Models of growth — towards fundamental change in learning environments

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This paper proposes that a major reason for the lack of change in education is not due to lack of ideas about learning on a micro or individual level, but rather is due to a lack of models for growth and change at a macro or systemic level. We critique existing models of growth and provide examples of broad social change in other fields. We look at their properties and use those as a guide to thinking about change in learning environments. We propose that there exists a grammar of school reform. We provide examples of attempts to facilitate fundamental change at a large scale, and attempt to synthesise their properties, leading to thinking about new models for growth.

1. Grammar of school reform

David Tyack and Larry Cuban postulated that there exists a grammar of school, which makes deviation from our embedded popular conception of school feel as nonsensical as an ungrammatical utterance [1]. They describe how reform efforts, whether good or bad, progressive or conservative, eventually are rejected or denatured and assimilated. Reform efforts are not attempted in the abstract, they are situated in a variety of social, cultural and historical contexts. They do not succeed or fail solely on the basis of the merit of the ideas about learning, but rather, they are viewed as successful based upon their effect on the system and culture as a whole. Thus, they also have sociological and institutional components — failure to attend to matters of systemic learning will facilitate the failure of the adoption of the reforms.

> the challenge is to devise ways of implementing new educational practice on a large scale

Reviewing reform efforts of US schools over the previous century, one can note that there also appears to be a grammar of school reform. Two models predominate: either there is a predetermined, usually massive, fully formulated design imposed from above, with the intention of every location carrying out this reform according to its prescribed steps, or take a particular change, test it in a small, controlled setting, and then attempt to spread it through the entire system.

It is not enough to have a new model of education that looks beautiful on the drawing board or that has given superior results in pilot implementations. The true challenge is to devise ways of implementing new forms of educational practice on a large scale. This means finding a workable model for how a new paradigm of practice can take hold and grow. Yet, what should one do? At what models should one look?

Two terms comprise the predominant models for growth — replicate and take to scale. Both models are explicitly top-down and hierarchical, and implicitly view education as a series of depersonalised, decontextualised steps carried out by willing, receptive, non-transforming agents. Yet, as Tyack and Cuban demonstrate [1], these models have proved insufficient for creating substantive change on a large scale. Oddly, despite the lack of success, not only is there a scarcity of models, but also there appears to be relatively little attention paid to thinking about systemic change and creating alternative models. Moreover, the terms replication and scaling are themselves problematic and misleading for development in learning environments. It is easy to think of replicating the hardware of the reform (i.e. the technology, the textbooks, the materials, the curriculum); however, these may be necessary but have proved insufficient to produce sustainable reform. The level of description for replication is inadequate. The form can easily be copied but the substance remains elusive, and thus the reform is compromised. Canonical approaches such as pilot programmes suffer from becoming isolated experiences that do not influence the whole system and eventually die out or become assimilated. Train the trainer schemes work for rote applications and simple closed systems, but fail when needed to address open,

complex situations such as learning environments. The push towards scientific, research-based approaches aimed at improving education as mandated in the No Child Left Behind act [2] will suffer due to the implicit model of growth as a matter of grafting a series of discrete treatments into a complex system and assuming they will be applied faithfully and uniformly and will fit into the existing local cultures.

> the terms replication and scaling are themselves problematic and misleading

Naturally, the greatest positive impact over the largest population in the shortest time is the goal. However, major change cannot be implement everywhere immediately. Still, it is curious that when attempting large-scale effect, the time dimension is typically de-emphasised and the scale dimension maximised, usually to the detriment of the quality of impact. Rather than only considering maximising the number of sites (dimension 1) in the shortest amount of time (dimension 2), one must aim to maximise higher quality (dimension 3) over sites over time, even if this means slower growth in the initial period [3]. This approach implies the early steps should lay the groundwork for greater subsequent growth and that the path is not necessarily linear.

This paper presents an optimistic view of the potential for fundamental change in learning environments on a large scale and offers hope for addressing the great educational needs created by the digital age by drawing upon two of its important innovations — digital technology, and the approach to organisation and organisational change that has come in the wake of the technology. We[1] describe examples to evoke new models for change based on our experience in Brazil of introducing different approaches to learning with the intention of facilitating large-scale impact. While our approach to learning and learning environments draws upon a variety of thinkers such as Dewey [4], Piaget [5], Vygotsky and Freire [6], as well as many contemporaries, the ideas about models of growth are not limited to such an approach. We believe the lessons potentially apply towards paradigmatic change with other approaches to learning as well as change in other fields. Simply stated, we believe that global transformation in learning environments will more felicitously occur through the greater aggregation of local powerful personal experiences.

2. A new framework for thinking about change and growth

This paper describes a form of intervention that intends to take steps towards a fundamental change in learning environments on a broad scale. Naturally, this can only be determined longitudinally, so this report is premature in some respects; still, we believe it can contribute to thinking about how to more productively create change in an essential area.

[1] The author adopts the plural 'we' as the work has been a collaborative effort, and the ideas developed in this paper have been a group effort among the Future of Learning group at the MIT Media Lab and its collaborators.

2.1 Kuhn and paradigms

In *Second Thoughts on Paradigms* [7] Thomas Kuhn states that paradigms consist fundamentally of three elements:

- exemplars,
- models,
- symbolic expressions.

We find Kuhn's construct useful for thinking about what needs to be developed in order to create different mindsets and practice about learning. Exemplars stand for the canonical examples of the new paradigm. Models provide a way of thinking about what one should expect to happen, what behaviours are paradigmatic. Symbolic expressions (or, for our purposes, the language of description) serve an explicatory purpose. Rather than failing by attempting new blueprints, we attempt to create an emergent design that does not plan every step in detail, but searches for models of robust growth and uses Kuhn's description of the components of paradigms to provide principles.

2.2 Change as learning — micro-level change and macro-level change

Seymour Papert has suggested [8] using a developmental framework for thinking about systemic change in education. Just as one cannot merely tell a child his thinking is incorrect and then expect everything to fall into place, so too we cannot expect simply to tell a school, a school system, a country, that its schools are wrong and how to fix them. He has also suggested using a lens of micro and macro levels to think about change. We find it useful to think of systemic change as a problem in learning as well, and many of the principles for learning environments for individual learners (the micro level) apply for thinking about learning and development of the system (the macro level).

> we cannot simply tell a school system that it is wrong, and then expect everything to fall into place

As we see it, real change is inherently a kind of learning. For people to change the way they think about and practice education, rather than merely being told what to do differently, we believe that practitioners must have experiences that enable appropriation of new modes of teaching and learning that enable them to reconsider and restructure their thinking and practice. The limitations inherent in existing systems based upon information transfer models are as impoverished in effecting systemic development as they are in child development.

