DOCUMENT RESUME

ED 304 310 SE 050 360

AUTHOR	Mandinach, Ellen B.
TITLE	Self-Regulated Learning Substudy: Systems Thinking and Curriculum Innovation (STACI) Project.
INSTITUTION	Educational Technology Center, Cambridge, MA.
REPORT NO	ETC-TR88-25
PUB DATE	Sep 88
NOTE	56p.; Last page (in Appendix C) will be marginally legible because it contains broken type.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	Chemistry; *Computer Assisted Instruction; Computer Simulation; Physics; *Problem Solving; *Science Curriculum; *Science Instruction; *Science Materials; Science Programs; *Secondary School Science; Systems Approach
IDENTIFIERS	Self Regulation; Systems Thinking and Curriculum Innovation Project

ABSTRACT

The Systems Thinking and Curriculum Innovation (STACI) Project is a multi-year research effort intended 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 integrating the systems approach into science and history courses to teach content knowledge as well as general problem solving skills. The project also examines the effectiveness of using STELLA, a simulation-modeling software program, as a tool by which to examine scientific and historical phenomena. The research focuses on learning outcomes and cognitive processing, particularly self-regulation, that are activated in an instructional environment that requires students to use high-order cognitive skills in the examination of dynamic phenomena. A total of 31 chemistry and 22 physics high school students were selected by criteria (course taking, ability, and gender), interviewed individually, and tape recorded. Appendices include: (1) "Self-Regulation Questionnaire"; (2) "Physics Problem"; and (3) "Chemistry Problem." (YP)

TR88-25

SELF-REGULATED LEARNING SUBSTUDY: SYSTEMS THINKING AND CURRICULUM INNOVATION (STACI) PROJECT

September 1988

Educational Technology Center
Harvard Graduate School of Education
337 Gutman Library Appian Way Cambridge MA 02138
(617) 495-9373

Self-Regulated Learning Substudy:

Systems Thinking and Curriculum Innovation (STACI) Project

Ellen B. Mandinach

Educational Testing Service, Princeton, New Jersey

September, 1988

Self-Regulated Learning Substudy:

Systems Thinking and Curriculum Innovation (STACI) Project

The Systems Thinking and Curriculum Innovation (STACI) Project is a multi-year research effort intended 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 integrating the systems approach into science and history courses to teach content knowledge as well as general problem solving skills. The project also examines the effectiveness of using STELLA, a simulation-modeling software program, as a tool by which to examine scientific and historical phenomena. The research focuses on the learning outcomes and cognitive processing, particularly self-regulation, that are activated in an instructional environment that requires students to engage high-order cognitive skills in the examination of dynamic phenomena.

A primary focus of the Systems Thinking and Curriculum Innovation (STACI) Project is the examination of students' cognitive processes and learning outcomes, and the strategies and processes that lead to knowledge and skill acquisition. Cognitive process analysis is the means by which the skills and processes engendered in tasks and learning activities can be identified and understood. Such analyses attempt to determine whether the same kinds of skills are applicable across tasks or are specific to domains and content areas (e.g., Glaser, 1984; Simon, 1976). Processes have been identified that are thought to organize a learner's cognition. These processes have been termed metacognitive (Brown, 1978; Flavell, 1976, 1979), executive (Belmont, Butterfield, & Ferretti, 1982; Snow, 1980), and self-regulated (Corno & Mandinach, 1983) and are used interchangeably.

Metacognition generally is defined as an individual's knowledge about one's own cognitive processes (Flavell, 1976). It refers to the active monitoring and consequent regulation and orchestration of cognitive processes. Metacognition requires active involvement on the part of learners. It also requires that learners exhibit awareness not only of the demands of the particular task or learning environment, but more importantly of their own capabilities and performances. Thus, learners must be able to evaluate and supervise their own cognitive behavior through the use of self-interrogation. Correspondingly, they must be able to adapt their performance in accord with task demands.

The present study espouses the concept of self-regulated learning and applies its definition in the examination of students' learning processes. Self-regulated learning has been defined as a student's active acquisition and transformation of instructional material (Corno & Mandinach, 1983). The construct consists of two component sets of processes — information acquisition processes and information transformation processes. Information acquisition processes include receiving stimuli, tracking information, and self-reinforcement (alertness, monitoring). These processes are seen as metacognitive when they regulate the second component of information transformation. Important transformation processes include discriminating relevant from irrelevant information, connecting new information with prior knowledge or skills, and planning particular performance routines (selectivity, connecting, planning).

Self-regulation is viewed as a normative ideal that few students use consistently. It is neither appropriate for nor encouraged by all classroom tasks. Rather, students are hypothesized to alternate between different forms of cognitive engagement or variations on self-regulated learning, both between and within different task situations. Moreover, the impetus of shifts among the variations may often be task demands and/or features of instruction. Learning can become less self-regulated when some self-regulation processes are assumed by teachers, peers, or characteristics of instructional materials.

Students who exhibit self-regulated learning engage both acquisition and transformation processes. The second form of cognitive engagement is characterized by learners who are exceptional organizers, but look to other sources for assistance with necessary transformations. Such learners, termed resource managers, are high in acquisition, but low in transformation processes. Students who passively receive instruction (engage in recipient learning) invest minimal cognitive effort in the task by permitting the instruction to accomplish much of the cognitive work for them. In this third form of cognitive engagement, both acquisition and transformation are invested at low levels. The final form of cognitive engagement characterizes students as displaying an engagement style with an almost exclusive focus on the task. In this form of engagement, students activate more transformation than acquisition processes. They select critical variables and connect new to old information; they readily perform subject-specific planning. What they do less well is adopt a wide-angle perspective, go beyond the information given, and carefully monitor the whole processes at a metacognitive level.

