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ABSTRACT

This paper describes a theoretical perspective in which teacher performance and classroom procedures in technology-based settings can be observed and compared. The paper uses as an example the Systems Thinking and Curriculum Innovation Network (STACIN) Project, which implements a simulation-modeling software package as an analytic problem solving tool and instructional strategy. This perspective can be used to classify the different modes of adaptation that teachers use as they implement technological curriculum innovations in their classrooms. A conceptual matrix is proposed. The first dimension in the matrix corresponds to teachers' level of mastery of the technology. A continuum of four stages is proposed, but the progression is not expected to be linear or uniform. The second dimension corresponds to the type of application with the software, in this case the STELLA simulation-modeling package. Four categories of application describe how teachers use systems thinking and STELLA in their courses. Applications depend on course content, subject area, level of student competence, and educational objectives. On this dimension a developmental continuum is not implied. Vignettes of three individual teachers and three sets of teachers who have been classified within the matrix illustrate how technology is impacting performance in the STACIN classrooms. (7 references) (BBM)

The Impact of Technological Curriculum Innovation on Teaching and Learning Activities

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Overview

This paper describes a theoretical perspective in which teacher performance and classroom procedures in technology-based settings can be observed and compared. The paper uses as an example the Systems Thinking and Curriculum Innovation Network (STACI^N) Project which implements a simulation-modeling software package as an analytic problem solving tool and instructional strategy. This perspective can be used to classify the different modes of adaptation which teachers use as they implement technological curriculum innovations in their classrooms.

A conceptual matrix is proposed. The first dimension in the matrix corresponds to teachers' level of mastery of the technology. A continuum of four stages is proposed, but the progression is not expected to be linear or uniform. The second dimension corresponds to the type of application with the software, in this case the STELLA simulation-modeling package. Four categories of application describe how teachers use systems thinking and STELLA in their courses. Applications depend on course content, subject area, level of student competence, and educational objectives. On this dimension a developmental continuum in not implied. Vignettes of teachers who have been classified within the matrix are presented.

The STACI^N Project

Objectives

The STACI^N Project is a multiyear research and implementation effort that examines the impact of learning from a systems thinking approach to instruction and from using simulation-modeling software. The systems thinking approach is a problem solving technique that uses modeling on microcomputers to simulate behavior of complex systems. As defined here, the systems thinking approach consists of three individual but interdependent components. First, there is system dynamics, the theory on which the instructional perspective is based (Forrester, 1968). The second component is STELLA (Richmond, 1985), a software package that can be used as a tool to teach systems thinking, content knowledge, and problem solving. The third component is the Macintosh microcomputer on which STELLA runs.

The purpose of the project is to test the potentials and effects of using the systems approach in middle and secondary school curricula to teach content-knowledge and general problem solving skills. The project contains three research foci: (a) the effects of the approach on teacher behavior, classroom processes, and curricula; (b) the effects on student learning outcomes and transfer; and (c) the impact of introducing such a curriculum innovation on the school as an organization. This paper focuses on the impact of the approach on teachers, their classroom performance, and professional development.

Project Phases

STACI^N contains two phases that are intended to facilitate the implementation of teaching and learning activities using the technologies of the systems thinking approach. The first component provides the support necessary to enable teachers to develop curriculum materials and instructional strategies with the approach. This phase focuses on inservice programs that assist teachers to develop, apply, and infuse this technology-based curriculum innovation into existing curricula. The inservice programs provide teachers with a new method by which to use technology effectively to improve instruction and learning in their courses. The second phase is the research that examines learning outcomes during and following the implementation. component

In the first phase, the primary activity is extensive inservice training. Because systems thinking and STELLA require understanding of the theory and concepts that underlie the approach, it is necessary to provide training in general systems principles. Training is ongoing, including intensive sessions during the summer and weekends in the winter. The emphasis is on providing teachers with a new, interactive instructional tool to be used to facilitate learning rather simply the transmittal of knowledge. The training emphasizes hands-on active participation by the teachers. The model of instruction espoused is to simulate with the teachers the interactive perspective that they will apply in their own classrooms.

Another source of support for the teachers is the sharing of knowledge with others who have similar interests or instructional problems. The project is designed to make consultation and advice readily available. For this reason, the teachers and schools have been organized into a network. The promotion of effective uses of computer-based teaching innovations is enhanced greatly by providing ready access to that network. Using a variety of modes of operation, the network provides many opportunities for the teachers to interact and share experiences concerning effective practices for computer-aided teaching with systems thinking.

Because it is critical for teachers to be able to seek assistance easily from experts and other teachers, an electronic mail network using AppleLink has been established among the schools, hardware and software producers, and Educational Testing Service. Thus, when teachers experience successes or difficulties, they can use AppleLink to seek feedback from peers, content experts, hardware and software producers, and the project management team. AppleLink also enables teachers to transmit and share models and curriculum materials. Iterations on the materials can be made by accessing the network, thereby facilitating wide dissemination and sharing of the systems modules.

A final activity is the provision for collaboration and access to expertise through disciplinary task forces. Teachers within a content area are able to garner only so much substantive assistance for curriculum development from the training sessions and network activities. Thus, another component is the substantive contributions made by content experts to each of the task forces. Distinguished scholars work with the teachers to provide critical substantive expertise.

The second phase of the project is the research on the approach's impact on teaching, learning, and organizational functioning. The examination of cognitive and learning outcomes must necessarily supplement and follow the teacher support component, allowing for sufficient curriculum development and implementation to occur before examining impact. This phase examines the extent to which knowledge is acquired through interaction with the systems approach. The ultimate goal is to address the transferability of skills across content areas. This phase also focuses on how using a technology-based curriculum innovation such as the systems thinking approach affects teacher behavior and the instructional process.

An ancillary goal of this component is to develop new measurement techniques that are appropriate for computer-based learning systems. Technologies such as the systems thinking approach allow for multiple pathways toward solutions and a focus on the process, not just the products of learning. Furthermore, learning often occurs in collaborative small group settings. Thus, new approaches to measurement are needed to capture group learning and cognitive processing. The project seeks to develop and implement such new measurement techniques.