2.3 Ecological, viral and genetic models

We look to ecological and evolutionary models of change for ideas about how new educational patterns will emerge and how we can actively contribute to them. We believe emergent design to be a useful tool for educational change [9]. It

supposes an evolutionary model, where we are not passive observers: we design and introduce new variants along certain principles and see how well they grow. We study the fitness functions, the social niches, and the local ecologies of culture and thought. We study change itself as a process of learning. Our role as the exogenous element in conducting the learning projects is to show the existence of a new way of instantiating dynamic learning environments. We bring in powerful ideas about learning and through our practice illustrate how to put them to work. The possibility for spread and growth is not through the exact replication of the actions since the context will be different and the culture is dynamic. Rather, the goal is for the appropriation of the principles and the development of models of thinking so that the agents can adapt and apply with the ability to continually develop through reflection on the feedback and changing environmental conditions.

real change is inherently a kind of learning

When we run learning projects, we build upon and take practical action towards existing local concerns. We do not arrive with a fully pre-packaged project design. The design of learning projects evolves and changes in dialogue with personal, collective and local interests, conceptions, and needs. It does not assume that all host environments are the same and that one can merely impose a new model. This design dialogue is what generates involvement, commitment, and staying power — people are learning what they need to know to take action about issues that are important to them. Learners are motivated to master the knowledge they need to solve problems that mean something to them.

Emerging viral models of communication provide another exemplar for how non-hierarchical structures can facilitate growth and operation on a large-scale with intelligence at the leaves [10]. Indeed, people are developing these models simply because of inherent limitations in hierarchical models with centralised control. Open software development [11], small-world networks [12, 13], and peer-to-peer sharing [14], are all salient examples of effective distributed non-hierarchical models.

3. Cultural examples

How can one overcome the design dialectic between instantiating significant change — which implies small, local scale since one cannot implement major change immediately on a large scale — and having the change grow to significant scale without diluting the change? To answer this question we first look to some examples of macro-scale learning from other fields in order to shed light on the potential for fundamental change in learning environments.

3.1 Better eating in America

Consider the change in cuisine in the USA over the past forty years[2]. This was a large-scale change that altered the social landscape, which was based upon myriad micro-actions that emerged without any preconceived plan. One can say there is a more widespread collective intelligence about food. Until the 1960s, despite having the benefit of immigration from many countries, the choices for eating did not reflect the richness of the possibilities. Chinese and Italian restaurants, while ubiquitous, did not exemplify the beauty and flavours of the real cuisines. While in 1975 a North American had to live in a major city to have a cosmopolitan choice of foods, this was no longer the case in 2000, by which time a myriad of new food options have become widely available in the North American milieu. How did this happen? Here are some ideas:

- people gradually became aware of more options,
- televised cooking shows demonstrated new possibilities and made them believable and accessible,
- people gradually had more opportunities to try new kinds of food as new restaurants and more speciality stores opened,
- more learning and demonstration materials became available through magazines, books, and eventually the Web,
- cooking courses,
- people could experiment and try things out,
- people had powerful personal experiences in creating and enjoying new cuisines,
- a new feedback loop was established — more choices available, more choices made, even more choices available.

3.2 Paradigmatic change in manufacturing[3]

In most other fields, including traditionally staid ones such as the military or large manufacturing plants, models of organisation and process have begun to move away from Ford/Taylor/Sloan models of hierarchical centralised control of standardised operations [15]. These models were not implemented in a top-down fashion throughout manufacturing, nor were they invented in the research lab and rolled out to society at large. Rather, advocates implemented them in order to fit local microculture. Progress was viral and evolutionary.

rather than merely copying the ‘best practices’, they studied the underlying principles

The spread of ‘lean production’ techniques is illustrative of the growth and development of a macro change. In post-war Japan, Toyota studied the state of the art in auto

[2] Within cuisine, with Walter Bender I am deeply appreciative of gains made in microbrewing. Our programme director, Jacqueline Karaaslanian points out that fashion also fits this macro learning model.

[3] I am extremely grateful and deeply indebted to John Seely Brown, Kent Bowen, and Dan Roos for most of this information and analysis I received through personal communication. I have benefited greatly from their research, observations, and comments. The insights are theirs while the mistakes perhaps introduced are mine.

manufacturing [16, 17]. However, rather than merely copying the 'best practices' of the time, or their phenotypic manifestations, they studied the underlying principles. They investigated how they could improve the processes and fit them into local culture. Even more important than putting into place any particular set of activities, they built a process for continuous learning throughout the organisation. They instantiated the process of looking at what works, focusing on underlying principles, and adapting the ideas, even if it means a radical transformation. The work is not finished with the first plan. Rather, the process of continuous improvement is what is important, and people, rather than serving as unthinking agents implementing preplanned activities, become active thinking agents working and reflectively critiquing the on-going processes in order to improve them. Japanese auto manufacturing grew from the rubble of World War II into the envy of the industrial world.

Yet, despite the overwhelming evidence, many manufacturing experts in the USA and Europe tried to deny the success of the new paradigm. Initially, rather than re-assessing their own assumptions and critically analysing the ideas and processes, they attempted to find excuses for why the evidence must be misleading in order to justify their own mindset. They alleged that the Japanese took advantage of the workers and forced them to work harder (not true — not harder, but better). They alleged that Japanese culture fostered the individual creativity and problem-solving ability demanded at every level of the workforce (not true — this approach was not ubiquitous across all institutions in Japan, and in particular did not permeate Japanese schools, which were extremely rigid, hierarchical, and resistant to change). The point is critical as, even though the existing manufacturing system prided itself on results, objectivity, logic, and squeezing every bit of productivity out of the system, rather than accept and attempt to appropriate the ideas, because the results were produced by a different paradigmatic mindset, they tried to rationalise the data away.

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Eventually, tired of losing market share, mavericks within General Motors (GM) proposed to try the new Toyota management within GM. They took a plant GM had recently closed due to its problematic operation. It was the worst-operating GM plant, with labour strife, high turnover, absenteeism, and substance abuse among the work force, and low quality and production rates for their cars. They took the same work force, and in a pilot project called NUUMI under Toyota management applying Toyota manufacturing techniques, they turned the plant around so that it became by far the highest performing automobile plant in the USA [17]. A key metric is that it became the highest performing US plant relatively quickly, but that was more a condemnation of the state of US manufacturing than a statement of overall quality, as the NUUMI plant lagged Japanese-based plants. What must be noted is that what was recently assumed to be the best possible, that is US auto production, was rapidly outpaced, not through incremental improvement but by fundamental re-thinking of process.

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It is critical to realise that Toyota did not just try to transplant its practices back to the USA. Even though they documented the process, they knew it was insufficient to send manuals or run rapid training workshops. Developing understanding among people who could organically grow the overall process was key, as merely attempting to implant the practices would not produce the desired results. They knew that the results were more than just a sum of the practices and that it was the mindset built upon the practices that needed to be developed in place, not merely transferred. Neither Toyota nor GM adopted the initiative as something that could be realised in the short term. Both companies dedicated substantial time and resources, including their best people, in order learn the principles in their full context and to develop trust and respect.

As systems and processes improved, the 'intelligence' of the people involved improved. Detractors previously would claim that manufacturing workers did not have the 'capabilities' to carry out the debugging, problem-solving, decision-making, creative process design, statistical quality control, and so on. Clearly, this was not a fault of human capability, but rather a systemic flaw producing waste by not enabling people to develop their full potential. We hear similar critiques regarding the lack of capability among teachers and others who work in learning environments. Our belief and experience is that in learning just as in manufacturing this perceived lack of capability is due to systemic and not personal flaws.