Systems Thinking

Systems thinking is a scientific analysis technique that provides a means to understand the behavior of complex phenomena over time. In recent years appreciation has developed particularly for the heuristic value of systems thinking. The creation and manipulation of models is increasingly recognized as a potentially powerful teaching technique. Based on the concept of change, system dynamics uses simulations and computer-based mathematical models to represent complex relationships among variables (Forrester, 1968). It is possible to understand the rule-like behavior of systems by constructing models of variables and their interactions, and examining the cause-and-effect relationships among the variables. The notion of a system is based on: (a) variables that characterize a system and change over time; (b) relationships among variables are interconnected by cause-and-effect feedback loops; and (c) the status of one or more variables subsequently affects the status of other variables.

Simulation models, simplified representations of real-world systems over hypothetical time, are used to examine the structure of systems. Using simulation software, characteristics of selected variables can be altered and their effects on other variables and the entire system assessed. To build a simulation, it is necessary to hypothesize the major variables that comprise the system. These variables are used to form a dynamic feedback system, expressed in 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 provides a means to understand how the elements contribute to the whole (Roberts, Andersen, Deal, Garet, & Shaffer, 1983).

STACI Project

The STACI Project is a two-year research effort that examines the cognitive demands and consequences of learning from a systems thinking approach to instruction and from using simulation-modeling software. The study, which was conducted at Brattleboro Union High School (BUHS), Brattleboro, Vermont, tests the potentials and effects of using the systems 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 (Richmond, 1985), a simulation-modeling software package that runs on the Macintosh, as a tool with which to teach systems thinking, content knowledge, and problem solving skills.

The systems thinking approach, as defined here, consists of three separate but interdependent components -- system dynamics theory, STELLA, and the Macintosh computer. The implementation of the systems thinking approach in instruction necessitates that students engage high-order thinking skills in order to solve effectively systems exercises and learning activities. The processes by which systems and STELLA models are constructed require students to exhibit self-regulated learning processes (Mandinach, 1988). Students must lay out, test, and troubleshoot their models, using many sources of incoming information. First, students need to be alert to incoming stimuli generated by the different representations produced in each computer run. Given the plethora of information, they need to discriminate relevant from irrelevant data, and connect incoming with existing information about their models. It is essential to monitor the results of the different iterations and representations to troubleshoot the models. Finally, it is useful to plan systematically iterations of hypothesize-test-troubleshoot sequences in an attempt to achieve working and theoretically accurate models of phenomena.

The examination of self-regulated learning is one of several foci of the STACI Project. The purpose of the present substudy is to examine indepth the cognitive processes and self-regulated learning skills exhibited by students as they solve problems in science courses into which the systems thinking approach has been integrated. Performance and processing comparisons are drawn among students with different levels of exposure to systems thinking classes, ability level, and gender. In addition, students' perceptions of the utility and effectiveness of the systems thinking approach are explored.

During the first year of the STACI Project, systems thinking was i tegrated into three general physical science, four biology, and three chemistry classes. An equivalent number of traditional (control) classes were taught concurrently by other members of the faculty. An experimental history course entitled War and Revolution, into which systems was completely integrated, also was taught. During the Project's second year, systems was taught in two physical science, four biology, three chemistry, three physics classes, and War and Revolution. Again, an equivalent number of traditionally taught classes served as controls.

Method

Subjects and selection procedure. The substudy focused on students enrolled in chemistry and physics during the 1987-1988 academic year. In chemistry, we sought first to identify an equal number of students in the systems and traditional classes who had taken either traditional or systems biology in the previous academic year. Thus, we identified students who were exposed to one of four sequences of science courses (i.e., systems biology-systems chemistry, traditional biology-systems chemistry, systems biology-traditional chemistry, and traditional biology-traditional chemistry). We also selected students based on ability and gender. Median splits of standardized achievement test scores were used to define high and low ability groups from which an equal number of males and females were selected. Thus, the study used a 2 x 2 x 2 x 2 factorial design (biology treatment, chemistry treatment, ability, gender), with two replications per cell (see Figure 1). A total of 31 chemistry students were selected who met the criteria on the four factors.

The factorial design was modified for physics because there were no controls for the systems classes. The first selection criterion was whether the student took systems or traditional chemistry during the 1986-1987 academic year. A second criterion was whether the student was enrolled concurrently in the War and Revolution seminar, the experimental history course into which the systems thinking approach was fully integrated. Ability and gender also were used as selection criteria. The design yielded 22 students in 11 of 16 cells (see Figure 2). No low ability students were enrolled both in physics and War and Revolution. In addition, there were no high ability females concurrently taking both courses.

Procedures. The substudy focused on two categories of cognitive behavior: the assessment of cognitive engagement processes; and the identification and assessment of general problem skills engendered in the systems thinking approach. Both constructs were assessed during a 50-minute interview administered in May.

An existing instrument used to assess metacognition was modified for the purposes of the study to measure the component processes of cognitive engagement (Howard, 1987). The Self-Regulated Learning Instrument (SRLI) contained 16 items, representing five subscales: selectivity, connecting, planning, alertness, and monitoring (Appendix A). The first four processes were measured with three items and the last subscale contained 4 items. Transformation processes were measured by concatenating scores from the selectivity, connecting, and planning scales; acquisition processes by concatenating scores from alertness and monitoring. Responses then was classified as self-regulated, task focused, resource management, or recipient based on the pattern of scores across the bivariate plot of transformation by acquisition processes.

Items were constructed in a forced-choice format. One alternative indicated the student's preferred response for a particular process; the other alternative indicated that it was not preferred. For example, the instrument included an item that asked if students double-checked their responses or more or less worked through the problems without needing to double-check. Double-checking is evidence of monitoring. Thus, students who reported that they double-checked showed evidence that they engaged in monitoring, an acquisition process exhibited by self-regulated learners and resource managers. Students who did not double-check showed low acquisition processes, a characteristic of task focus or recipient learners.

