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ABSTRACT

This document reports on the first year of the STACI (Systems Thinking and Curriculum Innovation) project, a two-year project which is examining the cognitive demands and consequences of using the STELLA (Structural Thinking Experimental Learning Laboratory with Animation) software to teach systems thinking, content knowledge, and problem solving. The study is also examining the extent to which this approach helps students to acquire higher-order thinking skills and generalize their new knowledge and skills to other areas. Teachers in physical science, biology, chemistry, and social studies at Brattleboro Union High School (Vermont) designed and tested ways to use STELLA; traditionally taught courses provided control. In addition to time constraints, teachers identified five difficult aspects of their task: (1) determining the appropriate sequence of knowledge that should be followed in teaching systems thinking; (2) identifying the points in the curriculum where systems thinking can best be used; (3) developing models that illustrate systems thinking but are simple enough for students to understand; (4) deciding how and when to introduce STELLA; and (5) assessing the effectiveness of systems thinking for teaching particular concepts. Teachers made progress in curriculum development, and students responded well to the new instructional materials. The teacher questionnaire, a class assignment, an analysis of time spent on curriculum topics, and a reprint of an article on the project are appended. (13 references) (Author/MES)

TR87-6

THE SYSTEMS THINKING AND CURRICULUM INNOVATION PROJECT

Technical Report, Part 1

September 1987

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The Systems Thinking and Curriculum Innovation Project

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ABSTRACT

TR87-6. The Systems Thinking and Curriculum Innovation Project: Part I

The field of systems dynamics focuses on connections among the elements of a system and how the elements contribute to the whole. Based on the concept of change, it uses simulations – simplified representations of a real-world system – and computer-based mathematical models to represent complex relationships among variables in a particular environment. In this study researchers examine the cognitive demands and consequences of using the systems thinking software STELLA (Structural Thinking Experimental Learning Laboratory with Animation) to teach systems thinking, content knowledge, and problem solving. The study also examines the extent to which this approach helps students acquire higher-order thinking skills and generalize their new knowledge and skills to other substantive areas.

In the first year of the project, experimental class teachers in general physical science, biology, chemistry, and social studies designed and tested ways to use STELLA as they proceeded through their curriculum; traditionally taught courses provided controls. Some experimental teachers were more successful than others in identifying appropriate applications for systems modules. All recognized the delicate balance between using traditional methods and infusing systems thinking into their courses. In addition to time constraints associated with their normally heavy teaching responsibilities, they identified five difficult aspects of their task: (1) determining the appropriate sequence of knowledge that should be followed in teaching systems thinking; (2) identifying the points in the curriculum where systems thinking can best be used; (3) developing models that illustrate systems thinking but are simple enough for students to understand; (4) deciding how and when to introduce STELLA; and (5) assessing the effectiveness of systems thinking as a way to teach particular concepts. Despite these dilemmas, teachers made considerable progress in curriculum development, and students generally responded well to the new instructional materials. Biology most readily lent itself to a systems approach, while the general physical science teacher and the chemistry teacher found it more difficult to identify appropriate topics and devise lessons. In the War and Revolution seminar, offered to selected students with advanced knowledge of both systems thinking and STELLA, systems thinking was used to study historical events and to develop analytical skills and an appreciation of the complexity and importance of policy decisions.

Using some published instruments and others developed specifically for this project, data were collected on student ability and achievement, on cognitive skills thought to be related to systems thinking ability, on content learning, and on acquisition of systems thinking skills. These data are considered quite preliminary and have been used mainly to guide researchers and teachers in adjustments, changes, and revisions for the second, more formal year of the project.

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The Systems Thinking and Curriculum Innovation Project
Technical Report, Part 1

General Background Information

The intent of the Systems Thinking and Curriculum Innovation (STACI) Project is to examine the cognitive demands and consequences of learning from a systems thinking approach to instruction and from using simulation modeling software. The purpose of the study is to test the potentials and effects of using the systems thinking approach in existing secondary school curricula to teach content-specific knowledge as well as general problem solving skills. The study also examines the effectiveness of using STELLA (Structural Thinking Experimental Learning Laboratory with Animation; Richmond, 1985; Richmond & Vescuso, 1986), a software package for the Macintosh™ microcomputer, as a tool with which to teach systems thinking, content knowledge, and problem solving. The research focuses on (a) the learning outcomes and transfer that result from using such an approach and software in classroom settings, and (b) the organizational impact of the curriculum innovation.

The study is being conducted at Brattleboro Union High School (BUHS), Brattleboro, Vermont in which four teachers are using systems thinking in their courses. The content areas include general physical science, biology, chemistry, and an experimental social studies course entitled War and Revolution. These four teachers were trained to use STELLA and system dynamics (Mandinach & Thorpe, 1987b). They are using systems models and illustrating them on the computer. Students examine the interrelationships among variables and system properties through their interactions with the simulation modeling software. The STELLA software enables students to model the characteristics and interrelationships of complex systems in the real world, and to follow the evolution of these models over time.

The purpose of the project is to examine the extent to which students acquire higher-order cognitive skills through exposure to and interaction with a curriculum infused with systems thinking and subsequently generalize knowledge and skills to problem solving tasks in other substantive areas. Comparisons are being drawn between traditionally taught courses and those that use the systems approach and STELLA. The research enables the examination of skill and knowledge transfer across content areas as students are exposed to several courses that use the systems approach.

Two ancillary studies are being conducted in conjunction with the main classroom study. The first substudy focused on a select group of students who received extensive exposure to systems thinking and STELLA in a social studies class on War and Revolutions. These students were studied in an intensive case study format. The objective of this study was to collect indepth information about the students' thought processes, performance patterns, knowledge, and general problem solving skills.

The second substudy is examining the organizational impact of the introduction and implementation of systems thinking in the high school. The objective is to analyze changes that occur in the structure and functioning of the school as a result of the curriculum innovation. These changes will be documented and analyzed to shed light on educational organizations.

The STACI Project, which began during the 1986-1987 academic year, is a two-year research effort that is concluding its first year. The purpose of this document is to report on the project's work conducted during Year 1. The report is based on six site visits, correspondence, frequent telephone conversations, and several presentations to professional audiences. We provide descriptions of systems thinking, the site, the design, data collection, instrumentation, the ancillary studies, and curriculum development. A forthcoming report will document the cognitive test results from the main classroom study and the War and Revolution substudy.

Systems Thinking

The field of system dynamics, based on the concept of change, uses simulations and computer-based mathematical models to represent complex relationships among variables in the environment (Forrester, 1968). It is possible to explore the rule-governed behavior of complex systems by constructing models of variables and their interactions, and examining the cause-and-effect relationships among the variables. Simulation models are used to examine the structure of such systems. A simulation generally is a simplified representation of the real-world system.

To build a simulation, it is necessary to understand the major variables that comprise the system. These variables can be used to form a dynamic feedback system, whose mathematical expression is a set of simultaneous equations. Over time, variables change and subsequently cause other variables and their interactions to change as well. Thus, system dynamics focuses on the connections among the elements of the system and how the elements contribute to the whole (Roberts, Andersen, Deal, Garet, & Shaffer, 1983).

The concepts that underlie the field of system dynamics form the basis for much of the simulation software that currently is used in educational settings. Until recently, the system dynamics approach to simulations was constrained to environments that had powerful mainframe computers (i.e., Dynamo and Micro-dynamo). The advent of a new software product has made it possible to translate these concepts to the microcomputer level. The software, STELLA, capitalizes on the graphical capabilities of the Apple Macintosh™ and enables learners to build systems models using icons and mouse technology. STELLA makes systems modeling approachable to the novice by minimizing the mathematical and technical skills needed to construct models. The user supplies the logic and knowledge of a domain necessary to build the model, and STELLA creates the structural diagrams, graphs, and data that represent the system. Thus, STELLA is a powerful software tool that enables students to build models and simulations within the context of a systems thinking approach to learning.

Site Description: Brattleboro Union High School

BUHS serves a rural five-town district in southeastern Vermont whose population is approximately 20,000. The school has roughly 1,600 students and a faculty of 80 teachers.

Since 1985, BUHS has been the site of a number of systems thinking activities, all with the purpose of introducing students, educators, and the public to the principles that underlie the field. Two informational workshops were an outgrowth of an initial collaborative group that was formed to support systems thinking activities. The first workshop was a one-day seminar given in the spring of 1985 by experts from the Massachusetts Institute of Technology (MIT). The intent of the meeting was to provide sufficient knowledge of system dynamics to high school teachers so that the concepts could be integrated into their courses. The second workshop was an intensive five-day introduction to systems thinking. Taught by representatives of MIT and Dartmouth, this seminar was attended by BUHS teachers, students, parents, school board members, and individuals from local business.

Four teachers comprised the core of the systems group at BUHS. All were trained by experts to use the systems approach and integrated this perspective into their courses. One course, entitled War and Revolution, was heavily infused with systems thinking and the use of STELLA. That is, systems thinking formed the basis for this course. In contrast, an integrative approach was used in the science courses. The approach was integrative in that the teachers identified concepts within their curricula that could be enhanced by the use of systems thinking principles. Rather than teach the particular concepts as they had in the past, the systems teachers explicitly emphasized the systemic nature of the topics, noting such ideas as causality, feedback, variation, and interaction. The courses covered the same body of knowledge taught in the traditional curriculum, but specific concepts and topics were discussed from a systems thinking perspective. These courses will be described in greater detail in the curriculum section. The BUHS teachers next plan to develop for the forthcoming academic year a new course entitled Science, Technology, and Society that will incorporate an extensive introduction to system dynamics and STELLA.

Design and Data Collection

Design

Systems thinking was integrated into three general physical science, four biology, and three chemistry classes. An equivalent number of traditional (control) courses were taught concurrently by other members of the faculty. Table 1 presents the enrollment figures for the classes participating in the study.

As noted in the first STACI progress report (Mandinach & Thorpe, 1987), obtaining parental consent was problematic. ETS and the eight BUHS teachers made every effort to gain permission for students' participation. We were able to obtain consent for 353 of the 412 students (or 86%). Consent was withheld for approximately 14% of the students. The figures differed across classes and subject areas, with nearly all chemistry students (94%) willing to participate. Biology, across the three teachers, had the lowest consent rate (77%). The consent rate for general physical science was 87%. The percents of consent for the systems (85%) and traditional (86%) groups were roughly equal.

Table 1
Classes and Enrollment Figures - 1986-1987

Class	Systems Thinking		Traditional	
	Classes	Students	Classes	Students
General Physical Science	3	40(11)	3	57(3)
Biology				
Teacher 1	4	68(16)	2	32(12)
Teacher 2			2	29(10)
	4	68(16)	4	61(22)
Chemistry	3	57(3)	3	63(4)
TOTAL	10	165(30)	10	181(29)
War and Revolution	1	7(0)		

Note: The numbers in parentheses indicate the students for whom parental consent was either denied or could not be obtained.

Data Collection: Instrumentation

As noted in the ETS proposal (Mandinach, 1986), several types of instruments were used to assess outcomes in various stages of the research. These instruments included pretest, in-class, and posttest measures, which were used to assess ability, content-specific knowledge, systems thinking, and higher-order thinking skills (including general problem solving, metacognition, and self-regulation).