After such a success at GM, what happened next? Despite the entreaties from some of the NUUMI team, GM did not agree to try the same paradigm in a greenfield approach. The advocates thought that instead of turning around an existing facility with its legacy, culture, and incumbent problems, beginning from scratch, a greenfield, would enable them to go even further. However, despite the recognised success at NUUMI, management declined. Unlike in education, the metrics of manufacturing are easily quantifiable. There are profitability, production rate, quality rate, pace of new model development, and so on. Yet, better quantifiable results do not guarantee convincing management of benefits or adoption of a different paradigm. GM does recognise they have much to learn from NUUMI and have used NUUMI to fashion their entire global manufacturing system and even placed a research centre next to the NUUMI facility. However, adopting the phrase of John Seely Brown, they have copied the 'syntax, not its semantics'. This distinction is crucial for thinking about learning on either a micro or macro scale.

Did this mean the end of the new paradigm in manufacturing? Not at all, as other mavericks in other places adopted the ideas and fitted them to their own situations. Thus, the growth was inter-institutional and bottom-up as opposed to intra-institutional and top-down. This fits how Richard Lester describes firms having their own cultures, and new ideas from other places, even best practices, cannot simply be grafted incrementally on to existing companies [18]. Rather, the ideas, no matter their merit, must be re-formed to fit the host culture.

What is clear from the manufacturing example is that fundamental change and macro-level learning is possible, even in places such as manufacturing where it was commonly believed that the personnel involved where not educated sufficiently to perform sophisticated thinking and analysis. What was needed was time, investment, continuity, commitment, and access to people with expertise and experience, and that the learning process was not merely a research-based accumulation of best practices grafted on to existing cultures.

3.3 Characteristics of fertile environments for growth

We begin to see patterns for felicitous conditions for macro scale growth. These include:

- volition — people must want to do things,
- appropriation and experimentation — people need to try out their own conceptions of the ideas in their own settings based upon their own priorities,
- concrete exemplars — there is a need to experience real examples of the ideas,
- community and communication — peer-to-peer interchange of ideas, explanations from practitioners at a variety of levels of expertise and experience,
- feedback — when one experiments one must not only see the results, but also get feedback from others,
- debugging — one must get the chance to 'make mistakes' and then use those to design and implement further work,
- materials — one needs things to work with that facilitate the new paradigm, and not merely work with the tools of prior instantiations,
- language — new paradigms re-appropriate old terms for new connotations, and even invent new terms to describe things in new ways,
- bottom-up and emergent — large-scale growth comes from the basis of many little contributions,
- time and continuity — major changes do not happen over night, as there needs to be enough continuous time to experience and develop the ideas in their full complexity,
- hope and expectation — people must come to believe that improvement is desirable and possible.

4. Emergent design and contexts for change

One cannot look at change in any major social realm such as education out of its cultural and historical context. Ideas about learning and education have historical roots, and ideas from the general culture have impact. That is, not only should one design to leverage cultural elements to enhance the change process, but also the full burden for change does not lie within the particular change effort alone. We divide the elements into three broad categories (reminiscent of Kuhn) — materials that enable leaning, cultural factors, and exemplars. Naturally, these categories build upon and inform each other. How groups choose to intervene and interact is emergent, both because certain elements are influenced by the broader culture and one cannot predict exactly what and in which ways ideas will take hold, be appropriated, and given meaning.

Materials that enable learning and doing are moving with increased rapidity into the world. These materials enable people to undertake their own projects and, through doing, learn a variety of things. Media plays a critical role in helping to form how we think about things due to the affordances of how knowledge can be represented in that medium. Computational media enables representation, sharing, and rapid modification of dynamic and complex ideas in ways that other media cannot. Evelyn Fox Keller has written eloquently about how the growth of biological knowledge was facilitated through the capability to model and visualise enabled by the computer [19].

The spread of computers, and their continuing rise in speed, memory, and connectivity combined with their relative dropping of price, has fundamentally changed the ways people learn and work. The range of options for learning and doing has dramatically increased, and thus people can learn and do more, with guidance and examples from more places, than ever before. The types of devices have also increased. Robotic devices such as programmable Lego bricks, other microcontrollers, cell-phones that are always on a network, more data enabled, digital still and video cameras, MP3 players, with more to come, bring more powerful devices into people's lives for appropriation for tasks of their choosing. Significantly, some localities are experimenting with giving each student a laptop computer. This action has the potential to fundamentally alter the environment in a large way [20].

Having powerful learning examples one can experience and participate in helps to break the mindset that learning must happen by being taught in schools. The attraction of such participation trumps the pessimistic view that technology is too difficult to learn and most will not do it. People are developing technological fluency in order to benefit from participation in the digital world. Combined with this more positive experience is a growing dissatisfaction with standardised, institutionalised schooling. Many people are beginning to reject the dominance of standardised tests and the resulting pressure on children and disfiguring education [21, 22]. Moreover, many are beginning to recognise that perhaps the greatest casualty of standardised, institutionalised schooling is children's creativity and joy in learning. Observing the harm to their children's spirit, many parents are increasingly turning to alternatives, including home-schooling in a variety of manifestations [23]. These

various small steps all help to combine into something much larger culturally.

4.1 Exemplar projects

Rather than focusing exclusively on micro-level questions (e.g. How might we better develop mathematical thinking?) with the implicit assumption that a cascading of growth to scale will necessarily follow, we pursue the possibility of taking micro-level approaches that improve practice and simultaneously aim to maximise the possibility for macro-level change. If one had the opportunity to take the challenge of everyone learning and try to dramatically improve opportunities, thinking and practice, what should one do? We provide some brief examples.

4.1.1 Pilot schools

Pilot schools enable the trying out of a particular set of ideas without the limitations of fitting into an existing institution or overcoming management resistance. They have focused on particular themes (e.g. math and science or performing arts or health), approaches to learning (e.g. progressive or basic skills or high-density computer use). Their primary benefit is to create examples of how things can be different. The major constraint inherent in pilot approaches is their difficulty in having an impact on the rest of the system due to their isolation (as we saw with the NUUMI pilot of General Motors).

4.1.2 Computer labs as islands of innovation and change

An early hope towards creating fundamental change was to use the computer lab as its own pilot to instantiate the potential of the computer as a powerful learning device; because the computer lab was new its use was not delimited by historical traditions (except the powerful ones owing to the fact that the labs were located in schools and thus inherited the constraints of the grammar of school). Costa Rica's early adoption of widespread computer labs at the primary-school level is perhaps the best example of what can be achieved. It has led to the development of technological fluency among a large proportion of the population, which in turn has led to Intel locating a semiconductor fabrication plant in the country. It has also connected many people to modern technology, new possibilities for learning, and set a precedent for national educational innovation. The major constraint here, though, is the same as in other pilot efforts. That is, while the design goal was that the computer lab would influence the school as a whole and help reform the teaching and learning not just in the lab but overall, the lab was isolated and could not broadly influence the schools.

4.1.3 Influencing the system by operating outside the system

Since the ideas of 'School' or 'Education' are truly paradigmatic in the Kuhnian sense, they carry with them a web of meaning, connections, processes, and models. Kuhn also described the incommensurability when the same terms are used by different paradigms [7]. Thus, any project that is situated in a school setting must overcome these inherent meanings, culture, and process.

Some projects then determine to work outside the system, setting up new learning environments that are explicitly not school. One such project was Project Lighthouse in Thailand, which we began in 1997 and continues to exist [24]. The four major thrusts within Project Lighthouse were:

- creating village technology learning centres,
- new programmes within the national non-formal education system,
- workplace-based programmes,
- a new 'e-school' in Bangkok.