Students were interviewed individually and tape recorded by the author. Upon arrival at the interview, students were told that they would be asked a number of questions about their science course, systems thinking, STELLA, the Macintosh, and the effects of systems thinking approach on teaching and learning. It was explained that a primary purpose for talking with them was to obtain information that could be used to improve the systems courses next year, and that their responses would in no way affect their grades. Students then were asked several questions about the use and effectiveness of STELLA, the computer, and systems thinking.

Students then were given an assignment that they had completed previously in class. The physics exercise was a simple acceleration problem (Appendix B). The chemistry problem, an essay on mercury pollution, related to the reaction rates chapter recently completed in both systems and traditional classes (Appendix C). Students were asked to recall the problem and describe in detail how they approached the problem, the processes by which they solved it, and how it related to similar problems assigned in class. One goal was to see if and how students applied the systems approach in solving the problem. The procedure used to elicit students' responses was retrospective, think-aloud protocol analysis.

Upon completing the description of their problem solving processes, students were asked think about the specific problem as well as analogous ones and respond to the SRLI. Students read and were talked through the instrument to insure that they understood the task. Those students who were enrolled concurrently in the War and Revolution seminar were probed about the applicability of their responses to the history and science classes.

Finally, students were asked to express their opinions about the effectiveness of using systems thinking in their courses. They were asked about their perceptions of using the Macintosh, STELLA, and systems, how the approach affected classroom instruction, their learning, and motivation. Students also were asked to suggest changes and improvements that might make the systems approach a more effective instructional strategy.

Results

Self-Regulated Learning Instrument. Differences in response patterns on the SRLI emerged between the chemistry and physics classes (Figure 3). Most students in both courses were classified as either self-regulated or recipient. Few students were considered task focused or resource managers. Whereas the most common level of cognitive engagement among the physics students was self-regulation (59%), the most common in chemistry was recipience (45%). The differentiating factor apparently was the chemistry students' responses to transformation items. Over 61 percent of the chemistry students were rated as low on transformation processes, whereas only 36 percent of the physics students were classified as low. An equivalent number of chemistry students were rated high or low on the acquisition items, in contrast to 68 percent of the physics students rated as high. Thus, it appears that the physics students were more cognitively adaptive to the assigned task than were those in chemistry.

Closer examination of the response patterns within each course took into consideration course-taking sequence, ability level, and gender. Course-taking sequence for the chemistry students accounted for treatment condition in chemistry (systems or traditional) and treatment in biology (systems or traditional). Thus, there were four possible course patterns across the two academic years. Tables 1 and 2 present the classification of students in the various course sequences. One difference between systems and traditional chemistry was that recipience was more common among students in the control class. This result can be traced to the majority of traditional students who exhibited low transformation skills. Major difference were apparent between systems and traditional biology classes. Whereas half of the systems biology students were classified as self-regulated, the majority of control students were categorized as recipient. This result is attributable to the traditional classes' low scores on both acquisition and transformation processes.

When course-taking sequence is brokendown into the four patterns, results indicate that students who took both traditional biology and chemistry were at a distinct disadvantage. Seven of the eight students were classified as recipient; the remaining student was self-regulated (a high ability female). A closer examination of these recipient students' scores (see Figure 1 for scores on the five component processes) indicate that they were able to select information and discriminate relevant from irrelevant data, but were lacking in connecting, planning, alertness, and monitoring skills. Only one student exhibited monitoring skills, while a second exhibited some evidence of connecting skill. Students who took traditional biology and systems chemistry exhibited deficits in transformation processes, but exhibited acquisition skills. Students who took systems biology, regardless of the chemistry treatment condition, exhibited similar patterns of cognitive engagement. Apparently, not having a systems course was detrimental; having some systems was advantageous, particularly if it was in biology.

Slight ability and gender differences were noted in levels of cognitive engagement. Collapsing across treatment conditions, more low ability students (60%) exhibited recipience than did high ability students (31%). High ability students tended toward resource management (25%) more often than those in the low ability group (7%). Some interesting response patterns were yielded by the interaction between gender and ability. High ability males tended toward self-regulation, particularly if they took systems chemistry. In contrast, the majority of the low ability males (and all in traditional chemistry) were rated as recipient. Low ability females who took only traditional courses were classified as recipient, whereas those who had some exposure to systems exhibited more adaptive levels of cognitive engagement. Moreover, three of four low ability females who took systems biology exhibited self-regulation.

Over half the physics students exhibited self-regulation, whereas 27% were rated as recipient (Tables 3 and 4). Physics students were more likely to exhibit high levels of transformation and acquisition processes, particularly those also taking War and Revolution. Students who had not been exposed to systems other than in physics (i.e., traditional chemistry without War and Revolution) exhibited a pattern of responses different from the other course-taking sequences. Half these students were rated as self-regulated; the other half were recipient. Further examination (see Figure 2) indicates three of four high ability students were self-regulated, whereas one was recipient. The reverse was found for low ability students; three were recipient and one self-regulated. The teacher confirmed that the high ability male who was classified as recipient showed little motivation for learning and consequently did not perform well in the course. In contrast, the low ability female who was rated as self-regulated was enthusiastic about physics and performed quite well. The teacher made similar observations about another high ability male and low ability female. Both students were exposed to systems in chemistry. The male was was rated as recipient; the female was self-regulated.

Gender differences were noted in physics. Females were more likely to be self-regulated (72%) than males (45%), and less likely to be recipient (18% versus 36%). In particular, six of seven high ability females were rated as self-regulated, in contrast to three of seven high ability males. Furthermore, although two recipient and two self-regulated learners were found among low ability males and low ability females, it is interesting to note that three of four recipient learners had not been exposed to systems thinking (other than in physics). In contrast, three of four self-regulated learners also took systems chemistry.

