People wondered if perhaps either we were not serious or did not know what we were doing. Second, people told us that the quality of the teacher corps was so low that they would be incapable of carrying out an ambitious endeavor such as ours.

However, we argued that it would be counter-productive, if not impossible, to develop any specific plan. It was not merely that we were not familiar enough with Thailand to know what would be the right things to do. More profoundly, what was needed was a philosophy of design based on recognizing that no one could know beforehand what would resonate, how people would appropriate new learning technologies and methodologies, what learners would choose as projects, how villagers would react to the intervention, and so on.

At the meetings we tried to show that there is a fundamental contradiction between having learning environments that function through connecting to, building upon, developing, and deepening the interests of the learners, and planning everything centrally in a top-down manner where all activities are predetermined for all learners and all locations. What is needed is a philosophy of design for educational innovation as different from traditional ideas of reform as the content of the new innovation would be from traditional educational content. The theoretical framework that evolved from this and similar experiences of Project Lighthouse is Emergent Design.

The phrase Emergent Design puts a spotlight on the need (which has not been recognized by education policymakers) to study the conceptual space where the purposeful stance implied by the word "design" mates with the openness implied by the word "emergent." This mating underlies modern approaches to organizational practice.

The emphasis on *emergence* as the guiding principle does not imply that this is an anything-goes environment reacting to the whims of the participant teachers and learners. As described above, we brought a very disciplined set of principles, methodologies, tools, activities, models, and exemplars for learning environments. However, to deliver a pre-set curriculum with pre-chosen problems, explanations, and sequence of events would be not only antithetical to the underlying learning philosophy, but also it would be incapable of taking advantage of the very benefits that the technology affords.

Nong Baot village, BuriRam province, northeastern Thailand, January 1998. The second scene from Project Lighthouse took place in Nong Baot in the northeast of Thailand, the poorest region of the country. It is approximately 100 kilometers from the Cambodian border. *The New York Times* described[22] it as having "two harsh seasons, flood and drought." The economy is based on agriculture but, due to the harsh weather, little can be grown. Nong Baot survives by cultivating one rice crop per season. There are some small vegetable plots used primarily for subsistence, because there is not enough water to grow enough crops to sell. Lately, some groups of villagers have tried to cultivate fish farms by creating small reservoirs during the rainy season. This, too, provides food for them for only a brief time, because the water is gone within a few months.

Nong Baot is an area that suffers from logistical problems that have stifled the potential for economic development.[23] It is tropical and does not have ready access by water to the rest of the world. These factors inhibit the development of industry. The soil is poor and there are no mineral deposits. Thus, it has remained an area of minimal means and wealth.

Education in this area likewise has been minimal. There is little incentive to remain in School. Many people leave school as soon as they are legally eligible, claiming that School has no relevance to their lives. Children need to work in the fields or in other occupations to help their families. Few people go on to attend a university.

Within this scenario, I conducted an introductory Logo immersion workshop to develop technological fluency. Unlike most projects that try to bring technology to remote or impoverished areas, my goal was to have the attendees quickly build projects and create programs.

The workshop had a mix of participants: villagers, teachers, and a few local economic development workers from the Population and Development Agency. I begin the workshop by showing what a computer is, how you turn one on and off, and how you operate one, because this was the first time that the villagers had ever personally seen a computer, except for viewing one on television.

In the evening the MIT participants held discussions with the villagers to get to know them and their situation. I asked why the villagers said they wanted us to place computers and Internet connections in their village. They told us that water is very scarce in this region. Worse, there is either too much of it during the two-month rainy season or there is none of it during the rest of the year.

It was in the discussion in the evenings after this workshop that the village leader expressed the need of the people to gain more control over their lives and the belief that certain uses of the technology could help them. The people described many of their problems as economic, caused by the harsh climate where there was either too much or too little water. They wanted access to expert knowledge, but most importantly they wanted to be in control of gaining the access to and making the decisions about what to do with the knowledge. They felt that the local authorities did not involve them in the thought process and decision-making whenever the villagers asked for assistance. This left the villagers feeling dependent and without the hope for their own progress. To make matters worse, due to the appearance of new problems with the cattle and the water, the villagers believed the advice and proposed remedies they were given to be harmful rather than helpful.

