the Creative Learning EXCHANGE

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The CC-STADUS Project: Developing and Nurturing a Cadre of Pre-College Teachers Using System Dynamics/ Computer Modeling in the Classroom

by Ronald J. Zaraza, Portland, Oregon

The CC-STADUS project has trained more than eighty pre-college science, mathematics, and social science teachers in the basics of computer modeling and system dynamics. In the process of teaching these teachers to build single content area and cross-curricular models, the project has experienced some major successes and a variety of problems.

More than twenty-five major cross-curricular models and many more single discipline models have been developed by the participants, working both individually and in teams. The training which was provided has evolved continuously in response to feedback from the teachers and formal evaluation. Most major difficulties were eliminated in the second year, allowing consideration of other less obvious problems. The third and final year of the program includes substantial revisions in the focus of the initial training, topics presented by guest speakers, the formation of modeling teams, and the amount of time dedicated to construction of cross-curricular models. Similar changes have been planned for the assessment and support of participants in the year following the training.

Consideration of the successes and problems encountered by the CC-STADUS staff can provide valuable insights to those attempting training of pre-college teachers in modeling or system dynamics. A variety of key factors have been identified that can enhance the effectiveness of the training and the subsequent support provided during the academic year.

Establishing the Grant

In August, 1992, the CC-STADUS (Cross-Curricular System Thinking and Dynamics Using STELLA) grant proposal was submitted to the National Science Foundation. The project was awarded funding on May 7, 1993. The three-year project was designed to train more than 150 pre-college teachers of science, mathematics, and social sciences in the design and use of system models in the classroom. STELLA II software, developed by High Performance Systems, was chosen as the vehicle for model development. Diana M. Fisher, Project Director (Math/Computer teacher at Franklin High School, Portland, Oregon, USA) and Ron Zaraza (Physics teacher/Computer Coordinator at Wilson High School, Portland, Oregon, USA) have served as primary planners and implementers of the grant. The other two principal investigators, Dr. Andrew Jonca (Educational Software Developer, specialist in numerical analysis, Image Builder Inc.) and Steve

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Systems Thinking "in 25 Words or Less"

by Debra Lyneis, Carlisle, Massachusetts

When we were first exploring the idea of systems thinking in our school district, a fellow school board member drew me aside and asked me to tell him "in 25 words or less" just what systems thinking was and what it had to do with educating children. I was stumped! Many months later, and somewhat further along, another school board member tactfully cautioned that we should not mention systems thinking in our upcoming public hearings because "people's eyes glass over" if it seems too deep!

For such a good idea, why is systems thinking in education so difficult to explain at first? People with some understanding of systems thinking (from those who have just caught glimpses of it, to those who use system dynamics modeling in their classrooms) are all very good at conveying their enthusiasm about it. Explaining it succinctly to people without that background is not so easy, however. Partly, this is because systems thinking is a big idea which applies to education at several different levels, from specific cur-

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CREATIVE LEARNING EXCHANGE: A CHANGE IN HOW WE WORK.

During the four years of the CLE's existence we have had the luxury of being able to "prime the pump" by sending out most of our materials and our newsletter free of charge. A number of people have generously donated to CLE, often without asking for any materials in return. We are grateful for the support we have received.

After four years, however, a closer look at the generous funding we originally received from John Bemis indicates that we will not be able to continue at the current pace for long. In response to these fiscal constraints, we have decided to charge the mailing and copying costs for the materials we send.

We are doing this in conjunction with a tremendous effort on our part to get everything we have on our list of materials in disk format and onto the Internet server. We will no longer list any material which is not in disk format, so that it all can go on the server. Materials will be available from the CLE in the following manner:

1. **On the Internet**. By the time you get this, there should be at least three folders available on the sysdyn.mit.edu ftp site. Please see Internet News for the full description.

2. **In disk form from CLE**. You will be able to order anything we have in disk form on disks directly from CLE. A list of materials will be available on the Internet and from the CLE. The disks will cost $5.00 for the first one and $3.00 for each subsequent one.

3. **In paper form from CLE**. For all school systems and teachers we will charge just our copying and mailing costs. For business organizations we will add a modest overhead fee for the work we do here.

Our mission remains the same—to nurture systems education in K-12 schools, and to facilitate the exchange of ideas and curricula. If there is a financial problem and you need the materials we have in either disk or paper format but can't pay, please tell me. I want you to have anything that will help you or others around you in the classroom.

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FROM THE EDITOR. . .

Welcome back to a new school year! As the days get shorter and crisper, I always feel a sense of excitement as the school year starts, with a new set of challenges, a new set of students. Isn't interesting that all three of the times of renewal which we have in the year—September school starting, the New Year, and the springtime awakening of the earth—are centered around the sun and the length of the days?

Enough philosophy. As you can see, this newsletter is full of the contributions of other people writing wonderful things about our mutual mission to bring systems education to K-12 education. Ron Zaraza gives us a good overview of some on the lessons and insights he has gained from working with the CC-STADUS project in Portland for the last two-and-a-half years. His paper was presented at the International System Dynamics conference in Tokyo this summer. Deb Lyneis has given us another succinct article—this time describing what System Thinking is. She, like many of us, has struggled with what we should say when someone asks us for a brief summary of systems thinking and system dynamics. I have found her rendition very helpful in the continuous process of re-forming my response. I hope you do, too.

Although we are short on updates since this is the first newsletter this fall, we have a great article/update from Frank Brooks in Australia. He describes his school, where they have created the learning organization and environment and now have started to branch out into the use of system dynamics as a powerful tool in that environment.

Finally, we have two items which are closer to the workings of the CLE—an announcement of next summer's conference and a short description of the way the CLE will operate in the future in order to be provident with the funding we currently have.

Good luck with your year and please keep in touch. I would love to hear what you are doing.

Lees Stuntz, editor (stuntzln@tiac.net)

The CC-STADUS Project

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Carlson (Assistant Superintendent, Blaine County Schools, Hailey Idaho), have assisted with the training and planning, review and validation of the models developed, and evaluation of the use of the models by classroom teachers.