A benefit of this approach is that . After all, no one knew what a village technology learning centre was, so there could not be existing rules. The success of this project was that certain prejudices based upon the standardised school experience were shown to be products of the system and not inherent in the culture. These included conceptions such as that rural families did not care about learning, that it was out of Thai culture for students to take the initiative and work in an open, learner-centred environment, that rural teachers were too poorly educated themselves to be effective, that once people learned technology they would abandon the project, that Thais could not innovate with technology, that it would take many years of prerequisite training before rural youth could effectively use the technology for learning and solving local problems. The downside to this approach was the same as the others: the overall system could not adjust on a broad scale to take advantage of what was demonstrated. The government did pass a new national education act, influenced in part by Project Lighthouse, that set aside a fund for experimental projects, and the current Prime Minister, an early benefactor of the programme, has instituted a number of laws to enable everyone to purchase computers, develop technological fluency, and build educational opportunities.

4.2 Mass attempts in large systems — Curitiba

In order to get beyond the limitation of pilot attempts while still accepting that immediate mass attempts cannot produce significant change, we focused on attempts within an entire city system. Curitiba is a city in Brazil famous for its bold and innovative attempts at urban planning, transportation, and sustainable environmental development [25]. In the current municipal administration they are extending this pioneering spirit to public education, modernising not only the organisational physical infrastructure of the schools and improving traditional education, but also investing in bridging the digital divide and giving access to computation. However, again they are not merely computerising existing learning environments, but using the technology to dramatically improve the city, the environment, and the schools.

The Future of Learning group at the MIT Media Lab collaborated with the Curitiba municipal education secretary Paulo Schmidt and his team to use the new computer presence to carry with it a new epistemological approach as well. In order to take root within the system as a whole, we adopted a three-pronged approach. We began with small workshops for around twenty teachers at a time, and a team within the secretariat dedicated to supporting the use of

technology to improve learning. The goals of the workshops were to not only introduce the new technologies to be used, but to use these workshops as models of the types of learning environments we hoped these teachers would begin to create for their students. Thus, the activities we put into practice served as the basis for reflection on learning and school that we would discuss in the course of the workshop. Also attending the workshop was a new staff group within the secretariat devoted to supporting learning with technology. This group would continue to hold workshops for more teachers on a regular basis.

one is not encumbered by pre-existing mindsets about what one must and must not do

However, as there are more than 100 000 students in the municipal public school system, there was no way that small workshops would ever reach all of the teachers. We thus ran a larger workshop, the 'Instituto de Inverno[4]', attended by more than 120 teachers from Curitiba, as well as activists from other projects throughout Brazil.

A primary goal was to give a sense of critical mass towards change. With twenty at a time, with two or three from a school, participants did not have a sense of change. However, with more than one hundred, even though this was a small percentage overall, the teachers began to believe that there was critical mass sufficient to make something compelling happen, and, critically, that the administration was committed to change.

Another major goal of the institute was to challenge the implicit mindset about the grammar of school by creating an environment for participants to experience powerful personal experiences. We could not do this by giving arguments in the abstract about learning, even though thinking about learning was critical for our purposes. Nor could we do this just by teaching a new computer environment, even though a critical element of what we bring is creative, expressive, and constructive use of computational technology to open new possibilities for learning and new possibilities for accomplishing the logistics of progressive learning on a large scale. Rather, we try to create an environment for powerful learning experiences to help create agents of change. We want these participants not to blindly follow a new set of instructions, but to further develop the capability to think about learning and learning environments. By developing this capacity and then having the freedom to apply these principles through reflective practice while also participating in a forum for collaborative discussion, they have the chance to continue to develop and progress autonomously as more effective actors.

We organised the institute into five major parts:

- morning talks to the whole group, focusing on learning and the underlying ideas, by a wide variety of people with varying areas of expertise,
- project work by teams of participants,
- small mini-workshops on using the various tools available,
- small group discussion on topics of importance to the participants,
- daily wrap-up discussions with the whole group, reflecting on the institute.

As always, the institute itself tries to practice what it preaches regarding learning environments. It is project-oriented, learner-centred, interest-based, and situationally driven (see Figs 1 and 2).

There is one critical difference, however, and that is time. When we work with children, there is ample time. We are not limited by only having a 2-week workshop period. Children can work on projects for a whole year or more, and thus have the time to go sufficiently deep to do serious work, uncover important ideas, and gain the satisfaction of accomplishing difficult tasks. In workshops we cannot do this and this has two fundamental limitations — the first is that there is no opportunity for the learning just described; the second is that there can be the tendency to merely replicate the workshop experience in the schools, thus negating the ideas of the experience. Not surprisingly, but true to how learning works, even though we tell participants that when there is time this is not what we do, they tend to do as we do and not as we say.

The experience led the teachers to use the final afternoon to discuss how to continue the spirit of the institute and improve the schools on a broad basis. One group proposed starting some new pilot schools where all the teachers were dedicated to the change. One teacher from this group had previously described how social pressure from her peers made her reform of her own classroom exceedingly difficult. Her students loved her class so much that they told their friends and parents who naturally put pressure on the school principal and the other teachers to change. Unfortunately, rather than change they put pressure on the popular teacher to toe the line and not be different. She did not desist but at the beginning of the institute she was pessimistic about the possibilities for change. Now energised, she and colleagues proposed new schools where all would be committed to change. This suggestion was popular until another teacher warned that the majority of children would not be able to attend the pilots and would thus be disadvantaged. She also said the new schools would be isolated from the overall system and would be in danger of eventually dying out. This argument proved most popular among the teachers until we suggested that both ideas could be accommodated. There could be a group of pilot schools that would serve as exemplars to the whole system.

[4] This translates as Winter Institute and follows the joke of Secretary Schmidt as the previous year we had invited him and his team and teachers to our 'Summer Institute' held in July in Mexico City, sponsored by Telmex and the Inttelmex Foundation. He responded they would be happy to come but inquired as to why we were holding a Summer Institute in July in the middle of winter. Accepting the perspective of the southern hemisphere, we held our Winter Institute in July, 2002 in facilities in a park in Curitiba.

Fig 1 Teacher soldering own electronic sensor at Curitiba Winter Institute.

The rest of the system would also strive to improve and adapt as there would be interchange among the projects.

The city would also create a new non-governmental organisation in order to continue past changes in city administration, as continuity is a major problem. The foundation's mission would be to support the schools by providing learning experiences for teachers, students, and parents, and by co-ordinating projects among the schools.

Fig 2 Teachers from Winter Institute with their robotic multimedia system for young children learning hygiene.

Significantly, I received an e-mail from one of our participating teachers ten days after the event. She said she told her colleagues how wonderful the institute was and how excited she and the other participants were about how they could change the system. She felt frustrated that despite her advocacy, her colleagues who did not attend were not moved. I reminded her that before she participated in the institute, she too would not have been compelled to change just by hearing about it. She had to experience it. This illustrates the limits to growth. Just hearing about a new paradigm is insufficient to motivate a change. How to spread the experiential component is the critical issue.

4.3 Emergent participatory design — São Paulo

The São Paulo municipal school system has more than 1.1 million students in approximately 1000 schools. Effecting change in such a large system is non-trivial. Fernando Almeida became the education secretary in 2001. He told us that he would not support pilot projects within the schools as 'quality for a few is a privilege'. He challenged us to come up with a plan that could have an impact on all the schools in as short a time as possible.