Pretests were used to assess subjects' ability, content-specific knowledge, and knowledge of systems thinking. Existing instruments were used or modified, and other tests developed where needed. BUHS supplied the students' most recent standardized achievement test scores. The California Achievement Tests served as rough estimates of general ability. ETS also administered a small battery of tests, including the Advanced Progressive Matrices

(Raven, 1958, 1962), to provide another index of general ability. Other measures related to skills hypothesized as important concepts underlying systems thinking were given. These included inductive and deductive reasoning, figural analogies, and understanding relationships.

Modified versions of previous final examinations were administered to both the systems and traditional classes. The general physical science, biology, and chemistry teachers took last year's tests, identified critical, yet basic concepts, and gave the shortened versions to their classes early in the academic year. These tests served as baseline assessments of content knowledge in the subject areas. An initial assessment of systems thinking skills, developed by TERC, containing 24 items, also was administered early in the semester to serve as a baseline for the experimental classes.

Teachers administered content-specific tests and exercises in their courses throughout the academic year. These examinations and exercises were roughly comparable for the systems and control classes in their subject-matter coverage. The teachers also prepared and gave common final examinations to their classes. Because traditional and systems thinking classes within a subject area received the same test, we were able to compare differences in content knowledge that resulted from using the systems approach. These measures of content knowledge were not used to assess pre- and posttest differences. Instead, they were used to provide information about the evolution of differential performance over time between the two sets of classes.

ETS developed a 39-item instrument that was used to assess knowledge of systems thinking and STELLA. The instrument contained items of increasing difficulty that measured a broad spectrum of skills along a continuum ranging from elementary concepts to complex modeling skills. These skills were identified in consultation with the BUHS teachers and systems experts and through rational task analyses as critical components that underlie systems thinking. Measures of systems thinking focused on concepts such as knowledge of graphing, equations, variation and variables, causation and causality, feedback, looping constructs, modeling, and STELLA. This test was administered at the end of the year to only the systems thinking classes.

It should be noted that instrument development is critical to the STACI project. Much of the project's success rests on the assumption that reliable and valid measures, particularly of systems thinking, can be designed. These measures must capture both qualitatively and quantitatively students' performance, understanding, and cognitive processing. Reliabilities for each of the instruments will be calculated. We will examine the systems thinking test's internal consistency, using the Cronbach alpha coefficient and will perform split-half reliabilities on the measures in the reference battery.

Given the exploratory nature of the first year, we developed and administered the instruments on a preliminary basis and plan to revise them as indicated by the results. Our primary focus will be on the required revisions to the systems thinking test. Examination of the reliability results, in addition to a factor analysis, will provide an indication of the consistency and performance of the instrument in assessing skills thought to be critical in systems thinking. Furthermore, we will examine item-level data by class to identify the appropriate level of difficulty for each course. Initial results indicate overlapping, but progressively more difficult ranges of performance in moving from general physical science, to biology and then chemistry. The data analyses currently are being conducted. Revisions will be made accordingly. The results will be reported in the subsequent document that will focus on the quantitative analyses.

Data Collection: Observations and Interviews

Classroom observations were conducted during six site visits throughout the school year. Two project members observed both systems and traditional classes to obtain information about course content, structure, and classroom procedures. Systems classes were observed when systems modules as well as traditional materials were presented. Observations were scheduled when similar topics were covered to see how the systems and traditional teachers differed in their approach to the highlighted concepts. For example, we observed how the chemistry teachers presented the topic of reaction rates, noting differences in emphases, presentation, and other areas due to the use of systems concepts.

Interviews with systems and traditional teachers were conducted to obtain additional information about the classes (see Appendix A). It was critical to gather information from the systems teachers concerning the issues they confronted during the implementation of the curriculum innovation. The interviews also provided an opportunity to probe teachers about their perceptions of the systems thinking modules, implementation difficulties, and other issues related to the effects of the curriculum innovation on their teaching activities.

To examine variation in content emphasis, all science teachers were asked to provide information on the number of days devoted to different curriculum topics. The systems teachers also were asked to indicate the time devoted to instruction in systems thinking and to which topics the approach was applied.

Ancillary Studies

The War and Revolution Seminar

The course. The War and Revolution seminar provided a unique approach and structure to the examination of historical events. The course was conceived by the teacher and David Kreutzer, of the System Dynamics Group at MIT, as a means of applying systems thinking to an understanding of political-social events. The unique aspect of this course was the prominent role given to systems thinking in the study of historical events. The course was offered for the first time to a group of seven academically talented students, three of whom were National Merit Scholars. Among these students were two seniors who received outside training in systems thinking and STELLA. These two students previously developed causal loop diagrams and structural models related to other topics. They also assisted their classmates in learning how to develop models and use STELLA.

The class functioned much like a college seminar. Students met together as a class three times per week with the remaining two periods spent working individually or cooperatively in small groups. Through class discussions and independent research projects, students analyzed dynamic situations from the perspective of decision makers. The intent was to develop both analytical skills and an appreciation of the complexities and importance of policy decisions. Through the course students developed abilities to pose questions, gather relevant information from a variety of sources, develop scenarios depicting relationships among kev forces, and critique as well as defend these views.

The primary text, Thinking in Time (Neustadt & May, 1986) was supplemented with other sources that pertained to topics for group discussion and students' independent research interests. Students were expected to read major newspapers including the New York Times and news magazines. They also were encouraged to broaden their sources of information to include professional journals, books, government documents, and other media.

The teacher used various revolutions (e.g., the 1956 Hungarian Revolution, the Iranian Revolution, and the Revolution in Nicaragua), as well as Kreutzer's model of terrorism, to introduce students to systems thinking as a strategy for analyzing the dynamics of historical and current events. They studied basic concepts for modeling systems, reviewed some existing models and experimented with constructing models of their own. Kreutzer conducted several seminars for the class to discuss the logic underlying model development, reinforce fundamental systems concepts, address specific questions, and assist students with their special projects. He provided consultation throughout the year as students developed their own models.

The study. The ancillary study focused on a limited number of students who exhibited particularly advanced knowledge of systems thinking and skills in using STELLA. The purpose of this substudy was to collect indepth information about the thought processes, performance patterns, knowledge, and general problem solving skills of experienced students who were exposed to a seminar fully infused with systems thinking and the simulation modeling software.

Students were introduced to systems thinking as a strategy for analyzing the dynamics of historical and current events. They studied basic concepts for modeling systems, reviewed some existing models and experimented with constructing models of their own. The students prepared final versions of their models of revolution during the last quarter of the year. Each student prepared a systems model to illustrate the dynamic factors underlying their particular topic, presented a formal report and STELLA model, and made a presentation to the class describing the model. In addition, the teacher requested that the students include in their reports a discussion of the effects systems thinking had on their work and perspective of the subject area.

In Year 1, the seven students enrolled in the War and Revolution class received extensive exposure to systems thinking and used STELLA for innovative applications of modeling. These students were studied in an intensive case study format throughout the academic year, culminating in a special project conducted during the last month of school ETS observed their performance in the seminar and with STELLA (observations of approximately 20 class periods), assessed their knowledge, collected verbal protocols, conducted interviews, and examined their major projects completed for the course. The interviews and verbal protocols elicited detailed information about how students approached, analyzed, and work through problems assigned in the course.

The special project for the War and Revolution class was conducted at BUHS during the weeks of May 18 and 25. The problem used was the Zimbardo Prison Experiment. This experiment created a simulated prison environment in which college students portrayed inmates and guards (see Appendix B for additional information). Initial reading materials were sent to the students, followed by a slide/sound presentation of the problem. Students were given a week in which to develop and prepare systems and STELLA models of the experiment. Kreutzer provided facilitation during the administration of the project. At the end of the week, each student handed in a brief report, their causal models, and a disk on which their STELLA models were saved. Analyses of the models and accompanying materials currently are being conducted.

<u>Organizational Case Study</u>

Interviews were used to trace the organizational impact of the introduction and implementation of systems thinking at BUHS. Whenever new technologies and expertise are introduced in schools, changes occur in organizational structure, division of labor, communication patterns, and distribution of authority and influence. These changes are being documented and analyzed to shed light on the impact of technology on the structure and functioning of educational organizations.

Initial data collection for the ancillary study was conducted in the April and May site visits. During both visits, interviews were conducted with a number of individuals at Brattleboro who had varying degrees of involvement in the STACI Project. Interviews included the systems thinking teachers, the science and social studies departmental chairpersons, the principal, superintendent, the head of guidance, and other BUHS teachers. Follow-up and additional interviews will continue throughout the next academic year. These data then will be synthesized in the form of a case study that depicts how systems thinking evolved at BUHS and wha its impact has been on the school as an organization. The case study will be reported at the conclusion of Year 2 in order to examine the innovation's impact as it evolves over the course of the project.

Curriculum Development and Implementation

This section describes the 1986-1987 curriculum for the traditional and systems thinking science classes. We begin with several observations about the curriculum in general. Summaries of both subject and systems thinking content are provided. Information about the curriculum content was obtained through interviews with teachers, brief questionnaires, textbook reviews, and classroom observations.

General Observations

Curriculum development in systems thinking has been a labor-intensive and ongoing effort. ETS recognizes that during this first year as systems thinking was introduced, instructional methods and course content underwent a great deal of experimentation. Some teachers were more successful than others in identifying appropriate applications for systems modules. All the teachers were acutely aware of the delicate balance between using traditional methods and infusing systems thinking into their courses.

Though the teachers were intrigued by the possibilities offered by systems thinking and STELLA, they grappled with the realities of developing an innovative curricular approach while maintaining heavy teaching responsibilities. One of the most difficult realities was the time required to develop expertise in systems thinking and then integrate the concepts into their existing curricula. Other issues included: (a) the appropriate sequence of knowledge that should be followed in teaching systems thinking; (b) the points in the curriculum where systems thinking can best be used; (c) the development of examples that illustrate important variables and relationships, but are simple enough for students to understand; (d) the introduction of STELLA; and (e) the effectiveness of systems thinking as a way to teach particular concepts. (Is systems thinking worth the tradeoff in time that could be spent teaching the subject matter in more traditional ways?)

Both the systems and traditional classes used the same texts in their classes as primary components of the curricula. Common final examinations also were administered to all classes within a given subject area. Despite these commonalities, the teachers differed in their content emphases, assignments, classroom organization, and instructional styles. These differences and the potential impact they may have on learning processes and outcomes were examined through observation, interview, and performance measures during the project's first year.

Curriculum development and implementation also were affected by the availability of hardware and software for project use. Apple Computer, Inc. donated fifteen Macintosh™ computers to BUHS through the Educational Technology Center for project use. A classroom set of STELLA software was obtained, in addition to a Limelight projection system. These acquisitions enabled BUHS to set up a computer classroom which was devoted to the STACI project. This room did not materialize as early as anticipated due to delays in the construction of a new science wing. It was not until March that the teachers moved into their new facilities, thereby making available the room in which the computer laboratory now is located. This delay hindered not only the introduction of systems thinking and STELLA, but also affected science instruction more generally.

In the coming year, the data collection procedures, implemented on a trial basis, will be revised in order to maximize the informativeness of the data gathered. We will collaborate with the teachers to develop efficient and complete data collection procedures. Because teachers were in the process of developing their curricula over the course of the year, it was somewhat difficult to schedule observations to collect the information relating specifically to the understanding of content or the effects of systems thinking. The teachers were often unable to specify in advance either the topics or dates when systems lessons would be taught. Due to differences in curriculum integration, the three science teachers did not conduct their systems lessons at the same time. As a result of these contraints and the distance between ETS and Brattleboro (approximately 300 miles), it was not possible to observe all instances of systems instruction. While teachers' notes, handouts, and exercises were extremely helpful in reporting about many aspects of systems instruction, it was not always possible to obtain data sufficient for a complete understanding of the curriculum innovation. Discussions with the systems teachers will be held early in the fall to consult about data collection requirements for Year 2.