Methodology and Selected Sample

Eight schools participate in the STACI^N Project. A high school in Vermont was the first site in the project. Two years after work began in Vermont, the project expanded to include four secondary and two middle schools in the San Francisco Bay Area. A high school in Tucson, Arizona recently became the project's eighth school. Over forty teachers are developing systems-based curriculum materials and implementing the approach in their courses. Content areas include general science, biology, chemistry, physics, mathematics, social studies, and humanities at the high school level, and science, mathematics, and social studies at the middle school level.

The project's primary focus to date has been to assist the teachers in curriculum development and implementation efforts. STACI^{N} provides opportunities and support for teachers to learn systems thinking and to use their own initiatives in developing new curriculum materials and teaching strategies. The teaching and learning strategies shed light on the procedures that can be employed to enhance students' general problem solving skills. Teacher support activities include the provision for: (a) intensive teacher training sessions on hardware, software, theoretical, and instructional issues; (b) release days to collaborate with project participants; (c) an electronic mail facility that enables teachers to communicate with one another as well as the software and hardware experts; and (d) "on call" consultants with expertise in systems thinking.

Data collection has focused on the factors that facilitate or impede implementation of the instructional approach and how the use of systems has affected teacher behavior and classroom processes. Data collection procedures include the evolution of teacher portfolios, intensive interviews, classroom observation, and videotaping of teacher work group sessions.

Results

Changing Role of the Teacher

Technology-based curriculum innovations such as the systems thinking approach stimulate some very fundamental changes in the role of the teacher and the processes by which teaching and learning activities occur in classrooms (Hadley & Sheingold, 1992; Mandinach & Cline, in press; Sandholtz, Ringstaff, & Dwyer., 1990; Sheingold & Hadley, 1990). Once instituted, these changes are likely to permeate classroom procedures and influence behavior both with computer-based and offline activities.

Ties to the ACOT continuum. Before describing how technology has affected teachers in the STACI^{N} Project, it is informative to discuss the stages which Sandholtz et al. suggest teachers are likely to encounter. These authors are working with Apple Classroom of Tomorrow (ACOT), a project in which classrooms are thoroughly infused with technology.

The authors outline three stages through which teachers pass as they begin to implement technology in their curricula. The first is the *Survival Stage* in which the teachers struggle against the technology while attempting to maintain traditional classroom practices. They are overcome by the barrage of technical, physical, and classroom management problems that assail them and do not have the ability or experience either to anticipate or resolve the problems. Physical problems include those that were mentioned above such as room configurations, chalk dust, and cooling. Technical issues include delays in equipment arrivals and repairs. From the standpoint of management, the authors highlight that the introduction of computers substantially increases the levels of noise and movement in the classroom. For most traditional teachers, an actively engaged computer laboratory looks like chaos. With experience the novice teacher will come to recognize that this actually is productive learning activity. Another issue that Sandholtz et al. raise is that students create new forms of cheating with the introduction of technology. Teachers often cannot identify which students are responsible for which work. Of course some novel cheating schemes can be expected. However, what may appear to be cheating to an inexperienced computer-using teacher may instead be collaborative and productive small group work products.

The second phase is the *Mastery Stage* in which teachers begin to develop strategies for coping with the problems they encountered during the previous stage. They become more tolerant of the newly created forms of classroom interactions and the environment more generally. With experience there is a corresponding increase in the teachers' level of confidence in their abilities to function effectively within the classroom structure. The teachers become more technically competent and are at least able to avoid some of the earlier technical problems. Similarly, classroom management creates an environment in which there is less or different student disciplinary problems. Students are more engaged in the instructional activities.

In the *Impact Stage* technology has become increasingly infused into classroom management activities and instructional procedures. Teachers are less threatened by the technology and the realization that some students might be more knowledgeable about the computers thus creating a different set of working relationships in the classroom. Instruction becomes more learner-centered, with students serving as peer tutors. Teachers no longer are simply the dispensers of knowledge and sole experts in the classroom.

However, it is important to note, both from the ACOT and STACI^{N} experiences that not all teachers are capable of such role redefinitions nor is the progression across stages unidirectional. Change comes slowly with regression to safe and more traditional procedures quite prevalent, thus necessitating a longitudinal approach to the application and examination of these deeply entrenched pedagogical behaviors.

Ties to the systems thinking approach. Sandholtz et al. (1990) outlined what they considered to be technology's impact on issues of classroom management. There are a number of other fundamental changes that occur not only in classroom management but also the role definition of the teacher and in how that role is carried out. Teacher knowledge is one such issue. There is no doubt that teachers must have the content knowledge requisite for the delivery of traditional and innovative courses. However, as mentioned above, they also need to acquire the theoretical and technical foundations that underlie the specific curriculum innovation, in this case systems thinking. Gaining a working knowledge of system dynamics, the STELLA software, and the Macintosh is substantially different from acquiring information about a specific topic within a content area of expertise or even another instructional approach to traditional disciplines. Systems thinking necessitates a basic understanding of the theoretical foundations on which the approach is predicated.

This is not to say that teachers must become systems experts, but rather that they must have a sufficient working knowledge of and experience with the theory and pedagogical approach.

This knowledge acquisition might differ according to how the curriculum innovation is being implemented. In some instances, for example, using causal loop diagrams (a form of systems representation that is developed offline), teachers need to acquire an understanding of the approach as a different instructional technique or curriculum strategy. In other cases, such as building STELLA models (representations generally performed as online activities), they also must supplement their content-specific knowledge with a more thorough understanding of the systems approach. They must acquire an understanding of the pedagogical perspective, general systems theory, and STELLA, then apply that knowledge to preexisting, disciplinary expertise. It is precisely for this reason that the STACI^N Project is providing continuous training and available "on call" consultants to assist the teachers. The ongoing training also serves to encourage continual progress and minimize regression of teacher knowledge.

We have observed that some teachers need to be completely knowledgeable about and feel confident of their mastery of the systems thinking approach in order to use it effectively. However, basic knowledge and confidence are not sufficient conditions to insure success in implementing the systems approach. The teachers must be willing and able to share control of the classroom and learning process with the students. With traditional methods, teachers most often know what sorts of questions and responses students are likely to pose. Teachers therefore can impart knowledge and exercise control through their disciplinary expertise.