The CC-STADUS project has four primary goals. Three are attainable each year. The fourth is a long term goal that could result in a systemic change in the nature of education. The first of these goals focuses on training teachers in the basics of system dynamics and in the development of computer models specific to their own content area. This is seen as the first step in developing teachers capable of bringing the concepts of system dynamics into the pre-college classroom. At the time of the grant proposal, fundamental ideas of system dynamics had achieved substantially less exposure in the educational community than in the business world. Though improving, this situation still persists. Through the project's summer institute training, teachers are exposed to the basic concepts of system dynamics in the context of their own subject matter as a means of demonstrating the usefulness of the approach.

The second goal is only achievable after some progress has been made on the first. While a number of individuals and groups have developed, and in some cases, distributed single discipline models for use at the pre-college level, very few multi-disciplinary models were in the public domain in 1993. Teachers interested in broader modeling have had little to build on. To remedy this situation, development of a collection of cross-curricular models and curricular materials, with broad applicability to mathematics, science, and the social sciences, has been the emphasis throughout most of the summer training. Once teachers develop a minimal comfort level with the ideas of system dynamics and the mechanics of the STELLA II software, they begin working in teams on a major cross-curricular model. This refines their understanding of system dynamics and modeling, facilitating building of models on their own. It is hoped that they will continue cross-curricular modeling when they return to their schools. However, completion of one cross-curricular model is required by the end of the three week training. These models and curricula are edited, validated, and then freely distributed through the Creative Learning Exchange·

Use of the models developed by the teachers in the summer is the third goal of the project. If the materials are to have an impact on the learning of students, these must be used and refined. Each participant in the project is expected to use materials in their classes, as well as to develop and use at least one other model. They are evaluated through individual in-class observations, videotaping, and written assessments.

The fourth goal of the project is by far the most ambitious. Many curriculum projects present and develop outstanding ideas and materials. However, they have little large-scale impact on education. Sometimes this happens because they are too specialized, other times because they rely on a few key people to prepare materials or provide training. In a few cases, those who originate the idea keep it under too tight a control. The real purpose of the CC-STADUS project is the training and encouragement of a large enough group of "users" and "developers" to become a self-sustaining movement. Significant numbers of high-quality models and curricula will create a demand for more models and stimulate their development. A cadre of teachers using and developing models will begin to expose others to the ideas and materials. Growth of the use of system dynamics and modeling concepts will not depend on the efforts of a few, but will be driven by a large group assisted by "experts" who emerge and develop through the assistance of the project. The core team, chosen each year from previous participants to train the next group of teachers, is already evolving into that group of "experts."

Evolution of the Summer Training Institute

The three-week summer institute is the most visible and first key component of the CC-STADUS project. In it, teachers are exposed to the concept of using simulations as a teaching tool. Then, they are specifically introduced to the use of STELLA II. After they have had sixteen hours of intensive training in the building and use of STELLA II models in their own discipline, they receive further training in the general use of the software and in the basic concepts of system dynamics. Finally, they develop a major cross-curricular model working with a team of teachers in other disciplines.

Although the structure of the summer institute has remained similar to that outlined in the original grant proposal, the specifics have changed substantially in the three years of the project. The first efforts, based on the principal investigators' assumptions about how they had learned and used STELLA II, have been modified to accommodate the experiences of the 85 people trained in the first two years of the grant. To understand what worked and what didn't, and why, it is best to look at each segment of the training.

Introducing Simulations/Modeling and Single-Discipline Training in STELLA II

In all three years of the summer institute, the first twelve hours of training have been dedicated to introducing the use of simulations and modeling as a teaching tool. After business and housekeeping formalities, teachers are broken into two groups. Each of these groups works through the

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Fishbanks simulation. This introduces computer modeling/simulation for those who have had no prior experience with it, providing an outstanding example of how an apparently single discipline model can have many multi-disciplinary implications. In this simulation, each group of participants forms six companies. These six companies control fishing fleets. The goal of each company is maximization of assets. To do this, the companies make decisions about the number of ships to buy and where to send those ships in the hope of maximizing fish catch. During the course of the activity problems arise, including potential catastrophic depletion of the fish population. After a ten-year simulation, the activity is ended and a debriefing is done. Discussion of the assumptions and problem solving skills used in the simulation are directed into a general discussion about the nature of situations that can be modeled or simulated.

Participant response to this activity has been uniformly positive. They regard it as a perfect way to introduce modeling, and a number of them have used the simulation in their own classes. This activity is followed by a population model tutorial using, but not directly teaching STELLA II.

The next 16 hours of training focus on learning the basic mechanics of building STELLA II models. In this segment, participants work within their own discipline groups. Training is designed and provided by the core team member in each discipline (science, mathematics, social science). This is also the portion of the training that has undergone the most extensive changes.

Development of the three week summer training program for the first year of the grant (summer 1993) was an exercise in improvisation. Training was to be provided by the principal investigators and a core team consisting of five other teachers who had some experience in using STELLA II. Only two of the principal investigators had used the software more than a full year. The other trainers had used STELLA II, but had a level of expertise substantially below that of the principal investigators. This meant that some decisions were made using assumptions that were not based on actual prior experience. An additional complication was the limited time available for preparing for the institute. The team of trainers began planning specific materials for the two days of STELLA II training in their content areas in March, 1993. However, the development of these materials was not fully pursued until the actual confirmation of the grant award. As a result, the majority of the development of activities and materials was carried out in the six weeks immediately before the training.

In developing these content specific materials for the first year of the training, each discipline core team planned the training and materials independently. There was no agreement on basic concepts covered. The math group focused on modeling structures (linear, exponential, and quadratic models) as well as some of the special input options in models (if-then statements, graphical inputs). The science team followed a similar pattern, but didn't identify the structures by name, nor did they emphasize their importance in looking at general models. Additionally, the science team introduced other models (S-shaped growth, oscillatory) that proved too complex for participants at that point. The social science team did not address basic structures. Rather, it looked at models of a rather high level of complexity because of their interest.