Introducing the first phase. The villagers wanted to end this cycle of dependency and lack of control by gaining access to information and gaining control of the situation via the technology. Even though I had to introduce the workshop by demonstrating what a computer is, including how to turn one off and on, through the symbolic value of the computer they viewed competency with the technology as a plausible path to this control. Although there could not have been any real experience with how computational technology could provide this path, they had heard enough about computers and the Internet to believe it had potential for them.[24] The computer was a symbol of modern technology and a connection to the modern world.

In short, the villagers were able to experience what we did in the spirit of "cultural leverage." As a result, the participants were soon building their own projects, first in Microworlds Logo, then adding robotics with LEGO-Logo. What at first was a foreign and potentially intimidating technology, now became a source of fun and pride in product. The villagers worked in multigenerational groups, from young children to the elders in their seventies and eighties. The teenagers and children did more of the programming, being more open to new technologies. The adults contributed their wisdom, maturity, and experience. They made all of the decisions jointly. They were doing programming and engineering, working on projects of their own design.

Moving to the second phase. When I returned in August, the situation was quite different. In a brainstorming session about potential projects, we quickly converged on the critical need for access to water for household and agricultural use. We discussed ideas broadly at first, looking for areas they felt were major problems or, from a more optimistic point of view, areas that they thought could provide major benefit if we could find means to create solutions within these areas.

Naturally, there were many trade-offs in the dimensions of each project. The MIT participants wanted to address major problems, but some problems perhaps were extremely difficult to solve. We wanted to achieve some quick successes to help change mindsets about possibilities, produce real results, and develop belief in what we were attempting. However, easy and quick successes are most likely rare or trivial. We believed in the potential of the technology to help think about and design potential beneficial projects, but the villagers were technical neophytes.

We did not want to just design solutions ourselves, because this would neither develop the villagers' own technological fluency and capabilities nor empower them in the long term. So we needed to choose initial projects that were approachable by people with their scant experience, yet were real enough to actually provide tangible benefit, while simultaneously providing a rich learning experience. Through my experience both in developing technical solutions to real-world problems, as well as working with adults and children learning to engineer and program, we worked to develop a group consensus on the initial set of projects. Knowing that we were committed for the long term relieved tension from feeling a need to accomplish everything immediately. The initial projects were to design a dam to create a reservoir for farming; investigating alternative strategies for rice cultivation; redesigning the irrigation system; developing new means to collect, store, purify, and distribute rain water; and creating new vegetable plots. In this discussion I focus primarily on the dam project.

A first, important project. We began work calculating the potential and the reality of building a dam. In each of the past two years the villagers had tried to construct a dam to create a reservoir. It was hoped that the dam would retain water at the end of the rainy season that could be used for agriculture in the dry season. In each of the past two years the project had failed, since the reservoir did not contain the water. Now both the villagers and the rural teachers worked to develop the new project together. I took a supporting, mentoring role rather than a direct role in the project myself, believing that the only sustainable benefit would be for them to develop the package of skills themselves.

They had not previously calculated the potential benefit from the dam. When we engaged in brainstorming about this topic with them, together we calculated that the villagers would more than double their yearly income if they could harvest a second vegetable crop. We walked through the flood plain and took some digital photographs. We measured the distances between relevant objects in the terrain using the odometer on a motorcycle. We uploaded the photographs into Microworlds Logo and the groups began making visual representations of the area.

To my surprise this was a totally new experience, not merely for the villagers but also for the teachers. While the fact that the villagers could not do this on their own might not be surprising, the teachers could not do so either. They had certainly taken school courses and passed school exams on this type of knowledge, yet in practice they could not make a map. Together, the teachers and villagers created accurate computer representations of the areas, preserving distances, maintaining relationships and ratios as they created various views at different scales and calculated the relevant distances between important objects.