However with the systems thinking approach, these interactions change substantially. Because there are generally many solution paths with the systems approach, there is no way that a teacher can anticipate the range of questions and possible solutions that students might suggest. As the innovative technology (both theory and equipment) becomes a more prominent part of the classroom, the teacher no longer serves as the sole expert with absolute mastery and control of content knowledge and instructional procedures. Instead, learning becomes more interactive with responsibility shared among teacher and students. The teachers no longer function solely as transmitters of content knowledge. Instead, they become facilitators of learning. Students play a more active role in their own learning. This shift often requires teachers to take risks and develop new instructional strategies to facilitate the learning process. They must relinquish deeply entrenched pedagogical behaviors. This creates some fundamental shifts in the way classrooms, teachers, and students function. Not all teachers are capable of or willing to explore and accept this evolving new role.

<u>A Conceptual Matrix for Technological Applications</u>

<u>The mastery dimension</u>. These findings and ACOT's three-category continuum correspond to one of the two dimensions that comprise the STACI^N Project's proposed matrix for the use of technological applications. This dimension is termed the teachers' level of mastery of the technology. We use ACOT's three categories, but add a fourth which is termed the *Innovation Stage*. The

Innovation Stage is thought to occur when a teacher uses technology to move beyond the mandated scope of the curriculum toward a complete restructuring of teaching and learning activities. Technology forms the theoretical and methodological foundations for changing foci of course content, pedagogical processes and procedures, and instruction.

Table 1 describes and compares some of the activities that occur in technology-based and systems-based classrooms across the four categories of the dimension. Activities in the technology column also are applicable when the systems thinking approach is implemented.

The technology-based activities teachers face at the Survival Stage have been described above. Teachers using the systems approach face these more general problems as well as several others. As they struggle to determine how to use the systems approach, there is a constant need for handholding. As the teachers look for applications that are amenable to systems, they search their textbooks, rather than having an intuitive feel for topics to which systems can be applied appropriately. Their systems model construction is a trial and error process in which they work until they get stuck and then stop, waiting for external expertise to troubleshoot and solve the problem.

At the Mastery Stage teachers show less reliance on systems experts. They are more able to troubleshoot problems with their own models as well as those of their students. Teachers are better able to identify parts of the curriculum to which systems can be applied. Their instructional modules are sounder and more complete, containing not just systems models but also ancillary materials. An increasing amount of systems thinking occurs in the classroom.

The Impact Stage reflects curricula that are infused with varied applications of systems thinking. These applications do not necessarily rely on on-line activities. Instead, there are portions of the curriculum that are based implicitly on systems theory and underlie the instruction, as well as those that are obviously systems-based. It is at the Impact Stage that teachers show less concern about some of the accountability issues that surround the implementation of a curriculum innovation. The students at Sunnyside High School in Tucson term this the "no more funnels" phenomenon. (see Figure 1) These students are rejecting the notion that education should consist of teachers who dump information into students' heads for the sole purpose of regurgitation of those facts onto tests, after which they forget what has been learned. Instead, instruction should concentrate on the process of learning and teachers should serve as facilitators of that process.

The final stage is Innovation. This occurs when the entire curriculum is revised using systems thinking as the underlying theoretical philosophy. Unlike the Impact Stage where there remains a balance between systems and non-systems based activities, the Innovation Stage consists of a transformed and all-pervasive systems learning environment.

The systems applications dimension. The second dimension of the matrix focuses on how the technology actually is applied. In the case of the STACI^N Project, the focus is on how the systems thinking approach is implemented in the curricula. As mentioned above, the systems approach with its three components, is considered the technology of interest here, not just the Macintosh or the STELLA software. Again, four categories are identified as systems applications, but do not imply a developmental continuum (see Figure 2). They are distinct categories whose appropriateness depend on course content, subject area, level of student competence, and educational objectives. However, the forms of application do differ with respect to anticipated levels of cognitive complexity. The categories include parameter manipulation, constrained modeling, epitome modeling, and learning environment.

The basis of the systems thinking approach is the creation and examination of models of complex phenomena over simulated time. Such phenomena are likely to contain many variables that are interconnected and form feedback loops not simply isolated events. This implies circular causality rather than linear causality. Systems-based instruction can occur online using STELLA or offline using a variety of alternative activities. Teachers can develop models and then structure activities so that students explore the phenomena with varying degrees of assistance or students can develop their own models.

The first category is termed *parameter manipulation.* Teachers generally construct a systems model and develop fairly structured worksheets as ancillary materials. The worksheets can vary in the degree to which they focus the students' examination of the model. In the most structured case, the worksheets step the student through every phase of the model, each variable, their parameterization, and the model's operation. These activities generally require students to manipulate the numerical parameters which underlie and define the variables and observe the effects on the system as the model is run dynamically over time. Students are asked to form hypotheses, run the model to test them, and revise the hypotheses according to test results. The teacher's role is to develop the systems model and ancillary materials which form a complete curriculum module. In most instances, the teacher will present the model to a class using a computer projection system, then let the students work through the ancillary materials in small, collaborative groups at each computer station. The teacher serves as a resource person and troubleshooter, moving from one computer to another as students encounter difficulties. These problems could be substantive, systemic, or operational with respect to STELLA or the Macintosh. Examples of parameter manipulation include the exploration of enzymes and the greenhouse effect.

The second category is called *constrained modeling.* Systems models can be extremely large, sometimes containing hundreds of variables and interactions. Such models are impossible to use for instructional purposes. Instead, students need models that contain a manageable and limited number of variables that can be examined systematically and their effects traced. These are considered constrained models, in that the number of variables are limited by the phenomenon under examination. Such constrained models are often found in textbooks. Teachers who used constrained modeling generally assign a problem to the students. The students then construct a model based on the problem's specifications. Students may solve these problems traditionally as would be the intent of most textbooks, they may choose to construct a systems model, or they may do both, depending on how the teacher structures the activity. Results from a past study indicate that students who used constrained modeling gained a deeper understanding of the phenomena than if they solved the problems using traditional methods (Mandinach, 1988). An example of constrained modeling is the acceleration problem found in typical physics textbooks.