Building upon the Freirean tradition [6] to which the secretary was committed, we proposed a project we called 'A Cidade que a Gente Quer'[5], where students would build computational models in a variety of media modelling how they would choose to improve life in their city [26]. The basic premise is that students will perform a critical inquiry into the life, culture, and functioning of their city and create new models of how they would like some aspects to be. They can either address something they perceive as problematic (e.g. waste recycling, transportation, energy generation and consumption, employment, crime), or propose a model for a grand new idea to provide some elements desired but not previously possible or conceived (e.g. interactive public entertainment and art spaces for the community, dynamic customisable clean transportation, instant playgrounds, responsive environments).

The project is based upon constructivist ideas that merge Freirean tradition and constructionism [26]. Constructionism builds upon constructivist ideas by asserting that learners construct their own knowledge especially felicitously through the thoughtful and reflective design and construction of personally meaningful artefacts [27]. The strength of Freire's tradition is to work on what he termed generative themes, as determined by the community of learners. The unifying concept of the focusing on the city provides a generative theme whereby any participant will have their own ideas and beliefs and can use these to guide their conception and implementation. Moreover, the participants can identify with the situation as they can place themselves inside their projects, using this as a means to guide their design.

We also wanted the project to better re-link the schools and their communities. The community provides the basis for

[5] This translates as 'The City That We Want.'

study and content. The school becomes a contributor to the improvement of its host community. Moreover, we designed the project so that students could place their projects on the Web and to discuss the merits of the ideas and analysis through a forum. A major goal in addition to the learning in mathematics, science, and other disciplines, was for the students to develop the belief that they could have impact on their environment and that they could be agents for positive change. Just as the desire to make a design implementation actually function forces the learner to deal with the underlying scientific principles, the desire to convince other participants of one's own analysis and solution requires the learner to support his or her argument with data and reasoning.

We designed this project not just as an end in itself, but also with a goal of how it could best help lead to macro change, so that the project itself could serve as an object to think with [28, 29]. We proposed the project as a concrete example of how to work in a more open, active learning environment and what content could be different. We would utilise this experience as a case for the teachers and administrators to reflect upon ideas for teaching and learning. The project is case-based active learning at the macro level.

We intentionally did not tell the schools exactly how to implement the project. We tried to navigate the dialectic between proposing an intervention from outside the system in order to help break its dynamic equilibrium and knowing that people will tend to resist changes forced upon them from the outside in which they have no vested interest.

We engaged in the design of the project with the secretary of education, his staff, and the technology group of the secretariat. It was important not only that each of these groups had a sense of ownership of the project, but also in order to improve the design through the incorporation of their local knowledge. Once we had obtained approval, we held an open session for administrators, pedagogues, and teachers of all the schools to present the ideas, show the project, show what similar things we had done elsewhere, introduce the technologies, show examples of projects children and teachers had previously constructed, and to take their questions and have a discussion, leading to the local and global decisions (see Figs 3 and 4).

4.3.1 Design for growth

We introduced two essential elements fitting to our model of growth that are curiously atypical of most efforts — schools had to volunteer into the project in order to participate, and the schools themselves would decide how and with whom they would implement the project in their schools. It is rather obvious that in any large organisation, when compliance is compulsory results suffer: people either ignore the new programme, comply minimally, waiting until the fervour passes, or even undermine the new initiative.

We wanted to focus on the dimension quality first, not fixating on number of sites at the expense of quality. The underlying hypothesis is that fewer places of higher quality activity create more felicitous conditions for sustainable growth with quality over the long term than a larger number of initial sites with subsequently lower quality. The design tension is over creating a sufficiently large, critical mass of sites such that they will not die out, combined with a mechanism for communication and contagion so that they can affect (or infect) other places.

Fig 3 São Paulo youth with their 'intelligent bus' built from scrap materials.

By asking the schools to determine how they want to implement the programme locally, we set the conditions for growth on a number of levels. Firstly, they come to be the owners and implementors of the project, not merely order followers. This typically ensures a more dedicated

Fig 4 São Paulo youth with their 'citizenship robot'.

participation, but also lays the seeds for growth, as they now are charged with thinking about the issues underlying the project. This also enables the project to take advantage of their local knowledge as well as their imagination and ideas. From the outside, we could not know who might be the best teachers to participate. By following an emergent participatory design, we were better prepared to overcome the limitations of centralised, hierarchical, bureaucratic approaches.

Another benefit of this approach emerged quickly — virtually all the schools adopted different approaches. This diversity of ideas and examples gave a more fertile ground for the next round of participants to appropriate models, improve on ideas, and extend the possibilities. This helped solidify the idea that learning should not be one size fits all and can be customised to local ideals, interests, and concerns, and that deviation from a standard model can be a strength.

4.3.2 Lessons from this experience

Key to the ideas about models of growth was that the experiences did not remain only in the locality in which they occurred. Because we designed for collaboration across the system, the diversity of experiences, both the successes as well as the means of dealing with events that did not go as anticipated or were difficult, were concrete cases for reflection and discussion. Just as at the micro level, having to construct a mechanism to accomplish something provides a variety of fine-grained situations for learning and discovering principles, this approach is designed for construction at the macro level by the participants. Rather than dictating exactly what to do with all the residual problems, we allow for the initial potential lack of total certainty about action as this can serve as the learning basis so that people can continue to make better decisions on their own, as well as feel pride, accomplishment and ownership over the project. They are thus developing capacity, which not only aids sustainability but also creates openings for innovations from every level of the system, not just the curriculum designers and administrators.

> we intentionally did not tell the schools exactly how to implement the project

We had hoped to have a high-bandwidth telecommunications infrastructure installed in time for our project, but unfortunately its deployment was delayed. This deeply limited one critical aspect of the project: we had wanted different groups of students in different schools and socio-cultural areas of the city to communicate, deliberate, and collaborate over their projects. In an emergent design approach this is both an important learning aspect and an important part of the model for growth, as the connectivity expands the circle of interaction for ideas on projects, mechanisms, and solutions. Lack of connectivity limited the types and amount of interaction between the teachers and supporters of the project.

We also had to work with three different secretaries in the three years of the project; the disruption and lack of continuity occurring with each administration change also severely limited the possibilities for change. Such intra-institutional problems highlight the difficulties of change as well as the need for broader models of growth that do not depend upon any one institution. With this in mind we had already planned and began a similar effort with a Brazilian foundation that operated schools around the country. Our purpose was to enable continuity by planting yet another seed, even if elsewhere, even if local again, and then to re-connect back. It is both the recognisable 'signature' of the new local experiment and the mechanism of re-connecting back that are the keys to sustainability. It also is the recognition that individuals more than institutions are the generators of growth, enhancement, and sustainability.

4.4 Combining in-person and on-line — Bradesco foundation schools

The Bradesco Bank is the largest private bank in Brazil. As a contribution to the society, Bradesco runs a system of forty schools attended by over one hundred and five thousand students. In keeping with their basic charter, the Bradesco schools are to be found in every state in Brazil, a large country with profound regional differences in culture and social life. These are private schools, but tuition is free. Students are either children of bank employees or are chosen according to highest economic need. In short, the Bradesco schools serve students who would otherwise be in the public schools.