Then, a remarkable thing happened! Immediately upon creating the maps, we discovered a mistake repeated each of the previous two years. The villagers had been building the dam in the wrong place! The original location benefited from natural terrain to create the reservoir; however, it was about two kilometers from the village water pump used for irrigation. Once the villagers constructed their own map of the area, they realized they could not create a reservoir large enough to cover the distance to the pump. Even if the dam had functioned properly, it would not have provided the expected benefit, because it was prohibitively expensive to relocate the pump and the irrigation hoses.

Discovering an exceptional student. As the design project continued, we observed how the efforts of one of the participants was exceptional. He told me that he had not had any success in school and left as soon as it was legal. He primarily helped his family with the farming. We had only introduced computers to the village within the current year. He spent this time working on programming—not by taking classes, but by programming his own projects.

What was so striking was that he had quickly become quite an adept software hacker.[25] Atypical of many of our experiences with more educated people, he, as well as others in other parts of Thailand, dived in and figured out how to build the projects he wanted. If something did not work, he was not daunted. Rather, he debugged the system and worked until it was satisfactory.

We discovered that he spent considerable time working with engines. By learning how to build and repair engines and by working on the farm with few resources, he had developed a *bricolage* spirit. That is, he would make what they needed with what little he had. If something did not work, he fixed it. If he did not have the right tool or material, he improvised. He took this spirit and applied it to computational technology.

As this skill and experience became apparent, he and others took me to visit their farms. At the farms, everyone who could used a small Kubota diesel engine to power a wide variety of local technological contraptions. They used the little motors to power rice mills, well-water pumps, irrigation pumps, one-person tractors, field vehicles, and even lightweight trucks. The barns contained little pulley systems for lifting the motor from one device to another. The logic of each machine was open and obvious. The innovation and creativity were remarkable. The utility was tremendous. The people had taken objects for other, often quite specific, purposes and combined them in a general-purpose mélange particular to their needs, resources, and budgets. The experience and expertise of those who worked with these engines and devices was quite impressive.

Thai combustion-engine culture. Virtually all commentators on Thai education and on the Project Lighthouse proposal believed that the quality of rural teachers was extremely poor and that they would be unable to work successfully in the proposed technologically rich, learner-centered environment. These same commentators bemoan the problems and capabilities of the overwhelming majority of rural students as well. Lack of faith in the intelligence and capability of economically disadvantaged children is an unfortunately widespread belief that is all too difficult to dislodge.

Contrary to the perceptions that rural and impoverished students are not capable learners, rural teachers are not competent technologists, and Thai culture is not amenable to innovation, collaboration, deep learning, and technical expertise, we discovered that there are deep intellectual roots and significant innovation practiced and learned over at least many decades, and presumably much longer. Indeed, although not written about in academic circles, there is a strong tradition of so-called "peasant technology"[26] in Thailand, particularly using and adapting the internal-combustion engine to satisfy local concerns and constraints. Our final scene in this section focuses on this "engine culture."

Perhaps the best example of this innovation is the creation of the long-tailed boat (Figure 1). There are many areas throughout the country where waterways are the principal means of travel. Significantly, this is also the case on the rivers and canals of Bangkok. In the past, as people desired to transport more and heavier goods, human-powered boats became problematic. In the north, one innovator decided to experiment with placing motors onto the boats. After several attempts with various types of inboard and outboard motors, he settled upon using an automobile engine with a long driveshaft so that the propeller was far from the boat. Typical outboard motors did not work well, because they churned too much water into the long canoes that everyone used. The many reeds in the rivers also jammed the propellers too often, negating their benefit. The driveshaft, or long-tail, not only solved the churning problem, but also served as a rudder for steering and enabled the pilot to lift the shaft from the water to avoid entanglement with the reeds. The use of an auto engine leveraged existing knowledge about repairs and benefited from not requiring parts manufactured outside of Thailand, which would be difficult and expensive to obtain. People quickly adopted this technological innovation throughout the country.[27]

Tuk-tuks are another similarly inspired innovation. Small motorcycle engines are placed onto the pedicabs, again to alleviate human stress and increase speed. Other rural innovators have also adapted engines to create low-cost, one-person tractors (Figure 2), irrigation pumps (including one ingenious invention to pump over roadways, since the native soil had the tendency to crumble into irrigation tunnels), and devices to help operate wells in drought-stricken areas.