A cross between parameter manipulation and constrained modeling also has been observed, but does not form a separate category of the dimension. This form of application is termed component manipulation. Instead of changing parameters, students are asked to manipulate components of a model. They may be asked to add or delete variables, or change the interconnections among variables. This task is somewhat more complex than simply altering the numbers that define the variables. It requires students to have a more advanced understanding of modeling and the nature of how variables interrelate within a system. Teachers generally structure this activity as they would parameter manipulation. However, there are cases when students construct a model and perform such component manipulations. It is a preliminary step toward more complex model construction.

The third category of the application dimension is called *epitome modeling*. Here complex phenomena with large numbers of variables are examined through model construction. The model becomes the epitome of the phenomenon to be examined. In almost all instances, students develop these models from scratch, using primary research as the foundations for their understanding of the phenomena. Teachers serve as coaches, resource persons, and facilitators of the learning process. They may guide the students to appropriate references relating to substantive issues and may also provide some troubleshooting expertise on systems thinking and the use of STELLA. But the actual cognitive work is done by the students as they accumulate information and begin to understand the interrelatedness of the variables within the system. Examples of epitome modeling include acid rain and the origins of war.

The fourth and final category is known as a learning environment. Here systems thinking becomes the philosophical foundation for instructional activities. A learning environment is created in which systems thinking becomes all-pervasive. *Learning environments* may take many different forms and teachers' role will differ accordingly. Activities here do not necessarily require use of the hardware and software. In fact, many of the learning environments observed involve offline activities. For example, one mathematics teacher begins his class with a complex theoretical question that is systems-based. The teacher's instructional objective is for the students to understand the mathematical concepts within the more general context of the world, using systems thinking to provide the interconnectedness. Two middle school teacher who team teach have created several multiweek units on various topics (e.g., wolves, owls, the environment) that use many different, cross-disciplinary activities that are systems-based to triangulate on the subject. An on example that requires online activity can be found in chemistry, where one teacher has created a large computer database on the periodic table to serve as a multipurpose reference tool.

There are several systems-based tools within the database, including models for each element.

Patterns across the matrix. Figure 3 presents the matrix with the distribution of selected project teachers identified across the cells. In addition to the identification of the teachers' level of mastery and form of application, the specific type of systems usage also is delineated. As the STACI^{N} Project has progressed over the years, it has become apparent that some teachers are systems model or curriculum model *builders* and others are *users*. Thus, we distinguish between those two categories of use. Some teachers both build and use models developed by other individuals. Two other categories have emerged. Teachers can also *create* learning environments in which they do not build models or ancillary materials, *per se*, but they construct situations in which students are free to explore phenomena using the systems thinking approach. The final type of usage is *facilitation* in which teachers make possible the use of systems either for students or other teachers, taking the role of mentor or coach. There also are different levels of expertise along this dimension, particularly in building and using. Some teachers are adept at building systems models or using them in creative and effective ways, other are not as adept. A further distinction can be made between what the teachers do and what they have their students do.

As can be seen in Figure 3, the 35 teachers represented in the matrix are distributed across the mastery dimension. Four teachers were classified as at the Innovation Stage, 12 at the Impact Stage, nine at the Mastery Stage, four are borderline Mastery and Survival, four at the Survival Stage, and two who did not even approach the Survival Stage.

The application dimension is more complicated because many teachers use different types of applications depending on the courses and students involved. Eight teachers use only parameter manipulation; 14 combine this form of application with constrained modeling; three others alternate between learning environments and parameter manipulation. Only two teachers use purely constrained modeling. One person combined this limited form of modeling with the more complicated type of application. Pure epitome modeling was found in only one classroom, but was combined with learning environments in two other instances. Learning environments were implemented by four teachers.

A number of interesting patterns emerge from the placement of the teachers within the matrix. First, note that there are no teachers in the innovation by parameter manipulation or constrained modeling cells. By definition of the Innovation Stage, it seems highly unlikely that curricula would be restructured by the use of these two types of applications. Also according to definitions, all but one of the teachers implementing learning environments are also some of the most sophisticated users of technology. It is notable that the four teachers who are creating the most pervasive and innovative learning environments are also those who rely more on the philosophical perspective of systems thinking than on the formal use of the hardware and software. The computer becomes one of many learning tools and activities, not the focal point of the instruction.

The students served by the teachers who implement learning environments fall into two distinct categories. In the case of those at the Innovation Stage, three teachers deal with quite able middle school students. The fourth teacher in this cell serves an at-risk, primarily minority, high school, population. All but one of the other individuals using learning environments also teach at both ends of the spectrum of students, either the most gifted or most at-risk. Only one of the teachers serves an average student group.

Also notable is the one teacher who lacked sophistication in the use of technology, but perhaps implemented the best example of epitome modeling. This individual did not even know how to turn on the computer, yet he could direct students to appropriate resources for their systems models and projects. Peer tutors served as computer experts in the class, making up for the knowledge the teacher lacked. Students were able to develop extremely complex systems models as long as there were other students who could provide the technological expertise.

Perhaps the most obvious finding is that the majority of the systems applications are either parameter manipulation or constrained modeling, the two forms of applications that are most easily fit into existing curricula. Teachers must contend with pressures for accountability - accountability to the school board, public, for standardized tests, specified curricula, and the like. Thus, there is pressure to minimize disruption to the status quo. Parameter manipulation and constrained modeling are alternative methods for teaching traditional topics. They do not completely innovate the curricula as is likely to occur with learning environments and to a lesser degree, epitome modeling. Additionally, individuals who teach more advanced courses or deal with older students often shift away from parameter manipulation to more cognitively complex applications or constrained or epitome modeling.

A final pattern that emerges is that in time, most teachers become increasingly adept at dealing with the challenges technology imposes on their classrooms. Some individuals struggle more than others, but they eventually become more at ease and familiar with the technology. The Impact Stage is the stage to which most teachers aspire and reach. However, with appropriate conditions, there is a level beyond Impact, the Innovation Stage, in which technology serves as a tool for the restructuring of not only the curriculum, but also the role of the teacher.