Comparisons among the physics students not only took into account treatment condition in their chemistry courses, but also whether they were concurrently enrolled in the War and Revolution seminar. Concurrent enrollment makes comparisons slightly more complicated because students in the seminar were a select, high ability group, not necessarily representative of the wider distribution found in physics. Thus, comparisons are made in Table 5 between the War and Revolution students and only the high ability physics students. The high ability physics students exhibited similar response patterns to those of the War and Revolution students. There was a larger proportion of high acquisition and transformation processes and consequently, self-regulated learning with the removal of the low ability students. Yet, 25 percent of the high ability students still exhibited recipience, the form of cognitive engagement not found among students in War and Revolution.

The SRLI was designed so that indepth analyses of response patterns could be performed. Examination of patterns across the five component processes yielded insightful results concerning students' cognitive performance. Three high ability males in physics exhibited pure self-regulated learning. That is, all responses indicated high levels of performance on all items across the five component processes. Four other students were rated as self-regulated on 15 of 16 items. Interestingly, three of these four students (all high ability females in physics, two of whom were in War and Revolution) responded similarly on one planning item that indicated a preference for attending to what other people are doing to get ideas, rather than exhibiting short-term planning on one's own. This notion of collaborative group learning was a critical factor in the War and Revolution seminar as well as in much laboratory and computer work in physics. In contrast, only one student, a high ability male in physics with no previous exposure to systems, responded in a completely recipient manner. Three other males responded to all but one item as recipient learners.

Other interesting response patterns emerged across the five component processes (Table 6). A number of students exhibited all but one skill; others exhibited only a specific component. Students who exhibited only a particular component generally showed evidence of one of the transformation processes, rather than the metacognitive acquisition processes. However, one high ability female showed evidence of both high-level acquisition processes, but failed to exhibit any transformation skills. Several other students showed evidence of all but one component. The deficits always occurred on one of the transformation processes.

The selected response patterns have implications for instructional remediation. In particular, for the six students who exhibited deficiencies on only one component, subsequent instruction can be focused to remediate the specific learning deficit. For the student who showed a weakness in selectivity, instruction could be targeted toward increasing her ability to discriminate relevant from irrelevant information. Similarly, for students who exhibited only one component, subsequent instruction need not focus on that skill, but rather target the four other skills that are deficient.

Responses to the SRLI also provided information about how students might differ in their cognitive approaches to different content domains. The concurrent enrollment in physics and War and Revolution gave students the opportunity to compare how cognitive skills might be exhibited in both courses. This is a particularly insightful comparison because physics is a quantitative domain, whereas War and Revolution is highly qualitative.

Six students were enrolled concurrently in physics and War and Revolution, two of whom also had taken systems chemistry. Students noted that a major difference between physics and War and Revolution was how and the extent to which monitoring skills needed to be applied in the two courses. One student commented that there was a greater need for cognitive monitoring in War and Revolution than in physics because there were no numbers to plug into systems models. Thus, students had to be more alert and monitor more carefully their thought processes. There are no right or wrong answers in War and Revolution, unlike in physics where solutions sometimes are more concrete, with only one correct response. Other students agreed that monitoring was more critical in War and Revolution, although not unimportant in physics. The plethora of information students must keep in mind in the history seminar necessitated that they double-check their work. Double-checking was qualitatively different in physics because problems often provided more constrained boundary conditions, thus enabling students to work through them without as much monitoring.

Correspondingly, students articulated that gaining a general understanding of a problem was particularly important in War and Revolution, where you must both focus on the parts but also how the parts of the problem contribute to the systemic nature of the whole. Conversely in physics, students sometimes simply focused on solving the problem if it wass sufficiently constrained, although there also was a need for general understanding, but to a lesser degree.

Connecting was a skill often mentioned as being applied in different ways in the two courses. Students were required to process a great deal of information in War and Revolution. Consequently, they needed to tie things together by connecting incoming information to extant knowledge. One student commented that everything was connected in some way in War and Revolution. Therefore, connecting skills were necessary to decrease ambiguity among the data. This was not generally the case in physics. Connecting also was evidenced in the need to seek parallels among related exercises and apply the principles to the current problem.

The wealth of information encountered in the history seminar also required students to exhibit and apply selectivity skills in different ways than evidenced in physics. In physics, students often were able to discriminate relevant from irrelevant information and select what data were needed to solve a given problem. Conversely in War and Revolution, all information was thought to be important, although students needed to focus on specific parts of their projects at particular times. As the focus changed, so too did the task demands, thus necessitating different levels of selectivity.

Cognitive processing and perceptions in physics. Of the six students who took both War and Revolution and physics, four reported that they solved the acceleration problem with STELLA. One student preferred a mathematical solution and another used a systems thinking approach with causal loop diagrams. The student who solved the problem with quadratic equations reported that math was more tangible unless a problem was especially complex. The particular acceleration problem was not sufficiently complicated to warrant analysis with STELLA. The student who used causal loop diagrams (and ultimately STELLA) reported that although math was logical and understood what the numbers meant, the systems thinking approach enabled her to organize and check her work mentally and focus on important concepts, despite her dislike of STELLA. Students who used STELLA expressed that the problem was made easier and more visually salient with the use of systems. STELLA provides visual representations that allowed students to see relationships among variables. The diagrams and graphics were important visualization aids that could be tied to real-world problems as well as the equations. Although these students noted that quantifying this particular problem and analogous ones in physics were straightforward, quantification had been difficult in War and Revolution. Students were able to concentrate on STELLA's equations, whereas in the history seminar they focused on parts of the model. All of the students highlighted that STELLA could be used for physics problems like the one administered, but cautioned that the systems approach was not appropriate for all physics problems. They also cautioned that you needed to have sufficient understanding of physics for the approach to make sense. Without the content knowledge, students would not have been able to apply STELLA as a problem solving tool.