For the most part, not only did these innovations not occur in universities, research labs, or corporate departments, such circles barely took notice of them. Rather, they were a grassroots effort, based in the interests, needs, and practices of Thai culture. People created and adapted new technologies to alleviate their burdens and to create new opportunities.

These innovations could not have achieved such widespread use if a culture of practice and knowledge had not also developed to spread and support them. In order to use engines widely, a group of people capable of maintaining them had to exist. This group did not do well in school and did not receive its training in school. Rather, almost exclusively they learned to diagnose and repair engines in informal learning cultures. Making this diagnosis and repair more difficult is the fact that among this social stratum in Thailand, there are not a lot of materials, parts, diagnostic equipment, or written manuals. These mechanics have to become *bricoleurs*,[28,29] that is, they must adapt materials at hand to satisfy their

Figure 1 Engine on a long-tailed boat

goals, even if it is not the accepted way to accomplish the goal nor the proper materials for the task.

Discussion

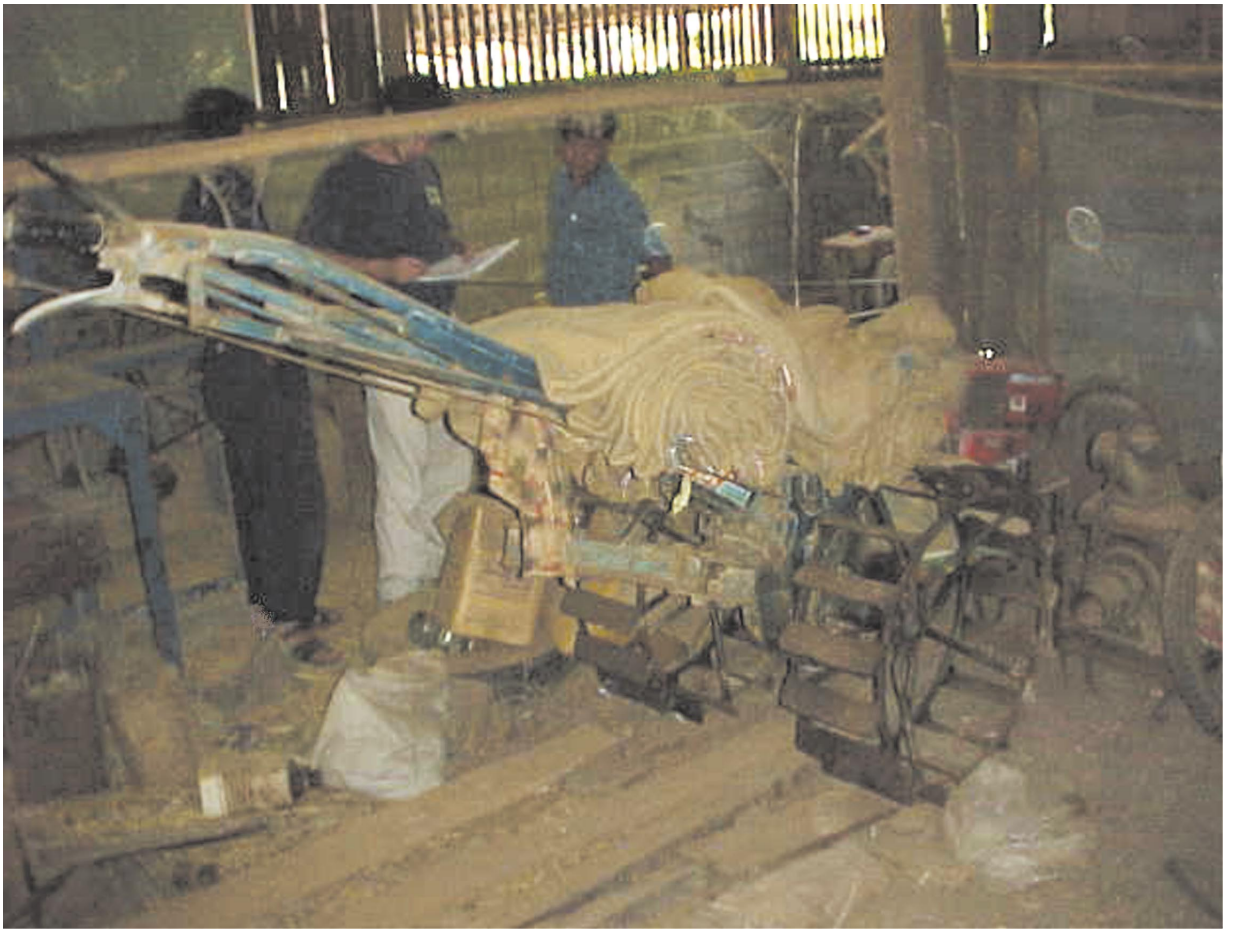
What makes this story compelling is that these mechanics, while respected for their mechanical abilities, were not regarded as academically capable. Conventional wisdom stated that people in this group may be good with their hands but they were not good with their heads. Moreover, the belief in the dichotomy that different people with different skills are required in order to be good with their heads remains.