Selected vignettes. We have selected three individual and three sets of teachers for illustration with brief vignettes to provide a more detailed sense of how technology is impacting performance in the STACI^N classrooms. These teachers have been classified into different cells in the matrix to provide a variety of illustrative scenarios.

A first teacher is the individual who has participated in the project the longest. He taught general physical science and physics, but now only teaches the latter course. He is classified as being at the Impact Stage on the mastery dimension, and as using both parameter manipulation and constrained modeling, but increasingly more of the latter form of application now that he teaches only the more advanced science course. He now is attempting to teach two forms of physics, which include one with a mathematical orientation and another with a conceptual orientation, both of which use systems thinking as the underlying philosophy. This teacher has always used a Socratic method in the classroom, rarely providing direct answers. He also is adept at facilitating laboratory interactions in the context of traditional science curricula. From all observations, he is not threatened by the prospect of a learner-directed classroom where students take an increasing amount of responsibility for their instructional activities. The teacher now functions as a mentor, guide, and coach, rather than a transmitter of information. The latter is a role which makes him quite uncomfortable.

The transition from the traditional curriculum to the systems thinking approach has been gradual and at times difficult. The teacher initially identified a few topics within his courses that he thought were amenable to the approach and constructed primarily parameter manipulation modules for those topics. As the teacher's expertise with systems and the technology increased, he began to see many more and less :opic-bound applications that could be implemented. Much of the current classroom activities involve constrained modeling and indepth exploration of physics concepts using the systems approach. The teacher's stated objective is to have his physics courses completely infused with systems, and he is well on his way to accomplishing that goal. It is safe to say that this teacher has become the project's intellectual leader from the standpoint of systems thinking implemented within the constraints of a traditional curriculum (i.e., in a non-innovative manner). He is the person to which other project members most often seek advice about implementation and pedagogical issues, and the most frequently cited curriculum developer. Along the mastery dimension, he has progressed from an individual who had little experience using technology, short of science laboratory procedures, and now has become extremely adept with all aspects of the technology.

An interesting contrast can be found in the teacher who has served at the project's most valued adviser and administrator. This is an outstanding teacher who also is a science department chairperson and local project director for STACI^{N}. (The first teacher also is a project director.) This teacher is at the cutting edge of many nationally recognized curriculum innovations and research projects. Thus, his advice to the project emanates from a global perspective of education nationally as well as within his own school. He is a late bloomer in the project with respect to the use of technology and the systems thinking approach. He admits that his role as chairperson was first to facilitate the progress of the members of his department and insure that the project became entrenched in the culture of the school and district. These are invaluable activities, given the pressures toward accountability that many schools encounter. Only then did he allow himself the time to begin developing and implementing systems in his courses on a large-scale basis. He laments having not come up to speed sooner with respect to the technology. Thus, he is classified at the higher end of the Mastery Stage.

The teacher uses constrained modeling and some parameter manipulation in biology and advanced biology classes. He collaborates with other biology and chemistry teachers in an attempt to bridge the conceptual gap between the two courses. Many interesting systems models and curriculum modules have been developed jointly and shared among this collaborative working group. The group has brought together teachers from several schools and disciplines to produce stronger and more cross-disciplinary applications. This teacher, in conjunction with his colleagues, is now developing some of the most sophisticated applications in the project.

A third example is a mathematics teacher who teaches in a school where three-quarters of the students are at-risk and only a small percent pursue further education. He teaches the spectrum of mathematics courses, from remedial, pre-algebra to calculus. It is difficult to express in words the energy and respect for the students and learning that this teacher infuses in his courses. The classroom is a whirlwind of activity. He, too, does not believe in answering any questions directly. Questions are deflected into procedures for seeking solutions. He has one of the most effective yet frenetic classroom management and pedagogical styles observed to date, especially given the challenging population of students.

This teacher is always looking for a better and more engaging way of presenting material to his students. He never conveys facts to the students, instead instilling in them a need for control over their own learning. His classroom is a prime example of learner-centeredness. The teacher serves only as a facilitator of the learning process. The students are constantly in motion, actively engaged in a variety of creative activities. His goal is for mathematics to come alive and make sense in terms of concrete applications. Systems thinking is the means by which he tries to accomplish that objective. He opens every class with a question of no apparent relevance to mathematics, then begins to tie the issue to mathematics and other disciplines. The point is to show students that much mathematics and of the world are interconnected and requires complex examination of the variables and their interactions. The teacher creates an innovative, systems-based learning environment, in which there are no easy answers but many creative problem solving strategies. The teacher rarely relies on the computer to create this learning environment, however, it is used as an effective instructional tool to enhance particular parts of the curriculum. The innovation and learning environment really occur in the creative mix of systems theory, technology, mathematics, and the extension to cross-disciplinary applications.

The next example is comprised of two young teachers, one male and one female, who also teach at-risk students. In fact, there are some 27 languages and dialects spoken in the school. Few students go on to further education. These teachers function in a district where there are rather strictly mandated curricula and pressures for accountability. When these teachers first joined the project, they expressed concern that doing systems thinking might be contrary to the curriculum standards and therefore be detrimental to their chances for tenure. Both teachers have since been granted tenure. In fact, the teachers have blossomed under the auspices of the project, showing striking professional development.

Their teaching responsibilities are vast, covering life science, earth science, biology, and chemistry. They work closely together as well as with two other science teachers in the project from their school. The two teachers have shared responsibility for project direction and curriculum development, and also have mentored along the other two project members. They are quite expert with the technology, both being classified at the Impact Stage. The male teacher has taken on the added responsibility of serving as part-time computer technician and guardian of the computer laboratory. He is only slightly more advanced with respect to the technology, although both teachers are equally expert at using the technology as a teaching tool.

Their use of systems thinking varies according to the course, level of student, and educational objectives. In most instances, the teachers have developed well conceptualized parameter manipulation modules with structured worksheets. The goal is to step the students through the thought processes engendered in systems thinking until they are able to carry out such cognitive activities on their own. With class sizes approaching 40, this means that the teachers must move among some 15 to 20 computer stations troubleshooting students' questions. The teachers report that this enterprise is absolutely exhausting, but that students are on task and learn more deeply. Teachers must be alert and constantly "on-call" to function effectively in this very different form of learner-directed environment. Clones, laboratory aids, or a team teaching situation might alleviate some of this burden. These teachers also have done some work with learning environments, one of which is a STELLAStack activity about earthquakes. Although the teachers built the model, the students are free to explore the environment which functions in the manner of a game-like simulation. These two teachers are prime examples where the opportunity to integrate technology into their curricula has changed the very nature of their roles, how they function in the classroom, their educational objectives, and has served as a vehicle for professional development.