Of the other eight high ability students, five solved the problem with STELLA, two used both STELLA and quadratic equations, and one used only equations. The student who used only equations was female who also had taken systems chemistry. She expressed that math made complete sense, whereas STELLA took longer on this acceleration problem. Those who used both methods noted that the STELLA solution was "self-reinforcing" and just as simple as the equations, but that a more complete understanding came from both the math and systems solutions. The students who solved the problem using STELLA did so for a variety of reasons. One student who was exposed to systems in both chemistry and physics noted that the approach was much more applicable in physics than chemistry. Another student noted that he had difficulty with quadratic equations, yet STELLA helped him to understand the concept of acceleration. He would not have been able to solve the problem and understand the concept without the simulation-modeling softw..re. STELLA helped several students to visualize the problem and its applications in a very real way.

Performance among the low ability students was quite different. Low ability males who had taken systems chemistry used STELLA to solve the problem. One female from systems chemistry used both STELLA and equations. The other female preferred equations, although she used both solution methods. She commented that she had difficulty with STELLA in physics, but thought it was much simpler in chemistry. In contrast, all the low ability students who took traditional chemistry solved the problem using equations, despite the fact that they did not understand the physics with the mathematical solutions.

Students were asked to describe if and how they thought the systems thinking approach influenced their performance in physics. The six students who also took War and Revolution each reported that particular aspects of the systems approach facilitated their learning. They commented that the approach helped by enabling them to simulate phenomena that could not be done without STELLA and the Macintosh. STELLA, through visual representations, made concepts more easily understandable, more tangible, and connected to real-world phenomena. The students also acknowledged that the approach was not appropriate for all types of problems and all academic disciplines. In physics, there was a perception that problems needed to be sufficiently complex to warrant application of the systems approach. One student noted that because of the quantitative nature of physics, the systems approach was more effective than in War and Revolution. A second student disagreed by adding that the approach was used more effectively in the history seminar where it served to decrease ambiguity in knowledge. Another student commented that the approach's strength lies in its applicability in social science courses such as economic and government. All students agreed that systems was a good supplement or adjunct to physics and War and Revolution when applied to the right kinds of problems.

Perceptions among the other high ability students were quite varied. Four students thought that the approach helped them to learn physics more effectively. The approach made learning easier, more interesting and efficient, more connected to other problems, and "brought reality to calculations." One student commented that although STELLA was abstract, it was easy to learn and an invaluable problem solving tool. Two students thought STELLA was confusing, but facilitated learning. One student noted that, "STELLA enhances your thinking, but is not necessarily easier. It takes awhile to understand how it relates - what affects what." Two other students thought that the approach did not help; one needed a slower physics course, the other required more time and a more intensive systems unit in order to apply the theory.

The low ability students focused on STELLA's capability to enhance learning through visual representations and internal calculations. It was as if these students perceived that the computer was shortcircuiting some of their cognitive processes by performing some to the problem solving. One student noted that, "the computer doesn't forget. It figures out the math for you and lets you see how it works." Another student added that, "STELLA helps you to know if you are doing it right." One student who had difficulty with systems thinking in physics commented that it was easier in chemistry. She needed assistance in content knowledge before the systems approach could be applied to physics.

Cognitive processes and perceptions in chemistry. The assessment of cognitive processing on the chemistry exercise was more difficult to carry out because of its essay format and the less direct connection to the systems thinking approach. Systems thinking rarely was used or mentioned as a solution to the mercury pollution problem. Moreover, students failed to see the problem's connection to chemistry. Students often commented that the essay was unlike anything they had encountered in chemistry (both in topic and format).

Despite students' lack of insight into the problem, certain observations can be made about their cognitive processing. Few students read the essay with an eye for the main idea. Instead, most students let the questions guide their approach to the problem. They worked through each question by searching for the answer rather than trying to gain a general understanding of the mercury pollution issue. The first three questions could be answered in such a task focused manner. The other six questions required a higher level of cognitive processing, interpretation, and a systemic understanding of the cause-and-effect relationships in mercury pollution. Students who used the answer searching tactic were less able to provide interpretations for these more complex questions.

Differences in performance between the systems and traditional chemistry classes also were assessed by in-class tests on reaction rates, the unit in which the mercury problem was given and where the systems module was targeted. A pretest was administered before the teachers began the reaction rates unit. No differences were found between the systems ($M = 4.00$) and traditional ($M = 3.60$) classes. The systems ($M = 8.67$) students performed slightly better than the controls ($M = 6.81$) on the posttest. This difference only approached significance, $F(1, 28) = 3.46$, $p = .07$. Students who were taught reaction rates using the systems thinking approach gained 4.78 points from pre- to posttest; the traditional students gained 3.27 points. Thus, although the students exposed to systems in their reaction rates unit performed slightly better than those in the control classes, the results only approached a minimal level of significance.

More informative were the chemistry students' opinions of the systems thinking approach. The chemistry students were asked to describe how the systems thinking approach influenced their understanding of science. Unlike the physics students who all had been exposed to at least one systems course, eight chemistry students had no exposure and 15 others had limited exposure in the previous year when the systems curricula were evolving. Consequently, there were expected differences in the amount and quality of feedback students could offer.

It was expected that students who took both systems chemistry and biology would be the most articulate about the approach's impact. All students recognized that systems could help if applied to the appropriate kinds of problems. The low ability students noted that the approach made science concepts come alive through visual representations. Systems made learning more interesting because they could see how things worked and progress in a step-by-step method. Several students noted the approach's applicability in other courses such as history and math, and its capability of linking science to other disciplines.

A high ability student commented that the systems approach was particularly relevant in science because it highlighted cause-and-effect relationships, and allowed you to explore science concepts without getting bogged down in calculations. Furthermore, the computer helped you to keep track of information. However, one low ability student commented, the "computer doesn't do it; you do." One of the high ability students articulated the approach's importance in science methodology. "I like STELLA. It's a lot simpler to use than previous methods. You can form a hypothesis in a short amount of time and test it. This is really good."