In Year 1, although we collected information from the systems teachers on student assignments related to systems thinking, we did not request classroom assignments on these same science topics from the control teachers. The decision to forego this information during this initial year was made to reduce the response burden of the traditional teachers. During the coming year we will seek classroom assignments from the traditional teachers for selected topics taught from a systems perspective.

General Physical Science

Subject content. General physical science is an introductory course for freshmen and sophomores consisting of one semester of chemistry and another of physics. Because of the temporary shortage of laboratory facilities this year (i.e., the construction of the new science wing), the systems and traditional teachers taught the course in reverse sequence. Chemistry was taught to the control classes during the first semester, followed by physics in the spring. The systems classes began the year with physics and studied chemistry in the second semester.

The course covered topics related to matter and energy. The purpose of the course was to introduce students to concepts in chemistry and physics as they apply in everyday life. Students learned the basic principles of measurement, concepts of work, energy, and motion. Chemistry concepts were introduced through the study of atomic structure, properties of elements, and chemical reactions. Physics concepts were covered through the topics of light, sound, heat, electricity, and nuclear energy.

Although both teachers used Focus on Physical Science (Heimler & Price, 1984), there were considerable differences in how textual and other supplementary materials were assigned (see Appendix C). The systems teacher spent more time on physics concepts and less on chemistry, whereas the reverse was true for the traditional teacher. (This was in part due to when the laboratory facilities became available.) The systems teacher supplemented the text with other material in addition to the systems lessons, whereas the traditional teacher followed the text more closely. Comparisons of students' understanding of particular science topics taught through a traditional versus a systems thinking perspective will take into account differences in exposure to topics as well as differences in instructional methods and materials.

Systems content. The general physical science teacher introduced systems thinking more slowly into his course than did the other systems teachers. He initially cited some difficulty in determining how to integrate the approach into his lessons and devising appropriate examples that students could understand. The mathematical nature of physics led him to begin with graphing cause-and-effect relationships and translating that information into simple arrow diagrams. This approach was used in a variety of topics over the course of the year, including discussions of motion, electricity, magnetism, light and sound waves, color, density, and compound formation. The teacher noted that though the approach was used for several topics, each discussion was very brief, averaging approximately 10 minutes.

Unlike the systems teachers in biology and chemistry, more complex causal loop structures were not developed in general physical science. The teacher reported that GPS curricular topics did not lend themselves to simple feedback relationships. Feedback was discussed briefly at the beginning of the year and again at the end during the introduction to STELLA modeling. However, the teacher reported that time constraints limited the discussion.

Models were introduced at the beginning of school and continued to be a major topic of discussion throughout the year. One week was spent on the general concept of models which included the "Modeling" video tape in the "Search for Solutions" series. The atomic model, used as an explanation for static electrical effects, was the first physical science model to which several class periods were devoted. Models also were used in explaining electrical circuits as well as the distinctions and relationships among potential, current, and resistance. A wave model was constructed to help students understand the behavior of light. While students were interested initially in the demonstrations and investigations, the teacher reported that several students had difficulty synthesizing the information and extrapolating the light wave model to analogous physical phenomena. The atomic model was revisited briefly later in the year to help explain chemical bonding and compound formation.

Simple mathematical modeling was introduced early in the year. Graphs were developed to illustrate relationships among distance, speed, and time. Mathematical modeling also was used to understand the concept of density as a function of mass divided by volume.

At the end of the year STELLA was introduced with the motion detectors developed at the Technical Education Research Centers (TERC), in Cambridge. A bathtub model was constructed to study the inflow and outflow of water. The teacher noted that the week allotted to the presentation was insufficient. Only one day could be devoted to introducing stocks and flows prior to demonstrating a simple STELLA model of a bathtub filling with water. Students were able to spend only a short time learning to use the Macintosh™ then exploring the bathtub model themselves on the computer. Difficulties with the equipment, notably the projection system and the probes prevented the most effective use of the limited time available.

Biology

Subject content. The systems and traditional teachers indicated that the content for all biology classes was similar. Though there was some variation in the selection and emphasis of certain topics (see Appendix C), all classes used Biology: Living Systems (Oram, Hummer, & Smoot, 1986) and followed the same sequence with approximately the same scheduling of topics.

The curriculum presented information about how living organisms are structured, function, and the processes by which they relate to other organisms and the environment. The text is organized around the theme that all living organisms share common life processes. The goal of the course was to develop an understanding of these basic processes and how they are expressed in a diversity of life forms.

To develop this understanding, the course began with an overview of the basic processes of food production and energy transfer, growth and development, maintenance and repair, and reproduction. The concepts of organization and interrelationship among living organisms also were introduced. Methods and measures of scientific inquiry were presented, followed by the general principles of chemistry and cellular biology necessary to comprehend physiological processes. A discussion of genetics covered the cellular basis of heredity, reproduction, and variation. The course also included the topics of evolution and adaptations that promote survival and reproduction. As the course proceeded, the five kingdoms were presented and described in terms of the life processes of their members, ranging in complexity from the simplest to the most intricate organisms.

Systems content. The science teachers agreed that biological science, of all the subject areas, lent itself most readily to a systems approach. Because interrelationships among living systems is a key concept stressed in this course, the potential is present for identifying a number of relevant examples to which systems thinking can be applied.

Systems thinking was introduced in biology, beginning with definitions and fundamental principles such as a system, components of a system, feedback, and causal relationships. The "Modeling" video also was shown to the biology classes. Following the introduction of terms and concepts, students were shown examples of causal loops. Initially, single loops were introduced, followed by examples illustrating complex loops. These ideas were presented using both biological and non-biological examples. Biological models included the fight/flight response of the cell during insulin reaction as well as models for cellular respiration, photosynthesis, and decomposition. Non-biological illustrations were drawn primarily from Introduction to Computer Simulation: A Systems Dynamics Modeling Approach (Roberts, et al., 1983). These latter models included examples of traffic dynamics and the spending, earnings, and savings model.

In assessing students' reactions to systems thinking, the teacher indicated that students appeared initially interested in learning the concepts and discussing simple causal diagrams. Difficulties arose as complexity was introduced. Not all students were able to follow the connections between loops. As other examples from the Robert's et al. book were introduced, including the development of a forest (which contains four loops and the carbon cycle which contains more than eight loops), the teacher found it helpful to discuss one loop at a time and give students a rule to guide their pathway through the system ("take the shortest route back to where you started").

After a few weeks, the teacher reintroduced causal loops using a model for the role of enzymes in metabolism. In presenting this example, the teacher displayed the prepared model and used a problem solving approach to interpret the process depicted. Using the analogy of a puzzle, the concept of structure, coupled with function was illustrated. Students were asked what would happen if one piece of the puzzle was changed. In this instance, systems thinking was employed to help students understand the process of metabolism and the idea of the relatedness among cell structures. Students then were given homework assignments to describe the metabolism diagram discussed in class and the process of how three cell structures were related.

The concepts of levels and rates were taught early in the second term in conjunction with a brief exposure to graphing. The concept of modeling was presented as an introduction to STELLA and the population model. Analogies were drawn to familiar scientific topics, including mitosis and meiosis, that students had just reviewed. The teacher reported that students were responsive to these discussions and demonstrations, but that time did not permit hands-on experience with STELLA.

After an interim of three months, students again were introduced to computer modeling in conjunction with laboratory work on temperature changes. Using the projection system, the teacher presented a model for "cooling soup" constructed on the computer. Students recorded temperature changes and constructed their own paper-and-pencil graphs as the soup cooled. The teacher modeled the temperature changes using STELLA. This experience provided students with an opportunity to see the effects dynamically portrayed in the STELLA model and compare their results with those displayed by STELLA.

A model of oxygen production was presented using STELLA prior to conducting a laboratory experiment on photosynthetic rate. Students then were asked to posit hypotheses to predict the relationship between light intensity and oxygen production. Through guided discussion, students also were asked to identify elements to construct a structural model by suggesting stocks, flows, and the factors that might affect the relationship. The teacher indicated that some students did not appear to understand the relationships depicted in the model. However, following a subsequent laboratory experiment, students were able to recognize the relationship between light intensity and photosynthetic rate.

Near the end of the school year, students were given a chance to use the computers to work on a model of oxygen production. Reactions to these experiences generally were positive, but many students indicated that more time was needed to become familiar with the computers and the model. The teacher also indicated that more hands-on time with the computers and STELLA was needed to assess the learning potential of this experience.

Chemistry

Subject content. All classes used Chemistry : A Modern Course (Smoot, Price, & Smith, 1979) with the same sequence and approximately the same scheduling of topics. The central theme of the course was that the characteristics of matter are dependent on their structure. A primary objective was to develop an understanding of the properties of matter and the relationship of structure to properties. In addition to principles of structure, the course introduced matter-energy relationships, the concepts of moles, thermodynamics, and chemical equilibrium. The course began by presenting the fundamental knowledge and approaches needed to solve chemical problems. Information was given on measurement, scientific notation, and classification as well as a systematic approach to problem solving that emphasized problem decomposition and pattern recognition. The structure and properties of solids, gases, and liquids then were introduced. Subsequent lessons were built on this foundation and described the behavior of matter in terms of energy and disorder, reaction rates and chemical equilibrium, acid-base behavior, oxidation-reduction, and electrical reactions.

<u>Systems content</u>. The teacher intended to use systems thinking to teach students about social and environmental problems related to chemistry. Problems were selected that had a chemical basis and were relevant to the students.

During the fall, chemistry students were introduced to basic terminology and concepts in systems thinking. The relationships among rates, time, and levels were illustrated through construction of formulas and graphing. Students were given verbal problems or data sets and were instructed in graphing data, deriving rates and levels, and interpreting graphical trends. These concepts then were applied to the construction of both causal diagrams and simple structural models. After introducing examples from everyday life, such as the rate at which cars enter and leave a parking lot over the course of the day, chemistry-related problems were modeled. These models included the development of smog and tooth decay.

According to the teacher, initially students were moderately interested in the problems and model building. The level of interest increased later in the year when STELLA was introduced and instruction focused on more traditional topics (reaction rates), thus enabling students to see the relevance and applications of the approach to content-related problems.

In addition to the problems of time mentioned by the other system teachers, selection of relevant, understandable examples was particularly difficult in chemistry. The teacher indicated that modeling a chemical system involved a high degree of complexity and knowledge that often was beyond the level of students' understanding. Even an apparently simple model of tooth decay became difficult due to the number of elements and the nature of the chemical reactions involved. Therefore, it was not easy to develop examples that were accurate, yet appropriate for students' level of knowledge.

An additional concern was the integration of systems thinking into the regular curriculum. While discussion of socially relevant topics was interesting for students, it did not relate directly to the core curriculum. Therefore, during the second part of the year, the teacher decided that the most appropriate application for systems thinking appeared to be in the instruction of reaction rates, a traditional topic for all chemistry classes.