The final two vignettes contrast two sets of middle and junior high school teachers who function quite differently with respect to systems thinking given the structural characteristics of middle and junior high schools. The first set is comprised of three social studies teachers who teach at the junior high school level. They are unique in the STACI^N Project due to their disciplinary affiliation (i.e., almost all the teachers are in mathematics and science). Their task of integrating systems thinking into social studies is made difficult for at least three reasons. A first issue is substantive. Although there is a natural fit between social studies and systems thinking, the systems can become quite challenging because of the need to parameterize a large number of variables. It is not intuitive as to how to quantify qualitative variables. Furthermore, the models produced in social studies are likely to much larger and more complicated, making the teachers' instructional task more difficult regardless of whether the teachers or the students construct the models. Second, much of the success of the project can be tied to the collaborative nature of the teachers. These three teachers work together, but have no colleagues to whom they can turn for expertise and advice. Therefore, they must rely on their own experience and expertise. All three were novice computer-users when the project began, and no one had a substantial background in mathematics.

This problem was alleviated because the school's project director, an experienced mathematics and computer teacher, served as an invaluable mentor for a few years until she resigned from the district.

A third reason for the difficulties experienced by these teachers concerns the structure of the junior high school. There are strict departmental boundaries and a great deal of pressure toward accountability and standards. Although the teachers are committed to using systems thinking for the potential advantages they perceive the perspective to have, they are constantly faced with a cost-effectiveness issue with respect to test scores and coverage of the mandated curriculum. It will be interesting to observe what happens as this school shifts to a middle school format next year.

The mastery continuum has been a difficult one for these teachers. None of the three had any experience with computers before the project began. All three sought out several additional computer courses in an effort to feel more comfortable with the technology. They are slowly achieving that goal. They have been classified as borderline cases between the Survival and Mastery Stages, primarily because most of their work has been in curriculum development rather than classroom applications. Only recently have they begun to introduce their students to systems thinking via the computer laboratory. With experience, their skills and levels of confidence are improving. The systems applications are parameter manipulation. The teachers have devoted vasts amount of time and energy into constructing models of immigration, health issues, water consumption, and the like, and the ancillary materials for those models. Because the students are so young, the teachers feel the need to step the them through the modules in fairly structured sequences. The students are gaining deep understanding of the content and are acquiring valuable experience with the technology. The objective is to provide the students with more flexibility in using the technology as they gain experience with systems thinking.

The final set of two teachers work at a small, middle school with a quite select and homogeneous student population. These teachers have been a team-teaching pair for several years. The structure of team-teaching and the cross-disciplinary emphasis of the middle school enables these two teachers to try some extremely innovative activities with their classes. Systems thinking forms the theoretical foundation for these activities. As mentioned above, the teachers have created systems-based curriculum units that operate for several weeks. For one unit, they selected environmental issues. The students developed independent research projects on various topics, using systems as the thread to tie to together all the projects, and then prepared a science museum. Another unit focused on an endangered species, the owl. The teachers integrated science, mathematics, literature, and social studies to explore the population dynamics of the owl. They conducted a similar unit on wolves. They also prepared a workbook of common activities that forced the students to consider the interconnectedness of their actions. The actions selected were relevant to the students' everyday activities. For example, if a student stayed up until 1:00 a.m., they were asked to hypothesize about consequences and causes of actions. Why did the student do this? What effect would such an action have on performance in school the next day, disciplinary actions, and the like?"

Most of the student activities do not require the computer, although they can be enhanced by the technology. The teachers are expert at identifying when and when not to use to computer as an instructional tool. The actual and innovative technology in action here is the philosophy of systems thinking that permeates all activities. Thus, these teachers have restructured many conventional activities into innovative and engaging systems-based modules that have served to restructure how the curriculum is delivered.

Discussion and Educational Implications

This paper has described a theoretical perspective in which teacher performance, classroom processes, and instructional procedures were observed and compared. The systems thinking approach was used as an example for classifying the modes of adaptation teachers use as they implement technological curriculum innovations in their classrooms. A conceptual matrix was proposed in which the mastery of technology and the type of application form its two dimensions. A subdimension also was proposed which specifies the role the teacher plays in using the technology. STACI^N Project teachers were classified along these dimensions. Patterns across the matrix were noted and vignettes of selected teachers described.

These dimensions have facilitated a better understanding of how teachers use technology, and how the technology affects the role of the teacher, professional development, classroom procedures, and instructional strategies. We have described numerous ways that technology has impacted the $STACI^N$ Project teachers. Technology in the case of $STACI^N$ refers not only to the Macintosh computer and the STELLA software, but also to the theory of system dynamics. Thus, when we refer to the impact of technology, we mean the philosophical perspective as well as the hardware and software. These three components which comprise the systems thinking approach have altered the professional activities and performance of teachers participating in $STACI^N$. The structure and functioning of the classroom and the role of the teacher have been transformed in many fundamental ways as a result of the implementation of technology.

The ACOT continuum for mastery of teaching with technology outlines many of the developmental changes one can expect to occur as teachers begin to introduce and integrate technology into their classroom procedures. The $STACI^N$ Project has extended that continuum by one stage to include technology's role in the restructuring of curricula and the classroom. That is, given the right set of circumstances, some teachers who are extremely talented and creative, and who are provided the needed freedom from accountability, can use technology as a stimulus to design innovative learning environments that change the way teaching and learning activities occur. Such innovation is analogous to the computer jocks who understand computer programs, games, or simulations so well that they can go beyond the explicit rules of the tasks to find creative solutions. Similarly, these teachers often stretch the implicit and explicit rules of the classroom to implement innovative and challenging technology-based applications. This requires a high level of pedagogical expertise as well as a great deal of insight into the classroom.