Although these students believed that systems was a useful tool, they also discussed how the systems courses could be improved. One student commented that there was a need to understand the chemistry concepts before using STELLA. Another mentioned that there should be more explicit explanations of how to set up models. A third student who was apprehensive about the computer expressed frustration with learning systems thinking and the computer together. Perhaps if she had had computer training first, the systems approach would have made more sense. Students in other treatment sequences concurred that the systems approach should be integrated more explicitly into the curricula. They also expressed the approach's applicability to other academic classes and hoped that the perspective would be used in other departments.

Students who took systems chemistry and traditional biology generally thought that systems enhanced their understanding of science. Some noted the approach's applicability as a general problem solving tool that could be used for a variety of problems, particularly those that required hypothesis testing and graphing. Systems served as a good adjunct to laboratories and lectures, highlighting some chemistry concepts that would not have been as clear without the approach. Two low ability students cautioned that the systems materials were taught too quickly. A slower and more explicit presentation would help them to make the appropriate connections to chemistry. Another low ability student felt she was at a disadvantage because she was in a control class last year, and therefore did not have enough computer experience.

Half of the students who took systems biology and traditional chemistry explicitly stated that they would have preferred to have taken systems chemistry. These students believed that they benefited from the approach in biology and thought it would have helped in chemistry. One student even requested a transfer into a systems class. Three other students noted that systems also helped them to understand scientific concepts such as cause-and-effect. Conversely, one low ability student commented that he was glad to be in the control class and wished he also had been in traditional biology because he was always lost.

The final group, those who were not exposed to the systems approach, did not understand what the approach really was, other than from discussion with other students. Five students knew it was a problem solving tool that might help them in their courses; three simply did not know. Two students explicitly expressed their wish to be in systems chemistry.

Students who took systems chemistry were asked by the teacher to fill out an evaluation of the systems thinking approach. All enjoyed working with the Macintosh, particularly those with more systems experience. Students generally liked using STELLA to answer chemistry problems and preferred the software to the lectures and laboratories on reaction rates. Females expressed slightly mixed reactions to STELLA, whereas the males were more positive. However, the females definitely preferred to use STELLA rather than do the laboratory. In general, most students expressed positive opinions about the use of the systems thinking approach in learning reaction rates.

Conclusions and Implications

The case study interviews conducted in this substudy provided intensive information about the effects of the systems thinking approach on student's cognitive processing and perceptions of the approach's impact on learning. No significant differences were found in inferential comparisons between systems and control chemistry classes on outcomes related to instruction on reaction rates. However, differences were noted among physics students in their ability to apply systems to scientific problems. Differences also were noted on students' levels of cognitive engagement. Patterns could be traced across course sequences, with students exposed to more systems exhibiting higher forms of cognitive engagement. Students with minimal or no exposure to systems were more likely to exhibit recipience. Furthermore, not all low ability students were classified as recipient, nor were all high ability students self-regulated. Forms of cognitive engagement varied across ability level, gender, and exposure to systems thinking.

Students' perceptions of the approach's impact on their learning were quite varied and differed in the physics and chemistry courses. Physics students were more articulate about how they could apply systems in their coursework as a problem solving tool. As a tool, systems could be applied to some, but not all problems. Applicability depended on the complexity of the problem. Traditional methods were seen as more useful and efficient for simple problems; the systems approach was considered more effective for complex and dynamic problems. Both physics and chemistry students saw the approach's applicability to other academic disciplines. History and social studies were most frequently mentioned as classes that would benefit from the teaching perspective.

The chemistry students also provided insightful comments about how the systems approach could be used more effectively in the science courses. Although opinions differed about the use of STELLA and the Macintosh, many students believed that the systems thinking approach was a useful problem solving tool that helped them to understand better the content of their science courses.

The systems thinking approach was integrated into science courses as an analytic technique that would help students solve a variety of problems and simulate phenomena dynamically over time. The intent of integrating the approach into the science courses was to examine its impact across courses as students were exposed to a sequence of classes that used systems. Results indicate that the systems thinking approach is not applicable to all problems encountered in science courses. However, it is helpful as a problem solving tool for many problems, particularly those that examine dynamic phenomena. The approach can help teachers convey to students concepts that heretofore were difficult to comprehend (e.g., osmosis). The approach should be thought of as one of many teaching strategies or one of many problem solving tools that can be applied when appropriate to instruct or solve particular types of problem or concepts.

The approach consists of three interdependent but distinct component, each of which contributes to its effectiveness. Systems thinking is a theory that can be applied to teaching and learning of dynamic phenomena. The Macintosh and STELLA are tools that enable student to implement systems theory and apply it in very real ways to many situations. However, many students failed to understand the systems approach. That is, they thought STELLA was systems thinking, which is a critical misconception. STELLA enables students to construct structural diagrams and models of systems, then simulate them dynamically over hypothetical time to test hypotheses. Yet, there is more to systems thinking than structural diagrams and STELLA. As many of the War and Revolution students noted in this study and elsewhere (Mandinach, 1988), a causal loop diagram is another viable representation of systems phenomena. The approach integrates the three components into one instructional medium, with both the theory and the tools contributing to the perspective's power as a teaching strategy and problem solving tool.

As an instructional strategy, explicit connections need to be made between the approach and the course content into which it is to be integrated. Students at BUHS were not quite sure how the systems approach fit into their science courses. If the approach is not well integrated or linked to the curriculum, students will perceive that systems thinking is peripheral to the course, rather than a tool that can be applied to help them acquire declarative and procedural knowledge. Systems would be seen as separate, something that is not tested and therefore an unimportant part of the course.

To accomplish such integration, teachers need to be knowledgeable, although not necessarily expert, about systems theory, STELLA, and the Macintosh. It is vital that they have sufficient working knowledge to troubleshoot problems, advise, and guide students' learning activities. In providing such guidance, the teacher's role changes from an instructor who directs a class and imparts knowledge to a facilitator who shares control and responsibility for learning with the students.