Bradesco engaged our group because they felt they were not getting the full benefit of the considerable investments they had made in technology. The Bradesco schools were well equipped with computers and Internet connections; they had students programming in Logo and doing robotics. Typical of many schools, Bradesco wanted to get better results with computers.

4.4.1 Activities with Bradesco

Our engagement at Bradesco took place over an eighteen-month period. We aimed for a combination of types of interactions; in-person, from prepared materials, and through synchronous and asynchronous on-line experiences. We ran small workshops as a primary activity. Teachers from every school except one attended these workshops, as well as some teachers from neighbouring schools of the public system. When some administrators and technical help first heard a general description of the work, that it would be 'project-oriented, learner-centred, constructionist', they replied 'We already do that'. By the middle of the first week, however, the same group of people told us, 'This is quite different. When we do projects we decide beforehand what the projects will be. We don't let them just choose'. We have had this experience in several locations. The terms had been disempowered and schoolified, losing their essence. Only through the participatory experience did the differences emerge.

Over the course of our engagement with the Bradesco schools, we have conducted a range of activities.

- We ran small intense workshops focused on re-thinking the learning process and environment, using the project theme as a coalescing force, and introducing the

technologies as a means of displacement from normal experience, habits and mindset.

- We held big meetings to give talks about learning, to introduce the basic ideas and orientation of the emergent paradigm, and the kind of learning projects that we do, and the technology we use. The talks were broadcast throughout the school network and archived on the foundation's Web site.
- We held small group discussion meetings, which were forums for reflecting on practical questions about implementing various projects ideas, as well as big theoretical questions about learning itself.
- We initiated regular monthly videoconferences dedicated to thinking about learning.
- We set up an electronic forum, so students and teachers could get on-line when they were stuck and get help. It turned out there was no time in the teachers' schedules to go on-line, and electronic chat was not part of the culture. So we shifted course and started setting up on-line meetings at particular times on pre-announced topics. We are now developing new Web-based environments designed more in the spirit of constructionist, collaborative learning and less along the lines of information presentation.
- We made a lot of short how-to videos relating to different facets of computational technology, programming, and sensors. This is a resource for the teachers and students who would otherwise lack the initial domain knowledge to begin to tackle more complex learning projects.
- We made videos using the technology but focusing on powerful ideas for learning.
- We gathered multimedia documentation on all the various learning projects that were under way in different schools.

We overcame some of the previous limits to growth as, when we arrived at new schools, thanks to the videoconferences, most people already knew what the projects were like and what technological tools were involved. Thus, instead of having to introduce everything at each site with the incumbent delays and confusion due to lack of familiarity, the barriers to entry at each site are diminished and things start much faster and with more depth.

Initially, there was the tendency to copy the first projects, but over time, because each learning project becomes individual, the set of exemplars expanded and diversified as more and more of the participants' local voices and viewpoints were expressed in the projects. There started to be various genres of learning projects, with strong individual variation within them (see Figs 5—10).

4.4.2 Digital documentation process

Another way of making learning visible was to have students document their projects using digital materials [26]. This included digital cameras, video, voice, and text. We have always tried to have children document their projects. The idea was to have them reflect upon their ideas, and to take a

Fig 5 Bradesco Foundation school in Manaus project to clean the rivers.

stance about what they were thinking and why. The different media, the representation, and the narrative all serve to enhance the learning experience.

As the students documented their projects in digital media, we made the material available at a fine-grained level for others to browse and search through the Web. This helped overcome a previous limit to growth of our projects. The main limits were technical (teachers did not have enough technical experience and expertise, as well as often lacking a 'hacking' spirit) and pedagogical (they did not have the experience of teaching and learning in a non-traditional environment). The images,

Fig 6 Bradesco Foundation school in Bodoquena project studying water quality to create a fish farm.

Fig 7 Bradesco Foundation school in Bodoquena studying cooling of classrooms and dormitories.

videos, and accounts of the participants combined with commentary and connections layered on top of it, helped to overcome these limitations.

4.4.3 Lessons from the experience

Through taking part in our workshops, the Bradesco people — students, teachers, and administrators — shifted their understanding of what they are working to accomplish from the technology to thinking about teaching and learning. At the final reflection meeting during the first one-week workshop in Manaus, one student gave the bittersweet comment that 'I won't be able to enter my classroom on Monday and look at it in the same way'. We were happy that he had such a moving experience with us, but still saddened that he would enter the old-style classroom. However, in Manaus, the school director

Fig 8 Measuring temperature and relative humidity.

Fig 9 Studying air flow and heat transfer.

told the students it was now their obligation to take this special experience that they had received and offer it to the other students of the school. The students and the excellent computer room teacher then continued to run workshops for groups of students, and the richness and diversity of projects increased considerably.

As witnessed in other programmes, where the school director was most involved, the projects progressed better. The Foundation's technology team accompanied us in every workshop, and they were a strong source for growth, support and development. They, the school directors, the activist teachers, the continuing students, the parents who witnessed the changes in their children, chose to become the engine for sustainability and further development.

On the other hand, there was a limited use of the on-line environment that hindered development. Primarily, it was not in the school culture to spend time on-line. Teachers' time is more than fully accounted for already. They have virtually no extra time for seeking answers to their questions, for edification, for curiosity, for improvement. This obviously is a

Fig 10 8-year old girls' investigative report on school bathrooms.

limitation for improvement within a system and a reflection of an outdated view of their function as purveyors of fixed information and not as developing professionals and learners.

Still, what was clear, relative to thinking of models of growth, was that through enabling powerful personal experiences in learning environments based upon constructionist uses of computational technology utilising generative themes connecting to culture and personal interests, combined with a multimedia support and collaborative environment made possible through broadband telecommunications access, we were able to overcome previous limits to growth. Previously, approaches based upon powerful personal experiences had an inherent limitation in the number of sites in which one could create environments with sufficient contact to catalyse the powerful experience. There was a vicious circle, where the limit on contact constrained the development of people, which constrained the number of sites for fundamental change, which limited the potential for scale. While still far from ideal, by using videoconference and image and voice combined with text and computational media, other sites ramped up projects much more quickly, and ideas, experiences, and shared reflections had a chance to spread through a larger network more effectively.

4.5 Evolution of projects

Having a telecommunications infrastructure combined with an overall sense of purpose enabled us to use the 'Cidade' project generative theme to not only develop a local learning culture but also to enable a broader learning culture in a heterarchical manner. We will use the evolution of a project across sites in order to highlight key facets towards technologically enabled models of growth. Significantly, this was not the only project that was appropriated and re-appropriated across the sites, but in the interest of space is the only one we mention here.

In the Curitiba workshop a group of teachers chose to do a project around food and hunger. Concerned about the amount of hunger in Brazil and the world, the teachers wanted to sensitise their students to the issue. They decided to make a scale that would weigh the amount of food wasted within their school, and use that to extrapolate how much food might be wasted on average across their city and country, and then to calculate how many hungry children could be fed with this leftover food.