The decisions to proceed this way were made for seemingly valid reasons. The math team felt that the basic structures were most important, and would be easily related to by teachers accustomed to looking at ideas in terms of functions and patterns. The science team also felt that the structures were most important, but that they could be best understood by developing them in the context of science content. The more complex models were an attempt to show the power of modeling in addressing problems normally beyond the scope of quantitative discussion in the pre-college environment.

The social sciences team chose a course based on the entire group's concerns about the social sciences participants, as presented by the core team. Of the three groups, it was clear that the social science teachers would have the least experience, and therefore the least comfort in dealing with quantified descriptions of problems and situations. Therefore, it was assumed that the simpler models, which were seen as highly numeric and not rich in a social science content, would be of less interest to social science teachers. There was a real fear that the social science teachers would become frustrated and disinterested if they spent too much time on these numeric models. As a result, the choice was made to focus on high interest models, at the cost of developing basic mastery of modeling language and structures.

The results of these choices became apparent in later portions of the training. It was clear that each group had been prepared with different strengths, and different weaknesses. The mathematics teachers had the clearest understanding of the structures and the mathematics behind the modeling process. However, they had less knowledge about ways these structures could be applied to describe real-world situations. This was in part due to their core team training, and in part due to their professional training in mathematics, which rarely emphasized application. The science teachers had some understanding of the structures, but clearly were not comfortable enough with them to quickly associate behaviors with structures. They could, however, with a little help, describe real problems which could be addressed by the structures.

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Open Learning—An Alternative to Traditional Teaching/Learning Models at St. Patrick's College

Ed. note: As we continue to introduce systems education to our schools, we discover various approaches. This is an interesting description from "down under" by Frank Brooks at St. Patrick's College.

St. Patrick's College is a Years 7-12 independent girls school with a student population of approximately 1000. The college is situated on a campus in Campbelltown, southwest of Sydney, Australia.

For many years now, St. Patrick's has been moving towards giving students more control over the pattern and style of their learning in acknowledgment of the fact that individuals who are flexible, creative thinkers with an interconnected vision of the world will be well prepared for whatever paths their lives take.

The first major step was taken by the college over ten years ago: the introduction of the vertical, modular curriculum model. In this model the students are given control of their learning patterns. Every subject area offers modular courses that run for one semester. Junior school students select a set number of units each semester, and have to complete a nominated number of units from each department to ensure that they meet school certificate requirements (The School Certificate is the year 10 certificate).

This model allows students to select the courses (or modules) that they will undertake in combinations that suit their needs and interests. It is quite possible as a result of this structure that no two students in the junior school will be following the same timetable pattern for a semester. Students are grouped by interest and ability, not chronological age. Given that not everyone has the same interests, or learns in the same way or at the same rate, who better to have input to the form that their learning takes than the individual concerned? Using this organizational structure, students are able to explore their potentials in areas that interest them. This is in sharp contrast with models that force the individual to move at the pace of the group and to undertake a course of study that is predetermined for them. Such 'lock step' organizational models are of course remnants of the Industrial Age and as such are rather outmoded in the world rapidly evolving around us.

Since we are in the midst of the greatest social change since the Industrial Revolution, students need a whole new set of skills, not the least being the ability to collect and synthesize information in an independent manner.

The Open Learning Centre

The purpose in introducing the modular time-table structure was to give students control of their learning patterns. This however, did not necessarily change the dynamics of the classroom.

A logical progression from the individualized time-table model was the development of an independent learning centre that would give students more control of their learning in the classroom. This has been done by creating an environment that requires a fundamental shift in the relationship between teacher and student by encouraging the teacher to become a facilitator rather than 'the font of knowledge'.

The centre in its present form has been in place since the beginning of 1994, but has been evolving for a number of years. The intention of the centre is to provide an alternative environment in which learning can take place. In the Open Learning Centre students work through programs at a pace that suits their abilities, while their progress is monitored by a supervising teacher. Programs are designed to offer individuals alternative pathways through the course. After each planned sequence, students make decisions about where their study will go next by selecting from a range of alternatives. The centre has responded to the reality that students have different learning styles and should be given the chance to take advantage of their individual potentials.

The college believes that the shift towards students working in a 'transparent classroom' that offers an information-rich learning environment is critical to the encouragement of flexibility and adaptability in the individual. Computer technology is an integral feature of this planned environment. The learning centre allows both day and night students to chart their own path of learning in a way that suits their learning style and needs.

The Physical Structure

The Open Learning Centre consists of two buildings linked by a study area. The complex has three large teaching spaces, a library, and five traditional classroom spaces. In any given period there will be three class groups using the large spaces, and all the classrooms will be in use. Since all of these spaces are connected to the library, resources can move freely within the complex. Senior students also make use of the complex as a study area. The library staff are critical to the functioning of the centre, as they are responsible for all the resources that are made available. This has broadened the definition of librarian and made them even more valuable than before.

Logistics

Students who are undertaking a course that is running in the centre have to meet with their teacher in a designated teaching space each period.

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The teachers may use this space in any way they choose, and typically the pattern of use will change during a semester. At times the teachers will use the space in the same way they would use a traditional classroom; at other times students will meet their teacher only to discuss progress or for rollmarking, and then will spend the rest of the period in a part of the complex where they can access the resources that they need to work on their project.

Students can make use of library resources, computer resources, and video resources in order to access the type of information that they need. Courses running in the OLC may have a whole group of students who are working in the same course, but often, there may be two or three different courses in history, for example, running in one group. Because the classrooms are open, i.e. students are moving in and out on a needs basis, it is necessary for teachers to develop strategies that differ from those traditionally associated with classrooms. In other words, teachers become true facilitators in a dynamic relationship rather than deliverers of knowledge to a group sitting in ordered rows within four walls.

It should be noted that since students are able to work in any part of the building, teachers time-tabled to open learning spaces can expect to have students from other classes in their area at any time. Senior students use the centre as a study space, so they can be found throughout the complex.