Science may not be the only discipline into which the approach fits naturally. Systems could be applied to mathematics, given that it underlies systems theory and STELLA. Perhaps the approach's greatest potentials can be found in its applicability to social science courses such as economics, history, and government. In fact, many students expressed that systems should be used in other courses; some students already applied systems methods in their social studies courses.

Contrary to early expectations, systems thinking is not just for high ability students; low ability students also are capable of applying the approach effectively. In addition, not all high ability students benefit from systems thinking. Some students in this study fail to recognize its potential as a problem solving tool; others who have negative attitudes toward computers find the software and hardware to be impediments to learning. In contrast, some students who previously had been less that successful in science courses have espoused the approach as a means by which to overcome past difficulties.

Finally, the systems thinking approach (i.e., system dynamics, STELLA, and the Macintosh) appears to be related to students' cognitive engagement. Some students in this study who have not been exposed to systems thinking were at a disadvantage; they exhibited lower forms of cognitive engagement. Students who had some systems thinking exhibited more adaptive levels of cognitive engagement. Those who had multiple exposures to systems showed the highest levels of cognitive engagement and were aware that strategy switching in accord with task demands is an effective and adaptive method of learning. Furthermore, ability and self-regulation, although positively related, are not synonymous. Not all high ability students are self-regulated, nor are all low ability students recipient. Moreover, the systems thinking approach may have assisted some low ability students to exhibit more adaptive forms of cognitive engagement.

A curriculum innovation such as the systems thinking approach requires a longitudinal perspective from which to assess its impact. The true test of the curriculum innovation will evolve as teachers become more experienced with and integrate effectively the instructional perspective, and students become exposed to more courses. Results reported here indicate that the systems thinking approach has the potential to serve as an effective teaching strategy and general problem solving tool. Subsequent studies will examine the approach's long-term effects on teaching and learning activities as the curricula continue to evolve over time.

Footnote

This research was conducted under the auspices of the Educational Technology Center, Harvard Graduate School of Education and was supported by the Office of Educational Research and Improvement under contract number 400-83-0041. Any opinions, findings, and conclusions or recommendations expressed in the document are those of the author and do not necessarily reflect the views of ETC, OERI, or ETS. The author wishes to acknowledge Hugh Cline, Nancy Benton, Colleen Lahart, and Peggy Thorpe of ETS, Dr. Barbara Bowen of Apple Computer, Inc., Charles Butterfield, Sam Groves, and Chris O'Brien of Brattleboro Union High School, Dr. Lyn Corno, and Dawn Howard for their contributions to this study.

References

Belmont, J. M., Butterfield, E. C., & Ferretti, R. P. (1982). To secure transfer of training instruct self-management skills. In D. K. Detterman & R. J. Sternberg (Eds.), How and how much can intelligence be increased. Norwood, N.J.: Ablex.

Brown, A. L. (1978). Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), Advances in instructional psychology (Vol. 1). Hillsdale, N.J.: Erlbaum.

Corno, L., & Mandinach, E. B. (1983). The role of cognitive engagement in classroom learning and motivation. Educational Psychologist, 18, 88-108.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L. B. Resnick (Ed.), The nature of intelligence. Hillsdale, N.J.: Erlbaum.

Flavell, J. H. (1979). Metacognition and cognitive monitoring. American Psychologist, 34, 906-911.

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

Glaser, R. (1984). Education and thinking. American Psychologist, 39, 93-104.

Howard, D. C. (1987). Metacognitive questionnaire. Burnaby, British Columbia, Simon Fraser University.

Mandinach, E. B. (1988). The war and revolution seminar case study: Systems thinking and curriculum innovation (STACI) project. Princeton, N.J.: Educational Testing Service.

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

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

Simon, H. A. (1976). Identifying basic abilities underlying intelligent performance of complex tasks. In L. B. Resnick (Ed.), The nature of intelligence. Hillsdale, N.J.: Erlbaum.

Snow, R. E. (1980). Aptitude process. In R. E. Snow, P-A. Federico, & W. E. Montague (Eds.), Aptitude, learning, and instruction (Vol. 1). Hillsdale, N.J.: Erlbaum.

Figure 1
Design and response patterns on the Self-Regulated Learning Instrument for chemistry students

		Chemistry 1987-1988			
		Systems		Traditional	
		Biology 1986-1987		Biology 1986-1987	
		Systems	Traditional	Systems	Traditional
High Ability	Male	11111 — 11 SRL 11111 — 11 SRL	11111 — 11 SRL 10011 — 01 RM	10011 — 01 RM 11111 — 11 SRL	10000 — 00 R 10000 — 00 R
	Female	10100 — 10 TF 00000 — 00 R	00100 — 00 R 10011 — 01 RM	00011 — 01 RM 10111 — 11 SRL	10001 — 00 R 11111 — 11 SRL
Low Ability	Male	11011 — 11 SRL 00100 — 00 R	10101 — 10 TF 00001 — 00 R	00000 — 00 R 01000 — 00 R	01000 — 00 R 10000 — 00 R
	Female	00000 — 00 R 11011 — 11 SRL	01001 — 01 RM	10111 — 11 SRL 11011 — 11 SRL	10000 — 00 R 10000 — 00 R

Note. Scores represent cognitive engagement components: selectivity, connecting, planning, alertness, and monitoring, followed by transformation and acquisition processes composites. 1 = high. 0 = low.
Each row in a cell represents one student profile.