However, in the context of Project Lighthouse, the capability of these motorcycle and engine mechanics was immediately evident. Not only did they learn the new computational technology quickly, they were also quite adept at adapting it and applying it to solve local problems. This was the case with designing dams, improving irrigation, and devising alternative methods of cultivation of rice and other crops in BuriRam.

Still, moving from one technology, engines, to another, computing devices, while impressive, would not necessarily be remarkable except that in order to accomplish the tasks with computational technology they had to competently handle some sophisticated mathematics, biology, engineering, physics, and computer science. What is remarkable then is that:

- They accomplished projects requiring competence in these recognized bodies of knowledge

Figure 2 Another local innovation, a small diesel-driven one-person tractor



- They accomplished this in extremely short timeframes
- They leveraged their mechanical expertise and "hacking" spirit to build a computational technological fluency
- They then utilized the technological fluency to gain competence in these bodies of knowledge previously inaccessible to them

To make maps they had to measure distances and perform calculations over these distances. To provide zoom-in and zoom-out views, they had to maintain proportions and adjust accordingly. To design the reservoir they had to again measure, calculate areas and volumes, and determine water usage for various crops over time while accounting for evaporation and drainage. To think about placement of the dam they had to think about how water flows over terrain. To design the irrigation system they had to think about networks and shortest paths. To determine which project to do or which decision to make within a project, they had to calculate costs and benefits, factoring in more subjective factors as well, and create compelling arguments to convince others. To test various rice cultivation methods and to create decision-support systems to assist them in the cultivation and care, they had to delve deeply into the supporting science. To create new LEGO robotic-controlled apparatuses to assist in farming and environmental sensing (or just for play), they had to go deeply into the underlying engineering, control, mechanics, and physics. What unified these various endeavors was the formal language for description.

Moreover, the dam design is but one example from one site. Other sites also had similar results. For example, in the north where water was not a problem, people worked on issues of soil erosion, developing and testing alternatives to slash-and-burn farming, experiments in nutrition, and cultivation of new crops. They also worked on social issues such as substance abuse, public health monitoring and awareness, and creating community on-line magazines. The point is not that everyone should design a dam, but rather that at each site the learners could work within the same methodology and same set of tools on projects of interest and import to them. That each site developed uniquely is an important result of this work.