Such innovation also requires some degree of administrative support to relax the accountability standards. The innovations reported here span the range of schools, from the most elite to the most needy. What these cases have in common is that the department chairpersons and principals are extremely supportive of the teachers' innovative efforts and often times must explain and actively defend the work to curriculum supervisors, school board members, and the public. Innovation, given the need for restructuring, requires such administrative support but so too do applications that are more in the mainstream. This need is created, in part, because the use of technology requires time, and time is a rare and valued commodity in education. The more time it takes to implement a technology-based program, the more time is taken from an already filled curriculum. The more at risk become test scores and accountability standards when there is the lure to devote substantial time to the integration of technology in lieu of time devoted to the traditional curricula.

In addition, there are two interrelated outcomes from technology that can be readily noted to influence classroom procedures and require the support and understanding of the administration. The first issue concerns the changes created in the classroom environment and the accompanying management problems. Take for example classroom observations by supervisors. If a supervisor observes a teacher's class when it is in the computer laboratory and also in its traditional setting, that individual is likely to see two distinct classrooms. The traditional class might look quite orderly, with students working quietly and alone at their desks. In the computer laboratory, students rarely work alone. There are usually dyads or triads of students at each computer, and other students wandering around, looking over each other shoulders, comparing solutions, and the like. There is constant activity as the students are actively engaged in their work. The rooms is abuzz with activity. It is often noisy and chaotic. An observer might assume that this chaos is unproductive, off-task behavior, when in actuality, it is just the opposite. Supervisors must recognize and understand the classroom management differences that are created with the use of technology.

A second outcome is the emerging need for new assessment procedures. Because students interact collaboratively when using technology, it is often difficult to assess who is doing what portion of the cognitive work. Is one student doing everything, or is there shared responsibility for the learning? What often happens is that students work in groups online, but are assessed individually and without the aid of the technology. There remains some implicit assumptions that collaborative work is tantamount to cheating and that assessment must remain at the individual level. This is unfortunate because most post-graduate work environments require collaboration, not just individual effort. There is a need to recognize that we give students mixed messages about when collaboration is acceptable behavior in terms of work and assessment.

Assessment procedures also need to change to incorporate the emphasis on the process of learning, not just the outcomes of instruction. Many of the computer activities focus on how the students attain solutions in addition to the gains in specific declarative knowledge. The increasing emphasis on the processes and procedures of learning change the nature of assessment, and run counter to most traditional assessment techniques. These are not issues that classroom teachers can change. But they are factors in the environment in which they must function, and in the environment of education more generally. An understanding of the issues is a first step. A recognition that there is a need for change is a second phase, and change does need to occur, but will occur slowly.

As a concluding remark, we return to traditional education as it is portrayed in Figure 1. The technology of the systems thinking approach has irrevocably changed the teachers in the STACI^N Project to the point that they are no longer content to maintain this model of education. In fact, the students at Sunnyside High School have adopted what has become the logo for the project - NO MORE FUNNELS (see Figure 4). The use of the technology and the systems thinking approach have created the need for a different form of education. The project's teachers, administrators, and even some of the students are now acknowledging that need for change.

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Table 1

Teaching Activities Across Stages of Mastery of Technology

Technology	Systems Thinking
Survival Stage	
Struggle against technology	Struggle to use systems thinking
Assailed by problems	Need for constant hand-holding
Status quo in classrooms	Trial and error model construction
Cannot anticipate problems	Stop and wait problem
Teacher-directed	Textbook search for topics
Unrealistic expectations	
Management problems	
Chaos	
Mastery Stage	
Developing coping strategies	Less reliance on systems experts
Increased tolerance	Sounder curriculum modules
New forms of interactions	Increased ability to trouble-shoot student problems
Increased technical competence	Increased use of modeling
Increased experience and confidence with new classroom structure	
More engagement	

Table 1 Continued

Impact Stage	
Infused technology	No more funnels
New working relationships and structure	Systems-infused curriculum
Learner-centered	More varied use of systems applications
Teachers as facilitators of learning	
Less threatened by technology	
Technology enhanced curriculum coverage	

Innovation Stage	
Restructuring of curriculum and learning activities	Curriculum revision based on systems thinking