A first observation was that although virtually everyone has at some time weighed themselves on a scale, very few thought about the mechanism for weighing. This highlights a recurring theme of searching for understanding of mechanism, of artefacts and systems. Rather than telling the group the answer, we engaged in an exploration of how it might possibly work. In this large gathering many of us served as facilitators. As the group of teachers had not had the benefit of prior engineering or technical experience, they asked a number of us at different times how we might approach building a scale. Not by plan, each of us engaged in a discussion with them where different ideas for mechanisms developed. Rather than finding this confusing or 'wrong', this diversity of opinion was an asset in that in many interesting and rich problems, there is not necessarily one right way to solve it. If we gave them the answers and the steps, this chance for analysis and learning would be lost. On the other hand, we do not say nothing either. We help based upon a number of factors, but more with the goal of fostering the learning process as opposed to having people quickly converge on a 'right' answer.

When we showed this project during the first Bradesco videoconference, the project idea resonated with a group from the second workshop site located in the northeast of the country where traditionally hunger has been a major problem. This group could neither merely copy it, as they did not have the same materials, nor could they see exactly how it worked. The stories and images with which to work were evocative and not prescriptive. Whereas the first group used a bend sensor to determine weight by translating calibrated movement into weight, the second group did not have a bend sensor and had to use a rotation sensor. Rather than being able to translate vertical movement into weight, they had to translate rotation. However, in the best constructionist sense, a new sub-problem emerged: how to enable small quantities of weight to move accurately while still maintaining sufficient tension so that an empty scale would not simply unroll. Searching for other mechanisms to keep tension while allowing movement, the group settled upon a spring. Searching for delicate springs, the group found one in a ballpoint pen. Thus, while ostensibly the projects were 'the same', the experiences were quite different. We did not want everyone to repeat the same experience, as it would not have the same meaning, import, freshness, sense of discovery, or emotional connectedness.

The Cidade project as a whole, as well as particular projects within it, were easily adapted by facilitators from the Omar Dengo Foundation and applied in schools in Costa Rica. Costa Rica has a basis in constructivism, constructionism, computer programming, and Freirean ideas. Through their experience, merely by hearing a description of the idea and viewing examples of projects, the facilitators from the foundation were able to quickly implement the project and achieve exemplary results[6]. Working in an intellectually fertile environment, with experienced and committed people, they were able to quickly adapt new resonant ideas.

the goal is to build an understanding of the underlying design choices

We have described this process as the roots, fruits, and shoots of projects [9]. There is a local rootedness, in this case, concern about alleviating hunger. The fruits are in the learning at a variety of levels, within the disciplines (e.g. knowledge of physics of the mechanisms, the mathematics underlying the calculations), in learning management of one's own learning projects, and in the meta-knowledge behind solving problems, searching for mechanisms, working by analogy from examples, using powerful ideas, etc. New shoots develop as the learners build new mechanisms and try the new and old mechanisms in new project areas. As this process reifies, new

[6] Personal observation and communication with the Omar Dengo Foundation. They are currently preparing a report on their experiences, and are attempting to expand the effort.

roots develop and a virtuous learning cycle can emerge. This is what enables meaningful, bottom-up models of growth.

5. A tool for documentation and re-appropriation

Ideas of constructionism, the uses of digital documentation, and the goal of making ideas appropriable, leads us to the design of support materials and collaborative environments to support more widespread adoption of new learning environments. We view the underlying mindset of Web publishing as fitting primarily at two extremes of a continuum — typically, there is either high granularity (publication of complete, finished projects), or low granularity (step-by-step instructions of what to do to complete a project). High granularity provides full concept examples of what to do, so if one is fluent with the ability to do it, then it is rewarding. If one is not fluent, however, then there is no handle with which to get started, or, once there is complexity in the development, one is lost. At the other extreme, step-by-step instructions are useful if one just wants to complete a particular project, but are not so useful if the situation differs or if the goal is to build an understanding of the underlying design choices. This is because at either extreme, the design choices and principles were made by the project designer and are thus opaque to the viewer. We are designing for learning through appropriation, and thus will present projects at various levels of granularity, along with commentary, animation, and opportunities for collaboration.

6. Developing new models of macro-level learning

With the critical mass of deployment of and fluency with computational technology new ways of learning and knowing became more possible at a broad scale. The inertia of institutions, their proclivity towards acting as immune systems isolating, rejecting, or co-opting and assimilating change, can make one pessimistic towards the possibility of change. While any one particular institution may resist change, change can occur through the work of individuals through the culture. Manufacturing is one example of this. In learning, the spread of the influence of Freire is another. Freire created his most powerful exemplar of his ideas in the northeast of Brazil. His compelling description of the ideas in *The Pedagogy of the Oppressed* provided the language and models [6]. His influence did not reach global proportions through any institution, through replication of his project. Rather individuals appropriated and adapted his ideas to their local interpretation and situation. As they tried the ideas, their thinking developed. Others then were influenced. This recursive virtuous cycle, where each stage benefits and builds upon itself, is typical of a new model. However, simply challenging the mindset is not enough unless one provides the basis for new models. There must be something to replace what is being challenged.

We are not claiming to know exactly how learning environments of the future should function, nor are we claiming we know exactly which model of growth will optimally facilitate the development of better learning environments. We are proposing a more nuanced study of models that enable learning on macro and micro scales, developing new models and mechanisms that can optimise impact over time.

6.1 Paths of change

Rather than focusing only on change within an existing institution, we adopt a broader view of change with human agents as carriers hosted by a variety of institutions with the change developing through improving practice and developing ideas through the reflective trial and error of creating exemplars. We note that dramatic changes can occur more easily in situations like manufacturing or in scientific fields, as the resistance is less, the metrics of and mechanisms for feedback are better, and the barriers to entry are lower (there are far more resources and thus it is far easier to start a company with different ideas and demonstrate effectiveness than to start and maintain a new school or learning environment with different ideas). Still, the critical element is change through powerful personal experiences, with the ensuing possibility to create and join new efforts attempting to further the growth and development of the ideas and practice. Connectivity and new computational media afford new possibilities to extend the time and space for collaboration such that these powerful personal experiences can be shared.

Kuhn noted how scientific progress was not just a monotonic accumulation of scientific facts and knowledge, but rather that world views predominate. The mechanism for change of world view was through the existence of a critical mass of data that contradicted or did not fit the prevailing paradigm. This enabled the acceptance of new models. We can note that on the micro scale this path holds as well. Children do not develop through the simple monotonic accumulation of new facts, but through development when the world pushes back and previous ideas can no longer account for the new phenomena and ideas.

> technologies can be generators when they are designed for appropriation and adoption

Thus, we believe that a key element to enable fundamental change is to create experiences that challenge ideas about learning and simultaneously provide the basis for the reflective development of alternative models. A focus then is not on maximising scale too quickly, but rather on planting the seeds for subsequent impact even if it appears slower in the short term. Maximising the short term typically is at the expense of real impact over time. Returning to the characteristics of macro-level learning enumerated above, we find that these remain key elements for developing new models of growth. These include the need to experiment, voluntary participation, appropriation, concrete exemplars, communities of practice, communication of ideas, feedback, debugging, new materials, development of new language, a bottom-up, emergent nature, time and continuity of purpose, and built upon a passion for a significant improvement.

6.2 Generators — things that make more things

Another element for re-framing is to not look only at structure (i.e. the thing for replication) but to examine the dynamics (i.e. the process of change). One must cede the possibility for certainty of outcome, and look instead at creating environmental conditions for growth. Instead of creating a particular thing that one would propose to replicate to scale, we can look at creating a mechanism that can grow and adapt. Such generators can be people, technologies, powerful ideas, and exemplary activities that others may appropriate.