Computer Technology

Until the OLC evolved into its present form, the majority of students accessing computers in the college were doing so in Computer Studies. This meant that many students had little or no access to computers. To alleviate this problem, the college has provided two computer rooms to serve the needs of the range of computer related courses running, and has also installed over twenty open access machines in the Open Learning Centre. In each of the large teaching spaces there are at least five Apple Macintoshes connected to a laser printer for student use. There are also five Macintoshes and a laser printer in the library. All of the open access machines have had At Ease installed on them so that students can have access to appropriate parts of the hard disk but cannot save to the hard disk. Ten of these Macintoshes have internal CD ROM drives and if a student needs to make use of a CD they simply request it from the AV room. This is a ‘low tech’ solution to CD access but it works.

Students and staff have access to the Internet, eWorld, the Electronic Classroom and Nexus. There are a number of French and Physics students having electronic tutorials with external tutors at OTEN.

As a result of these initiatives, the percentage of students in the college making use of computer technology in a range of subject areas has risen from approximately 40% to around 95%.

Pathways

The Open Learning Centre offers a flexible environment that gives students the opportunity to access information in a variety of media and from a range of sources. The pathways initiative (a change in organizational structure that is allowing students to undertake courses in high school that give advanced standing in tertiary courses) has broadened the range of options available to students, and is by its very nature causing people to rethink how schools are structured. Students at St. Patrick’s are well positioned to take advantage of the opportunities that pathways has opened up, and in fact many students have already done so. The college has a number of Joint Secondary School TAFE (JSST) courses running, and students and staff have already completed TAFE courses by satellite. (TAFE is the primary supplier of vocational education in NSW and has strong industry links).

Summary

The OLC offers an alternative teaching/learning environment that:

- allows for the diverse needs of the individual—both in interest and ability.
- gives full access to a range of computer applications to all students.
- offers an information rich environment that has full support available to the student but will allow students to work privately if they so desire.
- offers students a range of information and communication technologies that includes traditional library resources, video, satellite, television, and contemporary computer resources that will encourage students to make use of the myriad functions that can be achieved.
- offers access to eWorld, Nexus and Internet.
- is able to accommodate at least 250 students at any given time.
- is a working model of a true alternative to more traditional systems.
- encourages the use of appropriate technologies by both students and staff.
- encourages use of computer technology to discover alternative ways of communicating thoughts and ideas, e.g., use of desktop video and computer graphics (there is an AV Macintosh with Photoshop, Adobe Premier, Type Reader and Sound Edit Pro available for student and staff use. This computer is linked to a colour printer and flat bed scanner).
- gives the students greater control of their learning by creating an environment that encourages the shift from teacher-centred to student-centred learning.

We are looking at using Systems Thinking and STELLA in the class-

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The social science teachers had little idea of how to build simple models. They could outline and describe interesting models, but they had great difficulty reducing the models to simple structures that could be built. They were excited at the possibilities, but had anxiety about their ability to develop a model to fit problems. As the training progressed, they were the focus of much of the "remediation" in building models.

The training the second year was conducted by a new core team. This team was chosen from the first year participants. They participated in a lengthy debriefing and critique of the first year's training. In it, they strongly emphasized the need to make participants more comfortable with the basic modeling structures. In particular, the new social studies core team emphasized that they and their colleagues felt "handicapped" by their inability to quickly choose the correct modeling structure as they worked in their groups. They were supported by the observations of one of the most important people involved in the grant, Josh Behnke. Josh is a college student who was one of the first high school students taught systems modeling by Diana Fisher. He is a general assistant to the principal investigators and core team, and probably the most facile modeler involved in the project. In the first year, much of his time was spent providing assistance and support to the social science participants. He strongly recommended that the structures be emphasized, especially in the social science group, where their lack of quantitative training made it more difficult to identify the modeling behaviors desired without the language of the structures.

These recommendations were incorporated into the second year training, with gratifying results. All three content groups restricted themselves to learning and developing models using only three basic behaviors: linear, exponential, and S-shaped. These models were developed in the context of the subject area, but were clearly identified and discussed as basic modeling structures. In the mathematics training, they were used in looking at a variety of applications. Other recommendations from the first year resulted in some of the features of the STELLA II software being included in all training as well. Each group saw and built models with simple conditional statements and with graphical inputs for at least one variable.

It had been intended to teach the participants the basics of the authoring capability of STELLA II version 3.05, but copies did not become available to the core team until shortly before the training. Use of these authoring functions was taught individually as models were developed in the last week of training, on a "need to know" basis.

Debriefing and evaluation by participants and both the second year core team and the third year core team (chosen from second year participants) indicated that the comfort level with basic structures was far higher than the prior year. Participants felt comfortable with and understood the structures. In particular, they were able to identify the appropriate structures to start with in developing their large cross-curricular models. The same basic pattern is planned for the third year of training. Of note is the decision that authoring structures will not be included in this part of the training. The emphasis on simplicity and basic skills/structures was very successful. It will not be tampered with.

Industry/Research Experts

The first year of training was conducted without a "test drive." A number of speakers had agreed to talk about the role modeling played in their professional work. Discussions with them included a request that they provide some "hands-on" activities for the participants. All agreed. The actual presentations revealed the differences in interpretation of the concept "hands on" as viewed by academics, applica-

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room but progress is slow because there is no support network to speak of here. One of my colleagues, Elizabeth Clark, and I attended the conference in Concord last year. This was of great value and many friends were made, but nothing beats being able to sit down and talk to people in order to tease out problems. I do however make use of the net to try. We seem to have been in quite a different situation than most here at St. Pat's, where the catalyst for the changes in organizational structure came as much from above as below, although all changes took place in an environment of consultation. The leadership direction meant that I found myself in the fortunate position of working in an organization attempting to respond to the changing needs of its clients instead of imposing an outdated model on them.

What I want to illustrate is that most of the people I have spoken to started the change in the classroom with systems thinking skills and hope to bring about change at an organizational level at some later date. This has often meant that they have had to convince people above them in the hierarchy of the merit of what they are doing. My experience has been quite the opposite, since the environment changed first and then we started looking at systems in the classroom. It could be summed up by saying we went from global to local rather than local to global.