Students were introduced to STELLA with the "cooling soup" lesson used in the biology classes. They recorded and graphed the data for the cooling rates of two liquids with differing initial temperatures, and were instructed to note differences in the slopes of the two liquids and conclude which liquid had the faster cooling rate. Students also were asked to note changes in slope and hypothesize reasons for the changes. Initially a causal loop diagram was developed to depict the relationship between temperature and rate of cooling. A structural diagram then was developed to test the model and determine if the expected behavior would result. The teacher used STELLA to demonstrate the behavior of the model and showed students how the model could be changed to reflect different conditions and thus different hypotheses. A population model was another example used to familiarize students with STELLA and structural thinking.

In studying reaction rates, students were guided to develop systems models for chemical equations. Creating structural diagrams on STELLA provided an instructional tool not only to illustrate the function and relationship of certain variables to each other, but to hypothesize and then test changes in the behavior of these variables over time, under different conditions. From these experiences, a generic understanding of the behavior of a set of interacting variables could be developed.

As in the other science classes, models were used in conjunction with laboratory activities in a variety of ways. Sometimes models were created prior to experiments to introduce important elements in particular chemical reactions and predict how these elements might affect each other. At other times, models were created during or following experiments to illustrate the behavior observed, simulate other conditions, and comment on predictions.

Other Activities

Data Analyses and Quantitative Report

Due to the vast amount of data generated from the STACI Project's activities, the first year report has been separated into two parts: the present document which provides a general description of the site, curricula, and procedures, and the forthcoming document in which all data analyses will be reported.

The student cognitive test data currently are being prepared for analysis. The analyses will focus on the preliminary results of students' performance on content tests and the systems thinking instrument. We will examine ability differences, as defined by performance on the reference battery and standardized tests. Most importantly, we will compare performance differences between the systems thinking and traditional groups on the various measures, particularly the specific content areas which were taught as systems models. The analyses will be conducted and reported during the fall, 1987.

Dissemination of Project Information

During the first year of the STACI Project, several manuscripts were prepared for publication or presentation at professional meetings:

Mandinach, E. B. (1986). Innovative uses of technology to foster cognitive skills development in a high school science program: Research and design issues. City University of New York, Graduate Center.

Mandinach, E. B. (1987). Computer learning environments and the study of individual differences in self-regulation. Paper presented at the annual meeting of the American Educational Research Association, Washington, D.C.

Mandinach, E. B. (1987). Integrating systems thinking into the high school curriculum: The STACI Project. Paper presented at the National Educational Computing Conference, Philadelphia, PA.

Mandinach, E. B. (1987). The STACI Project: The second progress report (STACI Rep. No. 11). Princeton, NJ: Educational Testing Service.

Mandinach, E. B. (1987). The use of simulations in learning and transfer of higher-order cognitive skills. Paper presented at the annual meeting of the American Educational Research Association, Washington, D.C.

Mandinach, E. B., & Thorpe, M. E. (1987). Systems thinking and curriculum innovation: A progress report (STACI Rep. No. 2). Princeton, NJ: Educational Testing Service.

Mandinach, E. B., & Thorpe, M. E. (1987). The systems thinking and curriculum innovation project. Technology and Learning, 1(2), 1, 10-11.

Mandinach, E. B., & Thorpe, M. E. Caveats and realities in technological curriculum innovation. Technology and Learning, 1(4), 1-3, 5, 7.

An additional activity related to the project was a seminar given at the Apple Computer Company at the request of Dr. Barbara Bowen, Director of the Apple External Research Program, on May 12. Bowen asked ETS to make a presentation to Bay Area educators, representatives from state and county education offices, and Apple employees to describe the STACI Project and perhaps stimulate interest in STACI, systems thinking, and STELLA. ETS organized the presentation which also included a teacher and student from BUHS.

Potential Caveats

In general, the STACI Project has progressed smoothly with few evident problems. However, some of the implementation problems have been outlined in an article (Mandinach & Thorpe, 1987a) that recently appeared in Technology and Learning (see Appendix D for details). As noted in the first progress report, curriculum development took longer than anticipated and thus influenced the conduct of the study. STACI's first year was considered exploratory rather than a formal test of knowledge acquisition and transfer. In addition, data collection was slightly delayed due to the complexity of obtaining informed parental consent. These constraints limited the extent to which we were able to draw conclusions from the first year of data collection.

On the positive side, teachers have made considerable progress in their development of the curricula and students generally have responded positively toward the instructional materials. Despite delays in curriculum development, the teachers were able to identify, design, and implement systems modules that were integrated into the existing courses. We have collected a wealth of valuable classroom data from which we will be able to make preliminary comments about the impact of the curriculum innovation on teaching and learning activities. We also collected important information from the War and Revolution seminar about the effects of the systems thinking approach on the process of knowledge acquisition.

As the project begins its second year, we again will confront the problem of parental consent. We will attempt to obtain consent from parents who previously withheld permission. We also must identify those students who are new to the project and seek consent from their parents. This activity will be undertaken as early as possible in the forthcoming academic year.

Much effort will be focused on revisions of instrumentation, observations, and data collection procedures, as indicated by the first year's results. The system thinking instrument already has been revised. The formalization of data collection procedures will be critical. We have faced and again must confront the delicate balance between requesting certain pieces of information from the teachers and burdening them with too much documentation. As noted above in the curriculum section, we are working toward identifying the specific data that will best inform us about curriculum procedures and content. Such documentation must be made highly explicit in order for the teachers to be able and willing to comply. These data collection procedures are essential because of ETS's distance from BUHS, which limits the amount of time staff can spend on site. It is virtually impossible to document all uses of and outcomes of the curriculum innovation simply because we cannot be in Brattleboro all the time. Thus, ETS must rely on other documentation procedures that will be used in our absence. We do believe, however, that several week-long observations, in conjunction with the procedures noted above, should provide sufficient data from which to examine the impact of systems thinking.

Footnote

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References

Forrester, J. W. (1968). Principles of systems. Cambridge: MIT Press.

Heimler, C. H., & Price, J. S. (1984). Focus on physical science. Cincinnati: Charles E. Merrill.

Mandinach, E. B. (1986) Systems thinking and curriculum innovation: A naturally occurring classroom study (STACI Rep. No. 1). Prinreton, NJ: Educational Testing Service.

Mandinach, E. B., & Thorpe, M. E. (1987a). Caveats and realities in technological curriculum innovation. Technology and Learning, 1(4), 1-3, 5, 7.

Mandinach, E. B., & Thorpe, M. E. (1987b). Systems thinking and curriculum innovation: A progress report (STACI Rep. No. 2). Princeton, NJ: Educational Testing Service.

Neudstadt, R. E., & May, E. R. (1986). Thinking in time: The uses of history for decision makers. New York: Free Press.

Oram, R. F., Hummer, P. J. Jr., & Smoot, R. C. (1986). Biology: Living systems. Cincinnati: Charles E. Merrill.

Raven, J. C. (1958). Advanced Progressive Matrices (Set I). London: H. K. Lewis.

Raven, J. C. (1962). Advanced Progressive Matrices (Set II). London: H. K. Lewis.

Richmond, B. (1985). STELLA [Computer program]. Lyme, NH: High Performance Systems, Inc.

Richmond, B., & Vescuso, P. (1986). STELLA [Computer program] (2nd. ed.). Lyme, NH: High Performance Systems, Inc.

Roberts, N., Andersen, D., Deal, R., Garet, M., & Shaffer, W. (1983). Introduction to computer simulation: A system dynamics modeling approach. Reading, MA: Addison-Wesley.

Smoot, R. C., Price, J. S., & Smith, R. G. (1979). Chemistry: A modern course. Cincinnati: Charles E. Merrill.

APPENDIX A

TEACHER QUESTIONNAIRE

TOPICS

What science concepts/knowledge have you tried to teach using systems thinking?

Are these topics also being taught in the traditional classes?

INSTRUCTIONAL METHOD

How have you introduced these topics?
- Prerequisite knowledge
- sequence
- logic

Examples/illustrations used-

How would you have introduced these topics if you had taught them in the traditional manner?

STUDENT ASSIGNMENTS/ACTIVITIES (Paper/Pencil/ STELLA)

What have the students been required to do with systems thinking beyond class discussion?

Describe inclass activities & assignments

LESSON ASSESSMENT:(BEHAVIORAL/ANECDOTAL EVIDENCE)

How receptive were the students to these lessons?

What were the strengths of the lesson?

What, if anything, did not work as well?

What would you do differently next time you wanted to teach these concepts?

INTEGRATION

How satisfied are you at this point with integration of systems thinking which you have attempted?

Is the systems perspective influencing your teaching even when you are not discussing the behavior of systems? If so how, give examples.

NEXT STEPS

What needs to be done next?

Are there any particular problems/pressures that are inhibiting curriculum development or conducting lessons?

What type of assistance do you need?

APPENDIX B

War and Revolution Project
The Zimbardo Prison Experiment
May, 1987

You have learned a great deal about a number of revolutions and have translated that understanding into complex systems models. You're now going to be asked to use your knowledge of revolutions, systems thinking, and STELLA in a new problem.

This problem is the Zimbardo Prison Experiment, that was conducted at Stanford University in 1971. Dr. Zimbardo, a social psychologist, conducted an experiment to examine what would happen when college students were placed in a mock prison situation. In effect, Zimbardo constructed his own simulation.

Your task will be to try to create a systems model of the experiment. You are being given an article from the New York Times Magazine that describes the events surrounding the experiment. This article should provide valuable background information. Please read it carefully before class on May 22. On May 22, we will show a slide-sound presentation, then conduct a class discussion about the experiment. On Monday, May 25, David Kreutzer will join us to help facilitate discussion about the study and the models you are to build. The rest of the week will be devoted to building your models.

By Thursday, we hope that you will have some well-developed models. Don't worry about the final product because we know that the experiment is complex and contains many variables. All we ask is that you try to develop your models as thoroughly as possible.

Some Ground Rules

Use the New York Times article as a basic reference.

You can go back to the slide-sound presentation, if necessary. (We also will provide scripts of its narration for your reference.)

Use Mr. Clarkson, David Kreutzer, other students, and ETS as available sources of information.

Collaboration is fine. However, we would like to get final reports from each of you. That means you can work together as much as you would like, but each of you must submit your report and model separately.

You will be given disks and a notebook. We ask that you save a copy of each model you contruct toward the final one. We also would like to see any notes or other aids you use in constructing your model.

We really want to understand the process you use to develop your model. In the end, we will ask you some questions about how you worked toward a solution, your thoughts about the model, and the similarities and differences between this project and your revolution model.

At the end of the week, we will collect the work you have done. That does not mean you have to stop work on the model. Feel free to devote more time to the project. There is always lots more you can discover about the systems within the experiment. After you have handed in you model, we will provide some additional background information and show a model of the experiment constructed at MIT.

Good luck and have fun. We hope that this project will be challenging, interesting, and a chance to use some of the ideas you have learned in the War and Revolution class.

The New York Times Magazine/April 8, 1973

Contents

Cover:
Sunny-side up, an egg—fried in butter, rich in cholesterol . . . and fatal, say many nutritionists. Page 72. Is there no hope for the gourmet? See Page

Photograph by Shig Ikeda.

the activity and conversation of guards and prisoners. The physical environment was one in which prisoners could always be observed by the staff, the only exception being when they were secluded in solitary confinement (a small, dark storage closet, labeled "The Hole").

Our mock prison represented an attempt to simulate the psychological state of imprisonment in certain ways. We based our experiment on an in-depth analysis of the prison situation, developed after hundreds of hours of discussion with Carlo Prescott (our ex-con consultant), parole officers and correctional personnel, and after reviewing much of the existing literature on prisons and concentration camps.