Figure 1

Traditional Education

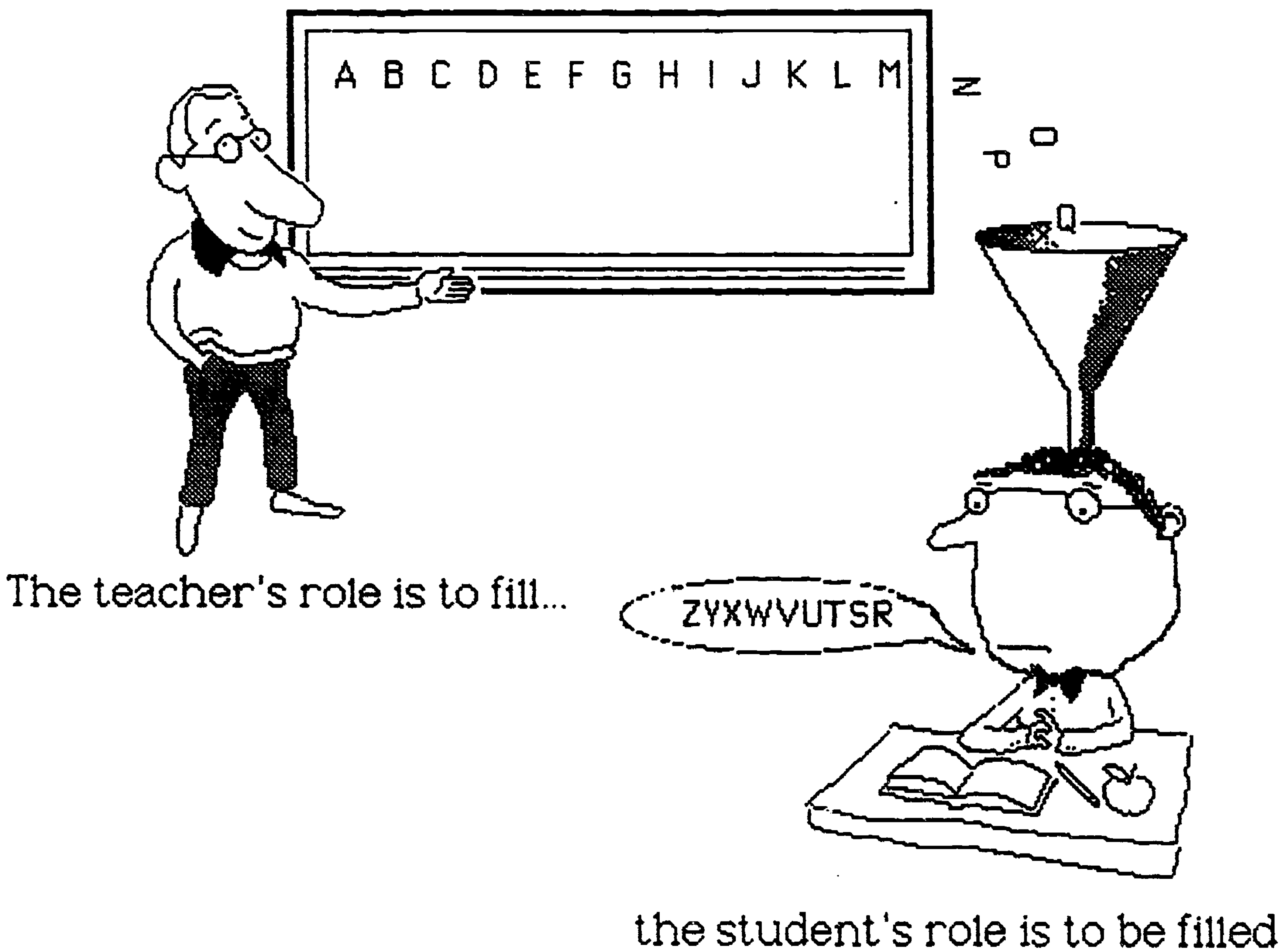

Figure 2

A Conceptual Matrix for Systems Thinking Applications

	Parameter Manipulation	Constrained Modeling	Epitome Modeling	Learning Environment
Survival				
Mastery				
Impact				
Innovation				

Figure 3

Distribution of STACI[N] Teachers Across the Conceptual Matrix

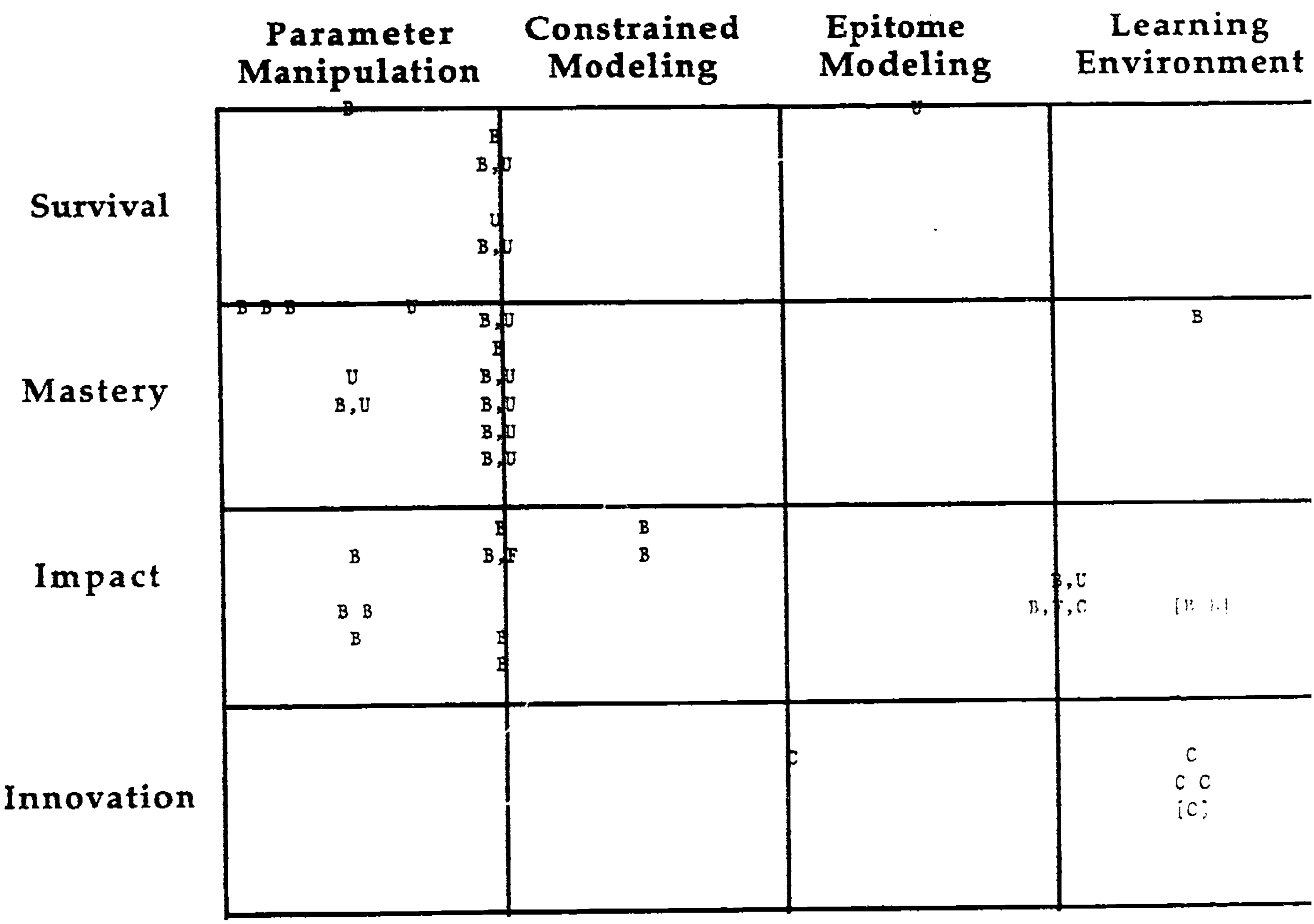

Figure 4

A Logo for Innovation Education