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tions oriented researchers, and teachers. We had anticipated that the speakers would present material for 45-60 minutes, then have the participants work on the computer for an equal time. This pattern would be repeated until the speaker was done. In the actual presentation, only one speaker did that. All other speakers had few activities for the teachers. The responses in the daily feedback sessions and in the final evaluations were strong and to the point. The most positive responses were given to Ed Gallaher, a research pharmacologist at Oregon Health Sciences University, who followed the pattern we'd requested. Mixed responses were given to those who had some STELLA-based activities, with the negative comments generally focusing on inadequate activities associated with the presentation. Those presenters who spoke about more general modeling topics and had no STELLA oriented activities got almost uniformly negative evaluations. Even when participants thought the speakers had something useful to present, the strong message was "if we don't have something to work with using STELLA as an activity, the presentation is of questionable usefulness."

Planning the second year speakers, we followed the strong advice of participants and the core team. Speakers who were not using STELLA were dropped from the program. Those who used STELLA were reminded that there had to be at least as many activities as there were oral presentations. The need to focus on seeing STELLA used and using STELLA became the key criteria in choosing and arranging speakers. The outside speakers retained for the second year were Ed Gallaher, who presented a full day on modeling chemicals in the body, and Nancy Miller of Batelle Labs, who spoke on climate modeling. Andrew Jonca, one of the principal investigators, again spoke on the mathematics behind STELLA. Two additional speakers were added. The core team and participants strongly recommended that speakers be arranged who would discuss topics more closely related to the social sciences. In the first year, social science teachers felt that the speakers had almost uniformly focused on science and mathematics. To remedy this, John Heinbokel and Jeff Potash, of Trinity College, Burlington, Vermont, presented their work in interdisciplinary modeling, with emphasis on their "Plagues and People" activity.

Evaluation of the second year's speakers was almost uniformly positive. All stayed within the guidelines, balancing computer activities with formal presentations. The mix of topics, content, and styles seemed to please everyone. This re-emphasized the requirement that presenters build on the training in STELLA done the first week. The activities increased familiarity and comfort with the software, while expanding the participants grasp of what could be done with it. The third year speakers plan is identical.

Advanced Topics in System Dynamics and Building the Cross-Curricular Models

Once basic training in STELLA is completed and speakers have given participants a glimpse of how STELLA can actually be used, the focus shifts toward the final product of the institute: cross-curricular models. In the first year of the grant, this took place in the last week of the institute. Steve Peterson, co-developer of the STELLA II software, presented an overview of system dynamics/ modeling for two days. This involved formal presentations and activities on the computers. He spent another day helping teams choose problems to model, as well as assisting them in developing their models. Participants then spent the remaining two days finishing their models and curricula. While this worked, it was the general consensus among both old and new core team members that this was not the best use of Steve's special talents. Additionally, it did not provide enough time for people to do the work necessary to develop models without putting undue stress on them. While the process certainly worked the first year, it could clearly be refined and made less stressful. In particular, more attention had to be paid to formation of the cross-curricular teams and choosing modeling topics. In the first year, none of the participants or staff could actually explain how or when the teams were formed. They were like mushrooms, simply appearing where none was before. Fortuitous chance could not be relied upon for a second year. Accordingly, the final step toward the completed models was revised.

Formation of the cross-curricular teams was always a major concern of both staff and participants. The entire project was viewed by some as a recklessly optimistic endeavor. Mathematics, science, and social science teachers tend not to cooperate. They have different skills, look at problems from different perspectives, and use different language to describe problems. The differences are not limited to quantitative versus non-quantitative approaches. They include an entirely different style in approaching and considering problems. It was assumed that the language of STELLA would be the common language that would allow them to cooperate. Originally, it was anticipated that participants would consist of three-person teams from individual schools or school districts, one from each discipline. This would provide ready-made cross-curricular teams. While about half of the participants fit this model, the other half didn't. Bringing those people into teams, and choosing topics to model presented the challenge.

In the second year of the institute, some progress was made toward developing a formal process for team formation. In the second week of the training, a large blackboard in one of the classrooms used for presentations was designated the "idea" board. Participants who had ideas for models would put up a simple description or title of the model with their name. During the course of the day, others interested in the idea would put up their initials next to it. During lunch, breaks, or in the evening, the interested parties would discuss the possibilities of the models. Some teams formed that way. Near the end of the second week, John Heinbokel and Jeff Potash spent an hour with the group talking about the potential of some of the ideas on the board. More groups were formed following that. Finally, the few who had not yet chosen a topic met to talk over possibilities and form the final groups. This approach worked, but it still is unstructured and haphazard. The principal investigators have some time designated in the schedule for "team building" activities in the third year of the institute, but at this writing the actual activities have not been developed.

Once groups are formed and topics chosen, the actual models can be developed. However, the basic training in STELLA was not sufficient to allow treatment of more complex ideas. More advanced training in systems thinking and modeling was provided by Steve Peterson in the first year of the institute. In the second year, that was largely taken over by the principal investigators, allowing more of Steve's time to be devoted to helping teams build models. In the second year he still presented some additional topics, but two full days of his time were devoted to working with teams. This additional expert help was essential for some teams.

The actual process of developing the cross-curricular models has produced two drastically different approaches. In one approach, the team chooses a simple concept or problem with multiple implications or many different relatively simple ways to extend the model. An example of such a model is "The Rulers", a packet developed in the first year of the grant. This packet consists of three basic models. The first is a population model with both births and deaths. The second is the same basic model, with the addition of a non-renewable resource that affect the population. The third model replaces the non-renewable resource with a partially renewable resource. The models are simple, and easily understood. The concepts involved, however, allow the posing of significant questions in biology, mathematics, history, political science, ethics, and even literature. The curriculum materials that accompany the model are an excellent example of how such a simple model can be both versatile and powerful.

The other approach involves choice of a complex problem, which often has a more narrow usefulness. The first year of the project provided an excellent example of such a model, "Mahenjo Daro", a model depicting the growth and destruction of an ancient city. The group that developed this model exhibited most of the behaviors that make developing the models difficult. Their original attempt to build the model had nearly a dozen interrelated factors, with several dozen modifying variables. They began by building a model with all the variables, then attempted to get it to run the way they thought it should. Two days of frustration brought them to the point of giving up on the model. Finally they simplified it and developed a very useful model, but not exactly the one they wanted.