"Real" prisoners typically report feeling powerless, arbitrarily controlled, dependent, frustrated, hopeless, anonymous, dehumanized and emasculated. It was not possible, pragmatically or ethically, to create such chronic states in volunteer subjects who realize that they are in an experiment for only a short time. Racism, physical brutality, indefinite confinement and enforced homosexuality were not features of our mock prison. But we did try to reproduce those elements of the prison experience that seemed most fundamental.

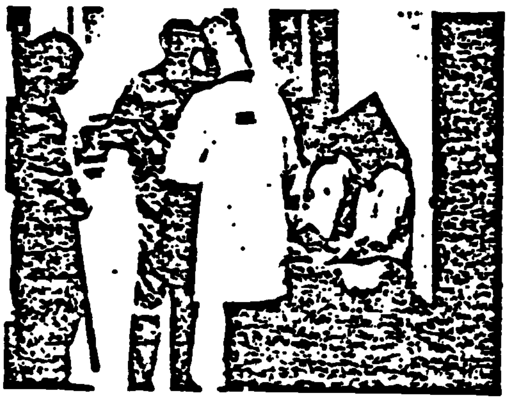
We promoted anonymity by seeking to minimize each prisoner's sense of uniqueness and prior identity. The prisoners wore smocks and nylon stocking caps; they had to use their ID numbers; their personal effects were removed and they were housed in barren cells. All of this made them appear similar to each other and indistinguishable to observers. Their smocks, which were like dresses, were worn without undergarments, causing the prisoners to be restrained in their physical actions and to move in ways that were more feminine than masculine. The prisoners were forced to obtain permission from the guard for routine and simple activities such as writing letters, smoking a cigarette or even going to the toilet; this elicited from them a childlike dependency.

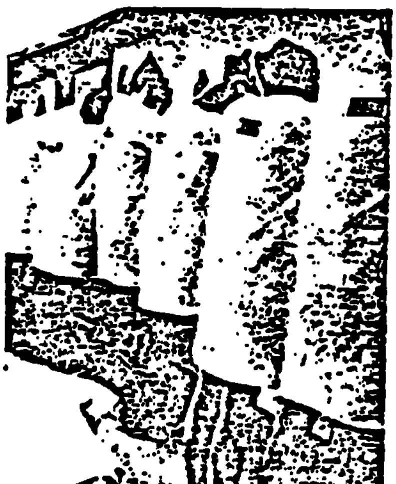
Their quarters, though clean and neat, were small, stark and without esthetic appeal. The lack of windows resulted in poor air circulation, and persistent odors arose from the unwashed bodies of the prisoners. After 10 P.M. lockup, toilet privileges were denied, so prisoners who had to relieve themselves would have to urinate and defecate in buckets provided by the guards. Sometimes the guards refused permission to have them cleaned out, and this made the prison smell.

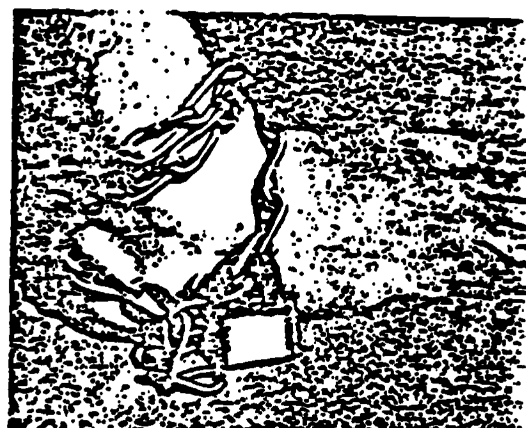
Above all, "real" prisons are machines for playing tricks with the human conception of time. In our windowless prison, the prisoners often did not even know whether it was day or night. A few hours after falling asleep, they were roused by shrill whistles for their "count." The ostensible purpose of the count was to provide a public test of the prisoners' knowledge of the rules and of their ID numbers. But more important, the count, which occurred at least once on each of the three different guard shifts, provided a regular occasion for the guards to relate to the prisoners. Over the course of the study, the duration of the counts was spontaneously increased by the guards from their initial perfunctory 10 minutes to a seemingly interminable several hours. During these confrontations, guards who were bored could find ways to amuse themselves, ridiculing recalcitrant prisoners, enforcing arbitrary rules and openly exaggerating any dissension among the prisoners.

The guards were also "deindividualized": They wore identical khaki uniforms and silver reflector sunglasses that made eye contact with them impossible. Their symbols of power were billy clubs, whistles, handcuffs and the keys to the cells and the

(Continued on Page 40)







Snapshots of mock-prison life: Above, a guard in uniform, a naked prisoner; left, prisoners blinded with bags await a parole-board hearing; below, the oppressiveness line-ups and ankle chains; bottom, a new prisoner is ushered to his cell.

"main gate." Although our guards received no formal training from us in how to be guards, for the most part they moved with apparent ease into their roles. The media had already provided them with ample models of prison guards to emulate.

Because we were as interested in the guards' behavior as in the prisoners', they were given considerable latitude to improvise and to develop strategies and tactics of prisoner management. Our guards were told that they must maintain "law and order" in this prison, that they were responsible for handling any trouble that might break out, and they were cautioned about the seriousness and potential dangers of the situation they were about to enter. Surprisingly, in most prison systems, "real" guards are not given much more psychological preparation or adequate training than this for what is one of the most complex, demanding and dangerous jobs our society has to offer. They are expected to learn how to adjust to their new employment mostly from on-the-job experience, and from contacts with the "old bulls" during a survival-of-the-fittest orientation period. According to an orientation manual for correctional officers at San Quentin, "the only way you really get to know San Quentin is through experience and time. Some of us take more time and must go through more experiences than others to accomplish this; some really never do get there."

You cannot be a prisoner if no one will be your guard, and you cannot be a prison guard if no one takes you or your prison seriously. Therefore, over time a perverted symbiotic relationship developed. As the guards became more aggressive, prisoners became more passive; assertion by the guards led to dependency in the prisoners; self-aggrandizement was met with self-deprecation, authority with helplessness, and the counterpart of the guards' sense of mastery and control was the depression and hopelessness witnessed in the prisoners. As these differences in behavior, mood and perception became more evident to all, the need for the now "righteously" powerful guards to rule the obviously inferior and powerless inmates became a sufficient reason to support almost any further indignity of man against man:

Guard K: "During the inspection, I went to cell 2 to mess up a bed which the prisoner had made and he grabbed me, screaming that he had just made it, and he wasn't going to let me mess it up. He grabbed my throat, and although he was laughing I was pretty scared. . . . I lashed out with my stick and hit him in the chin (although not very hard), and when I freed myself I became angry. I wanted to get back in the cell and have a go with him, since he attacked me when I was not ready."

Guard M: "I was surprised at myself . . . I made them call each other names and clean the toilets out with their bare hands. I practically considered the prisoners cattle, and I kept thinking: 'I have to watch out for them in case they try something.'"

Guard A: "I was tired of seeing the prisoners in their rags and smelling the strong odors of their bodies that filled the cells. I watched them tear at each other on orders given by us. They didn't see it as an experiment. It was real and they were fighting to keep their identity. But we were always there to show them who was boss."

Power takes as ingratitude the writhing of its victims.
—Rabindranath Tagore, "Stray Birds."

Because the first day passed without incident, we were surprised and totally unprepared for the rebellion that broke out on the morning of the second day. The prisoners removed their stocking caps, ripped off their numbers and barricaded themselves inside the cells by putting their beds against the doors. What should we do? The guards were very much upset because the prisoners also began to taunt and curse them to their faces. When the morning shift of guards came on, they were upset at the night shift who, they felt, must have been too permissive and too lenient. The guards had to handle the rebellion themselves, and what they did was startling to behold.

At first they insisted that reinforcements be called in. The two guards who were waiting on stand-by call at home came in, and the night shift of guards voluntarily remained on duty (without extra pay) to bolster the morning shift. The guards met and decided to treat force with force. They got a fire extinguisher that shot a stream of skin-chilling carbon dioxide and forced the prisoners away from the doors; they broke into each cell, stripped the prisoners naked, took the beds out, forced the prisoners who were the ringleaders into solitary confinement and generally began to harass and intimidate the prisoners.

Professor Zimbardo, as "superintendent" of the mock prison meets with a group of "prisoners" in numbered smocks.

After crushing the riot, the guards decided to head off further unrest by creating a privileged cell for those who were "good prisoners" and then, without explanation, switching some of the troublemakers into it and some of the good prisoners out into the other cells. The prisoner ringleaders could not trust these new cellmates because they had not joined in the riot and might even be "snitches." The prisoners never again acted in unity against the system. One of the leaders of the prisoner revolt later confided:

"If we had gotten together then, I think we could have taken over the place. But when I saw the revolt wasn't working, I decided to toe the line. Everyone settled into the same pattern. From then on, we were really controlled by the guards."

It was after this episode that the guards really began to demonstrate their inventiveness in the application of arbitrary power. They made the prisoners obey petty, meaningless and often inconsistent rules, forced them to engage in tedious, useless work, such as moving cartons back and forth between closets and picking thorns out of their blankets for hours on end. (The guards had previously dragged the blankets through thorny bushes to create this disagreeable task.) Not only did the prisoners have to sing songs or laugh or refrain from smiling on command; they were also encouraged to curse and vilify each other publicly during some of the counts. They sounded off their numbers endlessly and were repeatedly made to do push-ups, on occasion with a guard stepping on them or a prisoner sitting on them.

Slowly the prisoners became resigned to their fate and even behaved in ways that actually helped to justify their dehumanizing treatment at the hands of the guards. Analysis of the tape-recorded private conversations between prisoners and of remarks made by them to interviewers revealed that fully half could be classified as nonsupportive of other prisoners. More dramatic, 85 per cent of the evaluative state-

Voice from the real world

Professor Zimbardo's research into the psychology of prisons has put him in touch with many real prisoners. Here are excerpts from a convict's letter.

I was recently released from "solitary confinement" after being held therein for 37 months. A silent system was imposed upon me and to even "whisper" to a man in the next cell resulted in being beaten by guards, sprayed with chemical Mace, blackjacked, stomped and thrown into a "strip-cell" naked to sleep on a concrete floor without bedding, covering, wash basin, or even a toilet. The floor served as toilet and bed, and even there the "silent system" was enforced. To let a "moan" escape your lips because of the pain and discomfort . . . resulted in another beating. I spent not days, but months there during my 37 months in solitary . . . I have filed every writ possible against the administrative acts of brutality. The state courts have all denied the petition. Because of my refusal to let "things die down" and "forget" all that happened during my 37 months in solitary . . . I am the most hated prisoner in ——— Penitentiary, and called a "hard-core incorrigible."

Professor Zimbardo, maybe I am an incorrigible, but if true, it's because I would rather die than to accept being treated less than a human being. I have never complained of my prison sentence as being unjustified except through legal means of appeals. I have never put a knife on a guard's throat and demanded my release. I know that thieves must be punished and I don't think I will be a thief when I am released. No, I'm not rehabilitated. It's just that I no longer think of becoming wealthy by stealing. I now only think of "killing." Killing those who have beaten me and treated me as if I were a dog. I hope and pray for the sake of my own soul and future life of freedom, that I am able to overcome the bitterness and hatred which eats daily at my soul, but I know to overcome it will not be easy.

ments by prisoners about their fellow prisoners were uncomplimentary and deprecating.