The significant accomplishment in this work is demonstrating a significant gain in accomplishment among a population that had not previously exhibited such competence in educational institutions. This work demonstrates how to build on and enhance local knowledge. Within the design of this learning environment, the learners:

- Work from local knowledge and interests
- Bridge to other knowledge domains
- Liberate their local knowledge from its specific situated embodiment

While others have demonstrated the ability of people to develop technology and use science without the benefit of schooling,[29] the key point here is that the constructionist use of computational technology leveraged this ability and helped people apply their knowledge to new and varied situations in an extremely short period of time. The knowledge did not remain limited to the particular technology such as combustion engines, but rather they could use the malleable computer technology as a tool for understanding other domains. Moreover, bodies of knowledge such as mathematics and physics were opened to them in new and more accessible ways.

The role of the computer in this process is to draw on a set of skills that can be transferred to something different. Combustion engines provided a means for developing technical and diagnostic expertise; applications remained mechanical, however. Through computational tools, learners design and construct and thereby make the forms of knowledge they have more general. Developing technological fluency enables them to break out of the specific context and represent their knowledge in forms they can draw on in many contexts. Neither traditional education nor nonconstructionist use of technology enabled the recognition and leverage of this indigenous expertise.

Success was due to the existence of several critical elements in the design and affordances of the technology. The technology is a malleable, expressive tool for construction. We do not merely use the computer as a means of delivery of information or as a means of communication, although both of those uses are beneficial. Rather, the users program, in languages localized to their own language, building their own idioms, on projects of importance to them. By working on a variety of projects over time, they develop a technological fluency. The combination of relative freedom of expression and self-selected projects of interest facilitated the mobilization and leverage of indigenous knowledge.

The design of technologically rich learning environments and the reform of education. Discovering the engineering expertise and hacking spirit among so many Thai people who had previously not succeeded in school is a major benefit from the Emergent Design approach utilized in this project. Not only had Thai educators not built on this talent and intelligence, they did not even recognize it. The typical school reforms, despite their intention to promote creativity, problem solving, technological capability, and so on, also are generally incapable of discovering and leveraging such local knowledge. This is due to their top-down, preplanned, standardized, curricular approach.

There is no way to know beforehand for every site what will resonate and what local concerns and local knowledge exist. What one can assume is that there always is something. Using the Emergent Design framework, combined with principles of learning environments and open, programmable, technological tools, this "something" can be built upon and leveraged.

The work suggests a conclusion with a very broad sweep: The latent learning potential of the world population has been grossly underestimated as a result of prevailing mind-sets that limit the design of interventions to improve the evolution of the global learning environment.