Their experiences are characteristic of many of the attempts to build cross-curricular models. The success and frustrations participants have experienced the last two years lead to some generalizations. Many of the mathematics teachers had no idea what to model. They tended to focus on the structures, but had no idea what they described in the real world. The physics and chemistry teachers wanted to model situations that were already solved using algebra or very simple calculus. These models may be useful in their own disciplines, but they have little applicability as cross- curricular models (with the exception of models such as cooling curve models, which can be tied to mathematics, vocational education, and even the social sciences and biology through environmental discussions). Biology and Social Science teachers brought very large and very interesting problems to their groups. Unfortunately, they tended to want to develop an exhaustively complete model. Whether this is done in an attempt to imply validity or precision by adding all the details, or an attempt to simply tie together all the variables that normally can't be dealt with simultaneously, the result is an impossible model. These models are seductive and exciting to teams. They seem to be an ideal appli-

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cation of computer modeling: a complex problem that eludes solution and analysis by other means. However, they are so complex that they are frustrating, especially if, in their enthusiasm, people begin by building the entire model. Novices, in particular, seem captivated by the power of modeling and made this error. It was difficult to get them to remember the injunction taught all computer programmers (and more often ignored than followed!): KEEP IT SIMPLE!!

Many of these complex ideas can be developed into excellent models. The key is to start with a simple core model. That simple model should be adjusted until it runs correctly, even if it doesn't exactly illustrate the behavior of interest. Then the model can be modified to include other variables or linked to other simple models. In any event, the complexity level should probably never exceed two or three stocks. Beyond that, the logic and interconnections will be impossible for most precollege students to follow. Many of the groups started this way. However, unless monitored and reminded, they tend to revert to excessive complexity. It is also useful to remind modelers that a good way to proceed is to make multiple runs of a model after each modification. It is not unusual for a change in one variable to produce major changes as a second variable is modified, particularly in oscillatory models. Several of the models built the last two years initially appeared valid, but exhibited obviously wrong behaviors when other changes were made in combination. More test runs will reveal those flaws.

The drive toward increasing complexity and completeness appears so powerful as to almost be a law of nature. As models are built and enlarged, it is often necessary to remind the modelers that a model does not have to produce results or predictions accurate to the third decimal place to be useful. Particularly in the so-called "soft" disciplines (non-quantitative fields like history, political science, literature, and some aspects of biology), a model can be important because it becomes the vehicle for directing thought and discussion, not explicitly solving a problem. Excellent examples of such models are the "Lord of the Flies" and "Schuster Forest" models developed by Tim Joy, a core team member of the CC-STADUS project.

Other Concerns

As the summer institute has progressed, other causes for concern have emerged that cannot be directly addressed as clearly as changing speakers or changing the order or number of minutes spent on a topic. Most important of these is the fact that a major impediment to successful modeling can often be anxiety. This became apparent in the second year of the institute. In the first year, participants had a sense that they were part of an adventure, that expectations were not unreasonable, because there was relatively little to show them as examples of what their large models should look like. It was also clear that even the core team, while more experienced than the participants, were not especially sophisticated modelers. There wasn't much separation between the teachers and the students. The second year, participants were confronted with materials that were polished, professional-looking documents developed by the first-year participants. They were intimidated at the thought that they were expected to produce similar materials. In addition, the core team, which had the benefit of more training, more support, and more experience than the previous core team, seemed more "different", more separated from the participants. This became apparent to the core team and the principal investigators. In response, time was built in the second and third week to talk about how people were feeling, about their uncertainties and anxieties. These sessions were conducted, but not "led", by core team members. The result was substantial allaying of fears. The intensity level of the training, the newness of the ideas, make such "safety valve" sessions essential. The result will be a greater comfort level, not only while building models in the summer, but greater comfort as the participants build models in their own buildings.

Supporting the Participants: Facilitating Growth of the Use of System Dynamics

That the participants learn the basics of system dynamics and computer modeling with STELLA is indisputable. The more than twenty major interdisciplinary models developed during the summer institute give ample testimony to that fact. The large number of single discipline models that have been developed after the training, the observations and evaluations of classroom use, show that substantial progress has been made toward increased use of computer modeling in the pre-college classroom. Most of the participants in the first year of the grant have completed all their requirements, including development of an additional model, presentation of modeling to other teachers, and formal evaluation of their use of models in the classroom.

In December, 1994, the CC-STADUS project was designated an exemplary grant by the National Science Foundation. In its two years of operation, it has been seen as broadly successful in training teachers. However, supporting them in their efforts to use modeling in their classrooms has proven to be far more difficult than the training was.

Participants may be grouped into two categories: those who were members of a team (ranging from 2 to 6 participants) and those who were individuals attending the institute. In the selection process, preference was given to teams. Implementing new ideas is always difficult. Support of peers is always helpful in such an effort. It was assumed that the presence of a team in a school would increase the chances that one or more of the participants would not only use the materials received and developed in the summer, but would continue to develop new models and curriculum. The hope was that multiple users in a building would also stir interest within the building, recruiting additional modelers. In virtually every case where a team represented a building, at least one participant has become an active modeler, developing new models and encouraging others to explore STELLA and system dynamics. However, in general, only one member of the team has reached a high level of activity. The two exceptions to that have been a private school in which all three team members have increased their level of usage, have encouraged others, and have actually succeeded in making system dynamics a focus for reform in their school, and a middle school which had two science/math teachers who have collaborated on work and have recruited others.

What is rather surprising is the fact that about the same percentage of team members and individual participants have become high level users of STELLA in the first year of the project. This may be explained in part by the support they have been given by the project and by their building administrators.

The first year of the project, participants came from around the Portland metropolitan region. No one was more than 45 minutes by car from a principal investigator or core team member. Support or assistance could be gotten quickly and easily. Attendance at the monthly support meetings was steady, sometimes exceeding half of the participants in the institute. In the second year, however, more of the participants came from areas in the more remote regions of the state. Some participants live 150 or more kilometers from the nearest other participant. As a result, support is not as accessible. However, the number of "high" level users is about the same. The number of minimal users is slightly larger. Discussion with the core teams, who have been responsible for most of the evaluation of participants, indicates that encouragement and assistance are most critical to the minimal or average users. Help on a model, teaching a demonstration lesson, or simply a gentle reminder and words of encouragement serve to increase the level of work and commitment for many of the participants. Others, of course, require more extensive assistance.