This should be taken in the context of an even more surprising result. What do you imagine the prisoners talked about when they were alone in their cells with each other, given a temporary respite from the continual harassment and surveillance by the guards? Girl friends, career plans, hobbies or politics?

No, their concerns were almost exclusively riveted to prison topics. Their monitored conversations revealed that only 10 per cent of the time was devoted to "outside" topics, while 90 per cent of the time they discussed escape plans, the awful food, grievances or ingratiation tactics to use with specific guards in order to get a cigarette, permission to go to the toilet or some other favor. Their obsession with these immediate survival concerns made talk about the past and future an idle luxury.

And this was not a minor point. So long as the prisoners did not get to know each other as people, they only extended the oppressiveness and reality of their life as prisoners. For the most part, each prisoner observed his fellow prisoners allowing the guards to humiliate them, acting like compliant sheep, carrying out mindless orders with total obedience and even being cursed by fellow prisoners (at a guard's command). Under such circumstances, how could a prisoner have respect for his fellows, or any self-respect for what he obviously was becoming in the eyes of all those evaluating him?

Life is the art of being well deceived; and in order that the deception may succeed it must be habitual and uninterrupted.

—William Hazlitt,
"On Pedantry,"
in "The Round Table."

The combination of realism and symbolism in this experiment had fused to create a vivid illusion of imprisonment. The illusion merged inextricably with reality for at least some of the time for every individual in the situation. It was remarkable how readily we all slipped into our roles, temporarily gave up our identities and allowed these assigned roles and the social forces in the situation to guide, shape and eventually to control our freedom of thought and action.

But precisely where does one's "identity" end and one's "role" begin? When the private self and the public role behavior clash, what direction will attempts to impose consistency take? Consider the reactions of the parents, relatives and friends of the prisoners who visited their forlorn sons, brothers and lovers during two scheduled visitors' hours. They were taught in short order that they were our guests, allowed the privilege of visiting only by complying with the regulations of the institution. They had to register, were made to wait half an hour, were told that only two visitors could see any one prisoner; the total visiting time was cut from an hour to only 10 minutes, they had to be under the surveillance of a guard, and before any parents could enter the visiting area, they had to discuss their son's case with the warden. Of course they complained about these arbitrary rules, but their conditioned, middle-class reaction was to work within the system to appeal privately to the superintendent to make conditions better for their prisoners.

In less than 36 hours, we were forced to release prisoner 8612 because of extreme depression, disorganized thinking, uncontrollable crying and fits of rage. We did so reluctantly because we believed he was trying to "con" us—it was unimaginable that a volunteer prisoner in a mock prison could legitimately be suffering and disturbed to that extent. But then on each of the next three days another prisoner reacted with similar anxiety symptoms, and we were forced to terminate them, too. In a fifth case, a prisoner was released after developing a psychosomatic rash over his entire body (triggered by rejection of his parole appeal by the mock parole board). These men were simply unable to make an adequate adjustment to prison life. Those who endured the prison experience to the end could be distinguished from those who broke down and were released early in only one dimension—authoritarianism. On a psychological test designed to reveal a person's authoritarianism, those prisoners who had the highest scores were best able to function in this authoritarian prison environment.

If the authoritarian situation became a serious matter for the prisoners, it became even more serious—and sinister—for the guards. Typically, the guards insulted the prisoners, threatened them, were physically aggressive, used instruments (night sticks, fire extinguishers, etc.) to keep the prisoners in line and referred to them in impersonal, anonymous, deprecating ways: "Hey, you," or "You [obscenity], 5401, come here." From the first to the last day, there was a significant increase in the guards' use of most of these domineering, abusive tactics.

Everyone and everything in the prison was defined by power. To be a guard who did not take advantage of this institutionally sanctioned use of power was to appear "weak," "out of it," "wired up by the prisoners," or simply a deviant from the established norms of appropriate guard behavior. Using Erich Fromm's definition of sadism, as "the wish for absolute control over another living being," all of the mock guards at one time or another during this study behaved sadistically toward the prisoners. Many of them reported—in their diaries, on critical-incident report forms and during post-experimental interviews—being delighted in the new-found power and control they exercised and sorry to see it relinquished at the end of the study.

Some of the guards reacted to the situation in the extreme and behaved with great hostility and cruelty in the forms of degradation they invented for the prisoners. But others were kinder; they occasionally did little favors for the prisoners, were reluctant to punish them, and avoided situations where prisoners were being harassed. The torment experienced by one of these good guards is obvious in his perceptive analysis of what it felt like to be responded to as a "guard":

"What made the experience most depressing for me was the fact that we were continually called upon to act in a way that just was contrary to what I really feel inside. I don't feel like I'm the type of person that would be a guard, just constantly giving out . . . and forcing people to do things, and pushing and lying—it just didn't seem like me, and to continually keep up and put on a face like that is just really one of the most oppressive things you can do. It's almost like a prison that you create yourself—you get into it, and it becomes almost the definition you make of yourself, it almost becomes like walls, and you want to break out and you want just to be able to tell everyone that 'this isn't really me at all, and I'm not the person that's confined in there—I'm a person who wants to get out and show you that I am free, and I do have my own will, and I'm not the sadistic type of person that enjoys this kind of thing.'"

Still, the behavior of these good guards seemed more motivated by a desire to be liked by everyone in the system than by a concern for the inmates' welfare. No guard ever intervened in any direct way on behalf of the prisoners, ever interfered with the orders of the cruelest guards or ever openly complained about the subhuman quality of life that characterized this prison.

Perhaps the most devastating impact of the more hostile guards was their creation of a capricious, arbitrary environment. Over time the prisoners began to react passively. When our mock prisoners asked questions, they got answers about half the time, but the rest of the time they were insulted and punished—and it was not possible for them to predict which would be the outcome. As they began to "toe the line," they stopped resisting, questioning and, indeed, almost ceased responding altogether. There was a general decrease in all categories of response as they learned the safest strategy to use in an unpredictable, threatening environment from which there is no physical escape—do nothing, except what is required. Act not, want not, feel not and you will not get into trouble in prisonlike situations.

And the only way to really make it with the bosses [in Texas prisons] is to withdraw into yourself, both mentally and physically—literally making yourself as small as possible. It's another way they dehumanize you. They want you to make no waves in prison and they want you to make no waves when you get out.

—Mike Middleton, ex-con,
The Christian Science Monitor.

Can it really be, you wonder, that intelligent, educated volunteers could have lost sight of the reality that they were merely acting a part in an elaborate game that would eventually end? There are many indications not only that they did, but that, in addition, so did we and so did other apparently sensible, responsible adults.

Prisoner 819, who had

gone into a rage followed by an uncontrollable crying fit, was about to be prematurely released from the prison when a guard lined up the prisoners and had them chant in unison, "819 is a bad prisoner. Because of what 819 did to prison property we all must suffer. 819 is a bad prisoner." Over and over again. When we realized 819 might be overhearing this, we rushed into the room where 819 was supposed to be resting, only to find him in tears, prepared to go back into the prison because he could not leave as long as the others thought he was a "bad prisoner." Sick as he felt, he had to prove to them he was not a "bad" prisoner. He had to be persuaded that he was not a prisoner at all, that the others were also just students, that this was just an experiment and not a prison and the prison staff were only research psychologists. A report from the warden notes, "While I believe that it was necessary for staff [me] to enact the warden role, at least some of the time, I am startled by the ease with which I could turn off my sensitivity and concern for others for 'a good cause.'"

Consider our overreaction to the rumor of a mass escape plot that one of the guards claimed to have overheard. It went as follows: Prisoner 8612, previously released for emotional disturbance, was only faking. He was going to round up a bunch of his friends, and they would storm the prison right after visiting hours. Instead of collecting data on the pattern of rumor transmission, we made plans to maintain the security of our institution. After putting a confederate informer into the cell 8612 had occupied to get specific information about the escape plans, the superintendent went back to the Palo Alto Police Department to request transfer of our prisoners to the old city jail. His impassioned plea was only turned down at the last minute when the problem of insurance and city liability for our prisoners was raised by a city official. Angered at this lack of cooperation, the staff formulated another plan. Our jail was dismantled, the prisoners, chained and blindfolded, were carted off to a remote storage room. When the conspirators arrived, they would be told the study was over, their friends had been sent home, there was nothing left to liberate. After they left, we would redouble the security features of our prison making any future escape attempts futile. We even planned to lure ex-prisoner 8612 back on some pretext and imprison him again, because he had been released on false pretenses! The rumor turned out to be just that—a full day had passed in which we collected little or no data, worked incredibly hard to tear down and then rebuild our prison. Our reaction, however, was as much one of relief and joy as of exhaustion and frustration.

When a former prison chaplain was invited to talk with the prisoners (the grievance committee had requested church services), he puzzled everyone by disparaging each inmate for not having taken any constructive action in order to get released. "Don't you know you must have a lawyer in order to get bail, or to appeal the charges against you?" Several of them accepted his invitation to contact th— parents in order to se-cur— ne services of an attorney. —ne next night one of the parents stopped at the superintendent's office before visiting time and handed him the name and phone number of her cousin who was a public defender. She said that a priest had called her and suggested the need for a lawyer's services! We called the lawyer. He came, interviewed the prisoners, discussed sources of bail money and promised to return again after the weekend.

But perhaps the most telling account of the insidious development of this new reality, of the gradual Kafkaesque metamorphosis of good into evil, appears in excerpts from the diary of one of the guards, Guard A:

Prior to start of experiment: "As I am a pacifist and nonaggressive individual I cannot see a time when I might guard and/or maltreat other living things."

After an orientation meeting: "Buying uniforms at the end of the meeting confirms the gamelike atmosphere of this thing. I doubt whether many of us share the expectations of 'seriousness' that the experimenters seem to have."

First Day: "Feel sure that the prisoners will make fun of my appearance and I evolve my first basic strategy—mainly not to smile at anything they say or do which would be admitting it's all only a game. . . . At cell 3 I stop and setting my voice hard and low say to 5486, 'What are you smiling at?' 'Nothing, Mr. Correctional Officer.' 'Well, see that you don't.' (As I walk off I feel stupid.)"

Second Day: "5704 asked for a cigarette and I ignored him—because I am a non-smoker and could not empathize. . . . Meanwhile since I was feeling empathetic towards 1037, I determined not to talk with him . . . after we had count and lights out [Guard D] and I held a loud conversation about going home to our girl friends and what we were going to do to them."

Third Day (preparing for the first visitors' night): "After warning the prisoners not to make any complaints unless they wanted the visit terminated fast, we finally brought in the first parents. I made sure I was one of the guards on the yard, because this was my first chance for the type of manipulative power that I really like—being a very noticed figure with almost complete control over what is said or not. While the parents and prisoners sat in chairs, I sat on the end of the table dangling my feet and contradicting anything I felt like. This was the first part of the experiment I was really enjoying. . . . 817 is being obnoxious and bears watching."

Fourth Day: ". . . The psychologist rebukes me for handcuffing and blindfolding a prisoner before leaving the [counseling] office, and I resentfully reply that it is both necessary security and my business anyway."