**Trademark or registered trademark of the LEGO Group.

Cited references and notes

1. D. Cavallo, *Technological Fluency and the Art of Motorcycle Maintenance: Emergent Design of Learning Environments*, Ph.D. thesis, MIT Media Laboratory, Cambridge, MA (2000).
2. D. Tyack and L. Cuban, *Tinkering Toward Utopia: A Century of Public School Reform*, Harvard University Press, Cambridge, MA (1995).
3. *Ibid*., p. 85.
4. In the case of this work, the principles of the learning environment include constructionism, technological fluency, computer immersion, long-term projects, learner-centered activities, and connected projects. Later in this section I will provide a brief description of each concept. While it is beyond the scope of this paper to delve into detail for each, the sense of the work will emerge through the description here.
5. P. Freire, *Pedagogy of the Oppressed*, Herder and Herder, New York (1972).
6. J. Dewey, *Experience and Education*, Collier Books, New York (1938).
7. *The Essential Piaget*, H. E. Gruber and J. J. Voneche, Editors, Basic Books, New York (1977).
8. S. Papert, *Computer Criticism vs. Technocentric Thinking*, E&L Memo #1, Epistemology and Learning Group, MIT Media Laboratory, Cambridge, MA (1990).
9. R. K. Lester, *The Productive Edge: How U.S. Industries Are Pointing the Way to a New Era of Economic Growth*, W. W. Norton & Company, New York (1998).
10. F. W. Taylor, *The Principles of Scientific Management*, Dover Publications, New York (1998).
11. S. Papert, "Introduction," *Constructionism*, S. Papert and I. Harel, Editors, Ablex Publishing Corporation, Norwood, NJ (1991).
12. I. Harel, *Children Designers: Interdisciplinary Constructions for Learning and Knowing Mathematics in a Computer-Rich School*, Ablex Publishing Corporation, Norwood, NJ (1991).
13. *Constructionism in Practice: Designing Thinking and Learning in a Digital World*, Y. Kafai and M. Resnick, Editors, Lawrence Erlbaum Associates, Mahwah, NJ (1996).
14. D. Cavallo, *Leveraging Learning Through Technological Fluency*, master's thesis, MIT Media Laboratory, Cambridge, MA (1996).
15. M. Resnick, A. Bruckman, and F. Martin, "Pianos, Not Stereos: Creating Computational Construction Kits," *Interactions* **3**, No. 6 (1996).
16. D. Cavallo, "New Initiatives in Youth Development: Technology Works Enterprises," *International Conference on the Learning Sciences*, Lawrence Erlbaum Associates, Mahwah, NJ (1996), pp. 9–13.
17. S. Papert and M. Resnick, *Technological Fluency and the Representation of Knowledge*, proposal to the National Science Foundation, MIT Media Laboratory, Cambridge, MA (1995).
18. I am adopting the convention of capitalizing the word "School" when referring to School as an institution containing the prevailing mind-set around organization, process, learning, and teaching.
19. The Suksapattana Foundation was created by Thai MIT alumni in honor of the fiftieth anniversary of the King of Thailand's ascension to the throne. They procured funding and coordinated a number of socially beneficial projects in honor of His Majesty the King of Thailand.
20. Office of the National Education Commission, *Education in Thailand 1998*, Office of the Prime Minister, Kingdom of Thailand, Bangkok, Thailand (1999).
21. This paper will only describe some of the activity within one village learning center. For more detail, please see Reference 1, above.
22. *The New York Times* (January 21, 1997).
23. J. Sachs, J. L. Gallup, and A. Mellinger, *Geography and Economic Development*, presented at the Annual World Bank Conference on Development Economics, July 1998, World Bank Group (1998).
24. While I do not have strong evidence for this belief, I base this statement on a number of conversations with villagers and others who worked with them.
25. I mean this in the original, positive sense of "hacking" where the term signifies informal and creative engineering expertise, and not someone practicing malicious destruction.
26. This is the term in use in Thailand and so I adopt it, but prefer the idea of "indigenous technology" as it is respectful and not pejorative.
27. S. Phongsupasamit and J. Sakai, "Studies on Engineering Design Theories of Hand-Tractor Ploughs," *Proceedings of the Eleventh International Congress on Agricultural Engineering*, Dublin (1989), pp. 1617–1626.
28. S. Papert, *Mindstorms: Children, Computers, and Powerful Ideas*, Basic Books, New York (1980).
29. C. Levi-Strauss, *The Savage Mind*, University of Chicago Press, Chicago (1966).

Accepted for publication July 10, 2000.

David Cavallo *MIT Media Laboratory, 20 Ames Street, Cambridge, Massachusetts 02139-4307 (electronic mail: cavallo@media.mit.edu).* Dr. Cavallo is a research scientist in the Epistemology and Learning Group at the MIT Media Laboratory. His work focuses on the design and implementation of new learning environments and educational systems, at both the micro and macro levels. He also works on the design of new technologies for learning and the role of technology in facilitating the change process. His current projects are in Thailand, Brazil, Colombia, and a juvenile jail in the United States. Prior to his work at MIT, Dr. Cavallo led the design and implementation of medical informatics as part of a reform of health care delivery and management at the Harvard University Health Services. In addition, he has served as a principal and consulting software engineer at Digital Equipment Corporation's Artificial Intelligence Technology Center, where he led enterprise architecture and implementation efforts for using technology to produce change in the processes and operations of major companies by focusing on learning. He designed and built numerous knowledge-based systems for industry, most notable among them a set of intelligent simulations for training air traffic controllers. Dr. Cavallo completed his Ph.D. at the MIT Media Laboratory under the direction of Seymour Papert. He also holds a Master of Science degree from the MIT Media Laboratory and a Bachelor of Science degree in computer science from Rutgers University.