A major error made both years has been beginning the process of support and assessment. The first month of school is always stressful and tightly scheduled. It is a time when teachers are getting classrooms and classes prepared for the year, with little free time. Most regard it as a time for old, proven activities, a time to establish expectations and patterns of work and behavior, not a time to take a risk. As a result, the principal investigators and core team chose to begin assessment and support activities at least two months into the school year. This delay meant that many of the participants had four months between their last use of the software and beginning to think about using it in the classroom. The loss of enthusiasm and skill placed them in the position of relearning what they had done in the summer. This is reflected in almost all monitoring of participants, with the exception of the core team, which meets in October. For the third year, follow-up, assessment, and support will begin by October first.

The participants themselves report a number of obstacles to using the models and concepts in their classes. The most commonly mentioned obstacle is one that is endemic to teaching: lack of time. Putting in new activities takes time away from other activities. Preparing new activities and developing new models or strategies takes time from a life that is usually too full already. When teachers are provided time (in some cases, by their administrations), their ability to use and develop project materials increases dramatically. The core teams, with 6 days spent building models and planning training, are excellent examples of the benefits of free time. Their sophistication as modelers has exceeded all expectations. They have had the time to think, plan, and build models.

The second major impediment to wider use of models and systems concepts is a lack of hardware and software. Every participant receives one full-featured copy of the software. As part of the application process, their administrators must guarantee access to at least one computer when using STELLA in the classroom. Some participants have access to computer labs, others do not. However, only core team members, chosen on the basis of their modeling ability, creativity, ability to work with people, and enthusiasm, received an additional five copies of the software. While these core team members, the principal investigators, and other participants have shown that effective work can be done with only a single computer and a single copy of the software, it is clear that increased access to both hardware and software makes it easier to use the materials, and encourages development of new materials by both students and teachers. This summer, all new participants will be provided with 10 copies of the run-time version of STELLA II. This version will allow existing models to be run and modified, graphs to be printed, and models to be built but not saved. Additionally, all previous participants who have completed their requirements will also be given 10 run-time copies. Increased use is anticipated, and will be monitored.

While the majority of participants have used, and continue to use STELLA in their classrooms, the frequency and types of use vary widely. A few participants have started to let students do model building. This ranges

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Systems Thinking "in Twenty-five Words or less"

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riculum tools to the broader purpose, management and philosophy of education. Also, because a systems viewpoint seems foreign to some people, explaining it has to relate to their own experience to make sense, and that takes time, too. Here is one try, with a few more than "25 words or less."

"Systems Thinking" is a term that is gaining wider use and acceptance, but it is not widely understood. Although it sounds like a great idea, it is still quite confusing. Systems thinking does present a different way of thinking, but there is nothing mysterious, incomprehensible, or foreign about it. It is easiest to approach it as another form of common sense, only from a different perspective. At first, to get a good understanding, you need to suspend your own previous assumptions for a while and try to look at familiar things from a new angle.

Here is an example arising from educational experiences we all have shared. In school, we have been taught that social studies, math, language arts, science, and art are all separate disciplines, or bodies of knowledge. This stems back to the early days of modern science when the idea of reductionism took hold: the idea that you can best understand something by taking it apart and studying all of its pieces. Consequently, we have made great strides in the advancement of knowledge as experts have become more and more specialized. In education, students have followed this same model, with their instruction becoming more and more compartmentalized as they proceed through school. Our high schools have become collections of separate departments, each with their own facts to teach. Although we know that in the "real world" we seldom deal with each subject in isolation, we leave it to our students to synthesize all this information on their own...if they can.

From a systems thinking point of view, this synthesis is the most important part. Systems thinking encourages you to step back and see the whole picture, rather than focusing on just its parts. It is an attempt to see the "forest" as well as the "trees." Systems thinking explores the interdependencies among the elements of a system, looking for patterns rather than memorizing isolated facts. It focuses on the feedback loop structure of a system because that structure determines the system's behavior over time.

With a little bit of practice, you will see these patterns emerge. Furthermore, the patterns are strikingly similar across disciplines. Once you can begin to spot the similarities, it

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from a few students working independently during school time, to full-year system dynamics/modeling classes. Most participants have built at least one additional model, while others have built many. In general, these models are single subject area models. A few can be used in two content areas (e.g., physics and algebra, or literature and social studies), but most cannot. No large cross-curricular models have been developed by participants other than during the summer institute. When the numbers of users in any single building grow large enough, this should become a possibility, but at the current time none of the schools involved have reached that point.

The large cross-curricular models tend to be used primarily by those involved in their design, though a few of the models have had much broader use both within and outside the project. In particular, the models that are least specialized, such as "The Rulers", have the widest use and adaptation.

In looking at those teachers who have made the most use of system dynamics after being trained, some patterns appear. Young or new teachers, with few other commitments or major involvements in curriculum or professional activities, tend to make more use of the materials and to develop new ones. It may be suggested that they do not have other time commitments that reduce their ability to do new work. A second group of teachers who have been very active are very experienced teachers (20 years or more) who have strong support from their administrators based on past work, but do not have other major commitments. Teachers in the middle of their careers, with many involvements, tend to make the least effective use of the project materials.

These generalizations are, of course, subject to exceptions. It does, however, seem clear that teachers who push the limits of system dynamics in the classroom must make a major time and energy commitment to the work. Candidates for the third year of the grant are being chosen with that information and the performance patterns of previous years in mind. The candidate who has done everything, and is still doing it, may well not be as good a choice as the candidate who is more inexperienced, but shows creativity and has time.