Fifth Day: "I harass 'Sarge' who continues to stubbornly overrespond to all commands. I have singled him out for special abuse both because he begs for it and because I simply don't like him. The real trouble starts at dinner. The new prisoner (416) refuses to eat his sausage . . . we throw him into the Hole ordering him to hold sausages in each hand. We have a crisis of authority; this rebellious conduct potentially undermines the complete control we have over the others. We decide to play upon prisoner solidarity and tell the new one that all the others will be deprived of visitors if he does not eat his dinner. . . . I walk by and slam my stick into the Hole door. . . . I am very angry at this prisoner for causing discomfort and trouble for the others. I decided to force-feed him, but he wouldn't eat. I let the food slide down his face. I didn't believe it was me doing it. I hated myself for making him eat but I hated him more for not eating."

Sixth Day: "The experiment is over. I feel elated but am shocked to find some other guards disappointed somewhat because of the loss of money and some because they are enjoying themselves."

We were no longer dealing with an intellectual exercise in which a hypothesis was being evaluated in the dispassionate manner dictated by the canons of the scientific method. We were caught up in the passion of the present, the suffering, the need to control people, not variables, the escalation of power and all of the unexpected things that were erupting around and within us. We had to end this experiment. So our planned two-week simulation was aborted after only six (was it only six?) days and nights.

We've traveled too far, and our momentum has taken over; we move idly towards eternity, without possibility of reprieve or hope of explanation.

—Tom Stoppard, "Rosencrantz and Guildenstern Are Dead."

Was it worth all the suffering just to prove what everyone knows—that some people are sadistic, others weak and prisons are not beds of roses? If that is all we demonstrated in this research, then it was certainly not worth the anguish. We believe there are many significant implications to be derived from this experience, only a few of which can be suggested here.

The potential social value of this study derives precisely from the fact that normal, healthy, educated young men could be so radically transformed under the institutional pressures of a "prison environment." If this could happen in so short a time, without the excesses that are possible in real prisons, and if it could happen to the "cream-of-the-crop of American youth," then one can only shudder to imagine what society is doing both to the actual guards and prisoners who are at this very moment participating in that unnatural "social experiment."

The pathology observed in this study cannot be reasonably attributed to pre-existing personality differences of the subjects, that option being eliminated by our selection procedures and random assignment. Rather, the subjects' abnormal social and personal reactions are best seen as a product of their transaction with an environment that supported the behavior that would be pathological in other settings, but was "appropriate" in this prison. Had we observed comparable reactions in a real prison, the psychiatrist undoubtedly would have been able to attribute any prisoner's behavior to character defects or personality maladjustment, while critics of the prison system would have been quick to label the guards as "psychopathic." This tendency to locate the source of behavior disorders inside a particular person or group underestimates the power of situational forces.

Our colleague, David Rosenhan, has very convincingly shown that once a sane person (pretending to be insane) gets labeled as insane and committed to a mental hospital, it is the label that is the reality which is treated and not the person. This dehumanizing tendency to respond to other people according to socially determined labels and often arbitrarily assigned roles is also apparent in a recent "mock hospital" study designed by Norma Jean Orlando to extend the ideas in our research.

Personnel from the staff of Elgin State Hospital in Illinois role-played either mental patients or staff in a weekend simulation on a ward in the hospital. The mock mental patients soon displayed behavior indistinguishable from that we usually associate with the chronic pathological syndromes of actual mental patients: incessant pacing, uncontrollable weeping, depression, hostility, fights, stealing from each other, complaining. Many of the "mock staff" took advantage of their power to act in ways comparable to our mock guards by dehumanizing their powerless victims.

During a series of encounter debriefing sessions immediately after our experiment, we all had an opportunity to vent our strong feelings and to reflect upon the moral and ethical issues each of us faced, and we considered how we might react more morally in future "real-life" analogues to this situation. Year-long follow-ups with our subjects via questionnaires, personal interviews and group reunions indicate that their mental anguish was transient and situation ally specific, but the self-knowledge gained has persisted.

For the most disturbing implication of our research comes from the parallels between what occurred in that basement mock prison and daily experiences in our own lives—and we presume yours. The physical institution of prison is but a concrete and steel metaphor for the existence of more pervasive, albeit less obvious, prisons of the mind that all of us daily create, populate and perpetuate. We speak here of the prisons of racism, sexism, despair, shyness, "neurotic hang-ups" and the like. The social convention of marriage, as one example, becomes for many couples a state of imprisonment in which one partner agrees to be prisoner or guard, forcing or allowing the other to play the reciprocal role—invariably without making the contract explicit.

To what extent do we allow ourselves to become imprisoned by docilely accepting the roles others assign us or, indeed, choose to remain prisoners because being passive and dependent frees us from the need to act and be responsible for our actions? The prison of fear constructed in the delusions of the paranoid is no less confining or less real than the cell that every shy person erects to limit his own freedom in anxious anticipation of being ridiculed and rejected by his guards—often guards of his own making. ■

A mock prisoner enjoys the amenities of a "privilege cell" set up by guards to increase their psychological authority.

APPENDIX C

SCIENCE CURRICULUM: BIOLOGY

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
+1	Life: Common Characteristics	4		G
		3		C
		4	20	R*
2	Biology as a Science	9		G
		3		C
		3		R
3	Materials of Life	6		G
		3		C
		5		R
4	Energy of Life	6		G
		9		C
		8		R
+5	Cell Structure & Function	17		G
		12		C
		16	16	R
+6	Cellular Basis of Heredity	7		G
		6		C
		12	29	R
7	Principles of Heredity	8		G
		9		C
		8		R

+ Systems Integrated Here

%TIME PER TOPIC: Reflects the percentage of time devoted to each topic during 1986-87 school year. Percentage of time derived from the number of days per topic divided by total number of instructional days per year.

%TOPIC W/SYSTEMS: Reflects percentage of time a particular topic was taught from a systems perspective. Percentage of topic with systems derived from an estimate of the number of days devoted to instruction with systems divided by the number of days per topic.

TEACHERS: Godfrey (G)
Coles (C)
*Richardson (R) Systems Teacher

SCIENCE CURRICULUM: BIOLOGY

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
8	Genes and Chromosomes	11		G
		9		C
		24		R
9	The Genetic Code	7		G
		9		C
		7		R
10	Change With Time	-		G
		5		C
		-		R
11	Adaptation & Specialization	-		G
		5		C
		2		R
12	Classification	-		G
		3		C
		-		R
13	Monerans, Protists, Fungi	3		G
		-		C
		-		R
14	Plan	2		G
		-		C
		-		R
15	Sponges to Mollusks	1		G
		-		C
		-		R
16	Arthropods to Vertebrates	2		G
		-		C
		-		R
17	Simple Organisms	1		G
		3		C
		-		R
19	Simple Organisms	4		G
	and Disease	6		C
		-		R

SCIENCE CURRICULUM: BIOLOGY

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
20	Plant Reproduction and Development	8		G
		6		C
		-		R
+21	Plant Nutrition	8		G
		3		C
		12	50	R
22	Plants: Other Life Functions	-		G
		3		C
		-		R
24	Animal Development	-		G
		3		C
		-		R

+ Systems Integrated Here

SCIENCE CURRICULUM: CHEMISTRY

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
1	Nature, Science & You	-		B*
		1		G
2	Measuring & Calculating	4		B
		6		G
3	Matter	-		B
		2		G
4	Chemical Shorthand	12		B
		8		G
5	The Mole	8		B
		8		G
6	Atomic Structure	12		B
		8		G
7	Electrons & Clouds	8		B
		6		G
8	The Periodic Table	4		B
		7		G
9	Process of Bonding	4		B
		6		G
10	Results of Bonding	2		B
		1		G
11	Structure/Properties of Molecules	1		B
		-		G
12	Kinetic Energy	4		B
		2		G
14	Liquids	2		B
		8		G

TEACHERS: Groves (G)
*Butterfield (B) Systems Teacher

SCIENCE CURRICULUM: CHEMISTRY

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
15	Gases	6		B
		5		G
16	Gases and the Mole	7		B
		5		G
18	Solutions	2		B
		8		G
+19	Reaction Rate & Chemical Equations	12	100	B
		6		G
20	Acids, Bases, & Equilibrium	8		B
		3		G
21	Oxidation-Reduction	4		B
		-		G
23	Nuclear Chemistry	-		B
		10		G
+s	Environmental/ Social Problems (Ecosystems, Mineral Depletion, Smog, Tooth Decay, Water Pollution)	9	100	B
		-		G

\+ Systems Integrated Here

s Supplementary Topics

SCIENCE CURRICULUM: G.P.S.

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
+1	The Nature of Science	6		J
		9	7	O*
2	Force and Work	12		J
		2		O
+3	Motion	-		J
		9	13	O
+4	Laws of Motion	-		J
		1		O
+5	Properties of Matter	8		J
		9	7	O
6	Elements & Periodic Table	17		J
		9		O
+7	Compounds and Bonding	23		J
		9	27	O
8	Families of Elements: Metals	-		J
		2		O
9	Nonmetals	-		J
		1		O
10	Families of Elements: Carbon	-		J
		1		O
11	Organic Chemistry	-		J
		1		O
12	Solutions	-		J
		1		O
13	Chemical Reactions	11		J
		3		O

+ Systems Integrated Here

TEACHERS: Jessup (J)
*O'Brien (O) Systems Teacher

SCIENCE CURRICULUM: G.P.S.

CHAPTER	TOPIC	%TIME PER TOPIC	%TOPIC W/SYSTEMS	TEACHER
+15	Waves	- 9	13	J 0
+16	Light and Color	- 3	40	J 0
17	Light and its Uses	- 3		J 0
18	Sound	- 1		J 0
19	Heat	- 1		J 0
+21	Electricity	- 11	20	J 0
+22	Electricity & its Uses	- 11	5	J 0
s	Scientific Notation	10		J
s	Nuclear Power	14		J

+ Systems Integrated Here

s Supplementary Topic

APPENDIX D

technology and learning

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Caveats and Realities in Technological Curriculum Innovation[1]

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In a previous article (Mandinach & Thorpe, 1987), we described an innovative curriculum project that integrates a perspective known as systems thinking into high school science and social studies. Using software called STELLA (Richmond, 1985) on the Apple Macintosh™, students can build models and simulate the operation of those models over time. The user can test the effects of changes on selected variables or the system as a whole by altering characteristics of particular variables within the model.

The curriculum project, Systems Thinking and Curriculum Innovation (STACI), is a collaborative effort of four teachers at Brattleboro Union High School (BUHS) in Vermont and the Educational Testing Service, in cooperation with the Educational Technology Center at Harvard The BUHS teachers are the curriculum developers and implementers in general physical science, biology, chemistry, and an experimental course entitled War and Revolution. With the support of several individuals within their community, as well as experts from MIT and Dartmouth, these teachers have assumed responsibility for integrating systems thinking into their curricula. The role of ETS is to examine the cognitive demands and consequences of using systems thinking and the modeling software. Of primary interest is the extent to which students acquire higher-order cognitive skills through interaction with a curriculum infused with systems thinking concepts and, subsequently, generalize knowledge and skills to other substantive areas.

The intent of this article is to discuss issues related to the development and implementation of a technology-oriented curriculum innovation from the perspective of practitioners and researchers. Each perspective has its own responsibilities, objectives, and interests, yet there is common interest and reliance among the involved parties. We begin the discussion from the perspective of the practitioners, whose responsibility for the curriculum development and implementation underlies the innovation. We then describe the research perspective and issues that arise between research and practice in the effort to study curriculum innovation.

Practitioner Perspective

There are several issues related to curriculum development and implementation that arise from the practitioner's perspective – administrative support, physical resources, personnel considerations (e.g., release time, expertise, and support from colleagues), instructional concerns, and dissemination.