We look to develop people as generators through experiential means. Through compelling experience people can gain the volition to become the early adopters of the new practice. John Seely Brown uses the term 'stolen knowledge' to refer to how practice can be appropriated by people since so much of practice is implicit and thus instruction is an insufficient means for acquisition [30]. Not only does this framework fit a model of growth through a community of practice, but also we particularly appreciate the subversive appeal of the idea of 'stolen' as it has been our experience that belief in being part of a movement to create change in itself helps to fortify the commitment to change. Taken in this light, we view people as generators of change not in the 'multiplier' role as a cog in a machine cranking out identical parts, but as adaptive creators, developing more people and new ideas to continue to fit, adapt and alter the environment. We aim for exponents of exponential growth, and not multipliers for geometric growth.

Technologies can be generators when they are designed for appropriation and adoption. This fits a model of enabling authorship and creation within the user community, and not merely as information delivery devices. Their function as generators is dependent upon the possibility for development of fluency of use and expression. When people are comfortable to explore and create, and there are communities of practice and communication mechanisms for sharing ideas and creations, then growth can be facilitated. The development of the personal computer is an example of this, as is the free software movement.

Powerful ideas are also generators. As people come in real contact with such ideas, they appropriate and use them. Our use of generative themes within our projects is based upon this idea. Not only can virtually everyone have an idea for development from good generative themes, but they too are carriers of powerful ideas within the activities.

6.3 Exemplars — powerful new learning experiences

Integrating different learning environments into existing institutions is non-trivial. We have gone outside the system to create new entities (as in the village technology centres of Thailand) and we have used workshop experiences in schools to create an ambience for different practice[7]. The workshops were intended to:

- provide powerful personal experiences of a different approach to learning,
- break pessimistic mindsets about people's ability to learn,
- surface, reflect upon and discuss participants' own prior explicit and implicit assumptions about learning to the surface, and compare them to the new experience,
- encourage participants to think about the learning process itself,
- engage in thinking about the design and practice of learning environments in the local context,
- identify local people whose thinking and acting appear promising so that they can take on greater roles for change,
- debug our own thinking about the mechanisms of learning and our own pattern of practice in designing learning environments.

It is only natural, then, that the learning experiences the participants have in the workshops became valuable as case studies of learning itself, as objects-to-think-with, as concrete experiential data that could be shared and discussed and pondered and brought to bear on ideas about the basic mechanisms of learning and teaching. Learning things in new ways themselves, seeing other people learn things in new ways, seeing everybody operate as learners far beyond previous expectations, thinking about the basic mechanisms of learning — this was the long-term takeaway for the participants. They added a new stock of powerful ideas and techniques to their repertoire as learners — and as students, teachers, and administrators. They began to act and think in new ways.

This is not the work of a day, or a week; this is not a work of rhetorical persuasion, or philosophical conversion, or administrative fiat. This is a process where the chance to experience directly a powerful new practice of learning leads to a fundamental rethinking of what might be possible, and how to achieve it.

We found with Bradesco that if we can first establish the methodology, the 'how' of creating learning environments, then we can work to continually add content, the 'what' of learning environments. Significantly, this is not the same content as traditionally is taught in schools. The old content is technologically dependent upon paper, pencil, and textbooks. Ideas believed to be out of the reach of many children were not necessarily due to the inherent complexity of the content, but of the limitations of the materials. A key to models of growth of new learning environments is to develop new content that enables new learning.

The central focus of the workshops was to reflect on the learning process itself. This is a distinctive feature of our learning paradigm — epistemology all the way through. In order for a deep change to take hold and to avoid merely repeating the same experience, we want everyone to become a learning theorist. Sid Strauss points out how this is true in learning environments implicitly as the models of learning

[7] The term workshop itself is problematic as people have come to understand workshops, particularly those using technology, as isolated environments introducing the syntax of a software tool or some technique of action, and not as part of an on-going process for re-thinking and change. We sometimes use the term atelier but have not yet settled on a term that invokes the proper full image.

people hold guide their practice [31]. Yet, these models are not part of an on-going process of reflection and improvement. It is popular to speak about the importance of learning to learn, but how often do we get the chance to truly reflect upon our learning and to learn better ways of learning?

6.4 Lessons from the Bradesco experience — a model of growth

What we witnessed in the Bradesco Foundation schools was an example of how digital technology and telecommunications potentially enables going to scale. The work carried on at a site could have influence over multiple sites throughout the network. We were no longer bound so tightly by the limitations of spreading people to places. We no longer had to rely on exact definition of curriculum and could then accommodate a more personalised approach to learning based upon place and interest. The ability to communicate and collaborate synchronously and asynchronously combined with the use of digitised, searchable materials, enabled more people and places to engage more deeply with the new ideas. We were able to continue the development of a community of learners so that one did not only learn with the people in one's classroom, but with others throughout the network. We also were not limited to place as we could learn in the community and better re-connect the school and its host culture.

By working within the school but outside the normal structure and operation of the school (by having teachers and students learn together, by having long-term inter-disciplinary projects on a generative theme, by eliminating age segregation), we had some of the benefits of a greenfield approach. We were free to innovate and create real examples of what we would like to see in learning environments, while still remaining connected to the people and culture. Significantly, this enabled a change in thinking from 'we already do that' and 'improving the computer lab' to 're-thinking all the teaching and learning of the school'. The work provided a concrete basis to question existing practice, try new practice, and examine learning.

6.5 Emergent design for macro-level change

We think macro-level change in education will emerge as the outcome of a large number of micro-level changes that coalesce and set up a tipping point. When we examine how paradigms of practice have changed in other fields and other areas of society, we see the following patterns:

- new paradigms do not start out operating full-scale at the macro-level,
- contradictions gather and eventually there is too much that the existing paradigm cannot account for — people see a need for change,
- new models are posited,
- new technologies often prompt the change as they open the possibility for new ways of seeing the world.

We think that a new paradigm of educational practice can take hold and grow through an emergent design strategy for change. This follows from certain properties inherent in the situation — meaningful changes must proceed from local concerns, and no one knows the right answers in advance. In education as in other areas, we should expect the best designs will emerge from a process of modelling and testing and debugging and adapting to local conditions on the ground.

Ours is a strategy of creating diversity, of deliberate variation. Every project we do turns out differently, and yields unexpected results — this is an inevitable result of genuinely engaging with the local learning culture and local concerns. This is a great advantage for the progress of our research into learning, and it is the essence of what we are trying to do — encourage local variants to arise and adapt while creating mechanisms so that the variants have a chance to spread and adapt.

John Dewey has so eloquently described the role of learning for human development and the role of human development in the formation of just and equitable societies [4]. For Dewey a just society could only be built not based upon the dictates of clergy, royalty, or an elite, but depended upon the informed collective decisions of all, where every voice should be heard. This philosophy provides a basis for thinking of models of growth for learning environments. As Tyack and Cuban have described [1], it has proved insufficient to dictate new curricula and expect every actor in the system to merely follow the instructions. Efforts that depend upon existing personal expertise and rich networks of contacts have intrinsic limitations for scale. The only possible path, as well as the most just and equitable approach, is to foster development of all participants.

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