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becomes much easier to understand each discipline itself, along with the big picture. For example, exponential growth is one very common basic pattern in systems. Starting with mathematics, exponential growth is what develops if you take a very small number and, for example, double it. Next you take your answer and double that; keep doubling your answer again and again. In this example, 1 doubled becomes 2, then 4, 8, 16, 32, 64, 128, 256, 512, 1024, and so on. At first, your results are still small numbers, but as you keep doubling the answer, the results start to make much bigger and bigger jumps. Squaring a number takes even more dramatic leaps! Whatever the multiplier, the growth builds upon, or reinforces, itself.

If you stop to think about it, you can see that this pattern is ubiquitous. It applies to unchecked population growth, whether of bacteria in a petrie dish, gypsy moth caterpillars in your backyard, or human population. Just think of a family reunion or family tree where one elderly couple might have three children, nine grandchildren, and twenty-seven great-grandchildren: a very large family from just one couple! In social systems, you see the same pattern in the spread of a rumor, or the spread of an epidemic. Only a few people may be involved at first, but it spreads more rapidly as more people do the spreading!

In economic systems, a bank balance left to accumulate interest grows exponentially; a small amount of money grows to a large sum as the interest rate applies to a larger and larger principal. Spiraling wage and price inflation also behave this way. Every chain letter or pyramid buying scheme appeals to our basic understanding of exponential growth to lure participation. In fact, anything that you would already call a "band wagon," "snowball effect," or "virtuous cycle" probably fits the pattern of exponential growth.

Once you can recognize the patterns in these systems, you gain a deeper understanding of them. If you can grasp it in one example, you gain recognition and understanding of the rest. Furthermore, you begin to see how these structures determine the behavior of the systems in remarkably similar ways, and you can think in broader terms about their implications. For example, you learn that exponential growth cannot go on forever; there are almost always limits which are also part of the system. Sometimes you can even see your role as part of some systems—part of the problem and part of the solution. In effect, you come to see the "forest" as well as the "trees" because you see the interrelationships among the elements of the system.

Back to education, young children are intuitively good systems thinkers, probably because their learning has not becomeso fractured yet. In their eagerness to learn, they bring all that they know to their learning. Everything is related and relevant. We do a pretty good job at supporting this in kindergarten. When the children study the ocean, for example, they read and write ocean stories, count and sort sea shells, study and taste fish, and tie it all together with art projects. They might even discuss beach erosion and pollution in this interdisciplinary endeavor. They know that "everything is connected to everything else." What's more, they love it! In their interdisciplinary, learner-centered approach, they are pretty good budding "systems thinkers." Perhaps we would all be too, if our thinking had not become so compartmentalized as we progressed through school.

It is fun to explore the ideas of systems thinking because their applications are all around us. In education, we cannot expect to overhaul our current system, at least not all at once, but we can encourage our students to build on their early systems thinking tendencies, so that they are better equipped to deal with the much more complex systems they will face. They will need these decision-making skills.

Systems thinking is the broad concept we have discussed so far. The curriculum tool for building this skill is "system dynamics," a specific computer simulation technique. Students learn to specify and quantify the relationships and structures of a system and then simulate them to observe the behavior of the system over time under varying assumptions. They build a computer model of the system based on their experience and research and then experiment on it. For example, in a model of the gypsy moth caterpillar population, students would have to specify exactly what factors cause the population to grow exponentially. As the simulation unfolds, they would see that these same factors also play a role in the population's exponential decline.

System dynamics is the cornerstone of systems thinking. Learning system dynamics makes accurate, confident systems thinkers. Although systems thinking by itself yields fascinating and valuable insights, system dynamics gives you the tools to go further into critical thinking and problem solving. At the curriculum level, it makes education engaging, learner-centered, and relevant. By understanding the underlying system structure of the subject at hand, students gain not only a deeper understanding of that subject, but that insight also transfers to a deeper understanding of other subjects as well. Also, system dynamics modeling is interdisciplinary because students must bring all of their knowledge and experience to the task. For example, to model an epidemic, students would start with the biology of the infection, but political, economic, and social factors are also very important. System dynamics ties education together, and math becomes a natural part of all subjects. This synthesis offers students the confidence and problem solving skills they will

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INTERNET NEWS

The System Dynamics in Education Project (SDEP) has set up a Web page as well as an ftp server. You can access CLE materials directly by going to the ftp site (**sysdyn.mit.edu**) and downloading from the CLE folder. All the materials on the site are put into Common Ground, a program which allows cross-platform viewing and printing of documents. There are two miniviewers available in the utilities folder at the ftp site— one for Macs and one for Windows. You will need to download the appropriate one for viewing and printing the documents.

Ideally, you should be able to go to the SDEP web page (**http://sysdyn.mit.edu)** and be able to click to download any documents from the ftp server. I have been unable to do so as yet, and as of this printing do not know whether it is my connection or an inherent problem with the web site. We are trying to fix it, so when you log on, if it is not fixed, send an e-mail to the SDEP student in charge to indicate that you are having the problem. I think we will get it sorted out.

The folders on the CLE portion of the server will include:

1. A folder of new materials which have come to us since the last List of Materials—or if the List is just out, those which came to us in the months before it came out.
2. The latest List of Materials (LOM).
3. Folders which contain the materials we have on disk, sorted the same way they are in the LOM.

For ease of downloading, I am stuffing the documents into self-extracting archives (using Stuffit). Since I work on Macs, this may pose a problem for those who are working with Windows. I will be working on the compatibility using a Windows computer and downloading from the CLE folder. Please tell me if you have a problem, or better yet have worked out a solution.

I am anxious to hear how the Internet connection is working. Please give me feedback about ways to improve. If you have problems downloading or mechanically with the server, please e-mail the student in charge (address found on the server or on the WWWeb page.) I look forward to your feedback. My e-mail address is stuntzln@tiac.net.

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Systems Thinking "in 25 Words or less" *cont. from page 13*

need as they face increasingly complex social, environmental, and political systems.

Systems thinking may seem foreign, even frustrating, at first. Because it is a different approach than we have been taught, it sometimes takes a while to "sink in." There are also different levels of pursuit from just being aware of systems to building system dynamics models. At the beginning, just try to look for examples that apply to you and think of systems thinking as adding another dimension to your good common sense. Then, keep going, because it is exciting and important!

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