Administrative Support

A prerequisite for curriculum innovation is support from the administration. This support can take various forms and lends credibility to the project. Its absence can seriously undermine even the most educationally sound effort. For example, the principal at BUHS thoroughly supports the STACI project and has chosen to place responsibility for decision making and overall operation in the teachers' hands. He lends assistance, if necessary, but prefers to allow the teachers to administer their own project.

Mandinach and Thorpe (cont'd)

Physical Resources

A second issue is the provision of facilities, materials, and equipment — the resources that are necessary if implementation is to succeed. Because curriculum innovations that focus on new technologies are costly endeavors, they often are beyond the means of most school systems. Thus, assistance to obtain hardware and software facilitates timely and effective implementation.

Recognizing the difficulties of meeting their needs, the teachers sought assistance from internal and external sources. For initial development, they obtained a federal grant through which software and one Macintosh™ were purchased. Apple External Research generously donated a classroom set of 15 computers. In addition, BUHS was able to acquire 15 copies of STELLA and a portable projection system with help from ETS. Through the assistance of the principal, the teachers were able to secure a room which now houses the computer laboratory. Without these resources, the systems thinking project could have functioned, but at a substantially diminished level.

Personnel Considerations

A number of personnel issues confront practitioners involved in curriculum development and implementation Among the most pressing issues are release time, expertise, and support from colleagues.

Release time. Curriculum development is a time consuming and demanding process under normal circumstances. It is more difficult when there are no models to follow Because curriculum guides do not exist, the BUHS teachers have created their own curricula. Development required a considerable outlay of time to read, reflect, experiment, and refine ideas and lessons. Though the teachers began some preliminary work in the spring and summer of 1986, the major development effort occurred during the following academic year. As a consequence, the issue of release time for development was a primary concern. To free the teachers for development activities during the school day, paraprofessional support was obtained to assume some of their nonteaching functions. Although this strategy has allocated intervals of time for curriculum development, the competing demands of busy teaching schedules inhibited sustained activity and prolonged development.

There are no easy solutions to this situation. The teachers indicated that release time was essential to their development efforts. Before curricula could be developed for students, staff needed time to further their own knowledge of systems thinking and STELLA. Delays in developing expertise mitigated against the development of materials prior to the beginning of school.

Expertise. Curriculum development demands expertise in the domain of interest Although the BUHS teachers are experts in their subject areas, they had to develop expertise in systems thinking and the use of STELLA. This required substantial time to learn the concepts and experiment with the tools.

The teachers independently pursued further training or assistance pertaining to their particular needs. They attended a summer workshop on systems thinking and consulted experts in systems thinking from MIT. The developers of STELLA have consulted on appropriate uses of the software. Intellectual support from these experts has been instrumental in developing the teachers' level of knowledge and skill.

The process of developing expertise in systems thinking has had unintended but beneficial effects. It has provided teachers with opportunities to bring a fresh perspective to instruction by reflecting on curricular goals and considering how systems thinking can be used to demonstrate new ideas or to reinforce traditional concepts in new ways. It also has provided chances to broaden traditional instruction to include a problem solving approach that may be relevant to learning in other content areas. Furthermore, in attempting to understand systems thinking, teachers have identified confusions similar to those experienced by students that can strengthen their teaching of the curriculum. By anticipating possible problem areas, teachers may be able to adapt their instruction to clarify difficult concepts.

Support from colleagues. While intellectually stimulating, curriculum development can be an uncertain and frustrating process. To complete the process, difficult questions must be answered and creative solutions found. However, often the solutions are not readily apparent. While outside assistance has been invaluable, there is a need for internal support to deal with development questions. The four BUHS teachers have formed a collaborative group providing encouragement and assistance to pursue individual and common interests. They exchange ideas and instructional strategies, and collaborate to develop and test models.

Instructional Concerns

Central to curriculum development and implementation efforts are issues related to instruction. These concerns include questions of integration, instructional sequence, instructional time and academic standards.

Curriculum integration. The overriding concern is to determine what topics are most appropriately taught with a systems perspective, the selection of which has not been easy. Teachers have spent considerable time investigating areas that might be appropriate for a systems approach. In selecting topics, two criteria were applied. First, examples must illustrate a cause-and-effect relationship within a feedback structure. Second, examples must be within a student's level of understanding The availability of topics that lend themselves to systems thinking has differed across subject areas. Biology, with numerous examples of living systems, appears most readily suited to a systems approach Finding appropriate examples that are not too complex has been most difficult in chemistry (e.g., reaction rates).

Instructional time. Inherent in the development and implementation of any innovation are uncertainties about demands that accompany the adoption of a new approach. Foremost is the issue of instructional time. The introduction of new material is likely to decrease attention to traditional topics. In the present case, time was needed to teach systems terminology and concepts Thus, devoting time to instruction in systems thinking meant reducing time devoted to traditional subjects.

It was not known how long students would need to learn systems concepts, become familiar with the microcomputer, and learn

Mandinach and Thorpe (cont'd)

STELLA. Further, it was not clear when these concepts should be taught and if students would transfer knowledge across lessons or courses. From their experience this year, the teachers gained a better idea of learning time and the points where systems can most effectively be used in the curricula. As a result, more efficient use of instructional time will be possible in the coming years. Moreover, as students are exposed to systems thinking, less time will be needed to teach basic systems concepts, allowing them to focus on applications in the content areas.

Instructional sequence. Determining appropriate sequences for instruction is also a major concern. Again, because of the absence of model courses, the BUHS teachers experimented with various sequences to best determine how to order the materials. The teachers tried different patterns (e.g., varying when models or STELLA are introduced). Feedback from these efforts provided information needed for revisions to be implemented in the coming years. It is likely that several iterations will be necessary to determine the most effective instructional sequences. This means that the teachers will continue to tinker with their curricula.

Achievement standards. The introduction of an innovation raises concern for its effect on academic standards. Two types of standards may be imperiled if new instructional activities are introduced: performance on standardized tests may be jeapordized; and curriculum objectives may not be realized. Thus, the goals of the innovation may be perceived to be in direct conflict with the pressure to maintain academic standards. A tradeoff underlies this apparent conflict if the innovation is given a fair test. It is likely, however, that the innovation will require additional attention at the expense of some traditionally valued materials.

Academic achievement is valued highly at BUHS, thus creating pressure to maintain standards. Traditional curriculm objectives have been difficult to maintain due, in part, to the innovation. Allocating time to new material not directly related to traditional objectives caused conflict for the systems teachers. Commitment to the use of systems concepts and methodology shortened coverage of some traditional topics. In the long run, evaluative information concerning the effects of systems thinking should provide evidence relative to the assessment of the innovation's worth.

Dissemination

Dissemination can range from formal presentations or publications to more informal, personal contacts. These vehicles serve different needs. At one level, dissemination can serve an informational need, alerting others to the existence and nature of the innovation. At another, it can serve to solicit support or adoption by others.

The BUHS teachers have engaged in a number of formal and informal activities to share information about systems thinking with other staff members in their school. The systems teachers presented their project to the staff and welcomed inquiries from interested teachers. To encourage further dissemination, a training session was offered to interested students, faculty, and community members.

Research Perspective

Several issues related to curriculum innovation arise from the research perspective. These include balancing the research perspective from that used by the practitioner, obtaining student participation, design issues (e.g., units of analysis, treatment differences, the nature of the intervention), and burdens created by conducting the research.

Balancing Perspectives

The research perspective differs from that of the practitioner in a number of ways. Practitioners develop and implement the curriculum, whereas researchers study the process and effects of introducing such innovations. These differences provide opportunities for collaboration as each perspective brings information valuable to the efforts of the other. Without practitioners, there would be no innovation to study. Without researchers, the consequences of innovation may not be understood.

While researchers and practitioners recognize the potential benefits of collaboration, the realities of conducting research in school settings impose certain limitations and demands on both parties. To study school-based innovations, there must be a balance of the needs of both practitioners and researchers — a balance which is not always easy to maintain. Often research requires the cooperation and assistance of practitioners beyond their normal commitments. While researchers must be sensitive not to exceed reasonable requests, practitioners must recognize that to conduct valid studies, certain research requirements must be met.

Student Participation

If a formal study is to be conducted to examine the innovation's impact, informed parental consent is required to protect the rights non-participating and participating students. Efforts must be made to protect non-participating students from negative consequences as a result of their non-participation. At BUHS, approximately 15% of the students have chosen not to participate in the study. The non-consenting students received the curriculum innovation as a normal part of their instruction, but their work was not examined as a research activity.

Design Issues

A second intervention issue is the compatability between the research design and realities of classrooms. Methodology and design must be flexible to conduct research in school settings. That is, researchers must make compromises that will enable the collection of informative data. Common problems that arise include attrition, transfers, course changes, and other issues that alter the nature and composition of the sample and treatment.

Units of analysis. At BUHS, we are fortunate to have relatively equivalent treatment and control groups. An equal number of classes in each subject are being taught as treatments and controls. However, the added confounding factor that there is only one systems teacher per subject makes it difficult to distinguish between teacher and treatment effects. In the ideal design there would be several teachers for each subject. However, because schools rarely correspond to research designs, we must account for the confounding factor through appropriate statistical procedures

Treatment differences. Another potential confounding problem is if parts of the treatment become infused in the control classes. If assessment of an innovation's impact is to be made, there must be a measurable separation between treatment and control classes. Should teachers in the control classes adopt aspects of the innovation, there is no way to examine treatment differences. While this confound is a compliment to the innovative teachers, it is a nightmare to the researchers. Although infusion of the innovation distinguishes treatment from control, the course content of the groups should be comparable. Because achievement is a primary outcome, it is critical that both groups receive equivalent subject matter instruction. It would be otherwise impossible to assess the innovation's impact if course content were not held constant.

Nature of intervention. The nature of the intervention directly influences the design of research. Students must receive sufficient exposure to the new instructional materials if the innovation is to affect achievement and learning. Thus, teachers must develop and use sufficiently rich and numerous modules of the new curriculum for effects to be realized. There is always a danger that research will be conducted before the new instructional program can be fully implemented. It is difficult and unfair for researchers to assess an innovation's impact when there has not been a sufficient implementation.

Research Burdens and Contributions

Research brings to a school certain impositions that may interfere with instruction. The prime example is data collection. Research often requires the administration of tests that teachers would not normally use and observations that can upset classroom procedures. Teachers may be asked to collect information, document procedures, and perform other activities outside the range of normal duties. All of the requests place additional burdens and responsibility on the teachers because of the research project.

With all of these inconveniences, there also are positive effects caused by the research. Perhaps the most important asset is validity. Research can provide evidence that the curriculum innovation has had positive outcomes in learning, teaching, and instruction. It provides validation that the teachers' efforts have been successful and that the innovation was worth doing. The researchers' presence also indicates the innovation's importance, and that the results should be disseminated to others who might want to implement the curriculum.

Moreover, research can provide evidence of generalizability as well as local validity. The ultimate goals of an innovation are twofold. The curriculum must be effective for those who developed it and, more important, the curriculum can be implemented in other settings, thus establishing its generalizability. This is the ultimate compliment for innovative educators who strive continuously to improve their teaching and develop more effective instructional materials.

Footnote:

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References

Mandinach, E. B., & Thorpe, M. E. (1987). *The systems thinking and curriculum innovation project. Technology and Learning, 1* (2), 1, 10-11

Richmond, B. (1985). *STELLA [Computer program]* Lyme, NH: High Performance Systems, Inc