Figure 2
Design and response patterns on the Self-Regulated Learning Instrument for physics students

		Physics 1987-1988			
		Systems Chem 1986-87		Traditional Chem 1986-87	
		War & Rev	No W&R	War & Rev	No W&R
High Ability	Male	00011 — 01 RM 11111 — 11 SRL	00000 — 00 R 11111 — 11 SRL	11000 — 10 TF	111111— 11 SRL 00000 — 00 R
	Female		11111 — 11 SRL 00011 — 01 RM	11111 — 11 SRL 11111 — 11 SRL 01111 — 11 SRL	11111 — 11 SRL 11111 — 11 SRL
Low Ability	Male		01111 — 11 SRL 10111 — 11 SRL		00000 — 00 R 00000 — 00 R
	Female		00000 — 00 R 11111 — 11 SRL		00100 — 00 R 11111 — 11 SRL

Note. Scores represent cognitive engagement components: selectivity, connecting, planning, alertness, and monitoring, followed by transformation and acquisition processes composites. 1 = high. 0 = low.
Each row in a cell represents one student profile.

Figure 3
Distribution of cognitive engagement in physics and chemistry

Chemistry

Transformation Processes		Acquisition Processes: High	Acquisition Processes: Low	
	High	Self-Regulation 10 32.3%	Task Focus 2 6.5%	12 38.8
	Low	Resource Management 5 16.1%	Recipience 14 45.2%	19 61.3%
		15 48.4%	16 51.7%	31

Physics

Transformation Processes		Acquisition Processes: High	Acquisition Processes: Low	
	High	Self-Regulation 13 59.1%	Task Focus 1 4.5%	14 63.6
	Low	Resource Management 2 9.1%	Recipience 6 27.3%	8 36.4%
		15 68.2%	7 31.8%	22

Note. Acquisition processes include alertness and monitoring. Transformation processes include selectivity, connecting, and planning.

Table 1
Classification of cognitive engagement among chemistry students

	Course-Taking Sequence				Total	
	C_SB_S	C_SB_T	C_TB_S	C_TB_T	n	%
Self-Regulation	4	1	4	1	10	32.3
Task Focus	1	1	0	0	2	6.5
Resource Management	0	3	2	0	5	16.1
Recipience	3	2	2	7	14	45.2

	Systems Chemistry	Traditional Chemistry
Self-Regulation	5 (33.3)	5 (31.3)
Task Focus	2 (13.3)	0 (0)
Resource Management	3 (20.0)	2 (12.5)
Recipience	5 (33.3)	9 (56.3)

	Systems Biology	Traditional Biology
Self-Regulation	8 (50.0)	2 (13.3)
Task Focus	1 (6.3)	1 (6.7)
Resource Management	2 (12.5)	3 (20.0)
Recipience	5 (31.3)	9 (60.0)

Note. $n = 31$.
C_SB_S = Systems chemistry, systems biology.
C_SB_T = Systems chemistry, traditional biology.
C_TB_S = Traditional chemistry, systems biology.
C_TB_T = Traditional chemistry, traditional biology.

Table 2
Classification of component processes of cognitive engagement among chemistry students

	Course-Taking Sequence					
	C_SB_S	C_SB_T	C_TB_S	C_TB_T	Total n	Total %
Transformation						
High	5	2	4	1	12	38.7
Low	3	5	4	7	19	61.3
Acquisition						
High	4	4	6	1	15	48.4
Low	4	3	2	7	16	51.6

	Systems Chemistry	Traditional Chemistry
Transformation		
High	7 (46.7)	5 (31.3)
Low	8 (53.3)	11 (68.8)
Acquisition		
High	8 (53.3)	7 (43.8)
Low	7 (46.7)	9 (56.2)

	Systems Biology	Traditional Biology
Transformation		
High	9 (56.2)	3 (20.0)
Low	7 (43.8)	12 (80.0)
Acquisition		
High	10 (62.5)	5 (33.3)
Low	6 (37.5)	10 (66.7)

Note. n = 31.
C_SB_S = Systems chemistry, systems biology.
C_SB_T = Systems chemistry, traditional biology.
C_TB_S = Traditional chemistry, systems biology.
C_TB_T = Traditional chemistry, traditional biology.

Table 3
Classification of cognitive engagement among physics students

	Course-Taking Sequence				Total	
	$C_SW\&R$	C_S	$C_TW\&R$	C_T	n	%
Self-Regulation	1	5	3	4	13	59.1
Task Focus	0	0	1	0	1	4.5
Resource Management	1	1	0	0	2	9.1
Recipience	0	2	0	4	6	27.3

	Systems Chemistry	Traditional Chemistry
Self-Regulation	6 (60.0)	7 (58.3)
Task Focus	0 (0)	1 (8.3)
Resource Management	2 (20.0)	0 (0)
Recipience	2 (20.0)	4 (33.3)

	War and Revolution	No War and Revolution
Self-Regulation	4 (66.7)	9 (56.2)
Task Focus	1 (16.8)	0 (0)
Resource Management	1 (16.8)	1 (6.2)
Recipience	0 (0)	6 (37.5)

Note. n = 22.
$C_SW\&R$ = Systems chemistry, War and Revolution.
C_S = Systems chemistry, no War and Revolution.
$C_TW\&R$ = Traditional chemistry, War and Revolution.
C_T = Traditional chemistry, no War and Revolution.

Table 4
Classification of component processes of cognitive engagement among physics students

	Course-Taking Sequence				Total	
	$C_SW\&R$	C_S	$C_TW\&R$	C_T	n	%
Transformation						
High	1	5	4	4	14	63.6
Low	1	3	0	4	8	36.4
Acquisition						
High	2	6	3	4	15	68.2
Low	0	2	1	4	7	31.8

	Systems Physics	Traditional Physics
Transformation		
High	6 (60.0)	8 (66.7)
Low	4 (40.0)	4 (33.3)
Acquisition		
High	8 (80.0)	7 (58.3)
Low	2 (20.0)	5 (41.7)

	War and Revolution	No War and Revolution
Transformation		
High	5 (83.3)	9 (56.2)
Low	1 (16.7)	7 (43.8)
Acquisition		
High	5 (83.3)	10 (62.5)
Low	1 (16.7)	6 (37.5)

Note. *n* = 22.
$C_SW\&R$ = Systems chemistry, War and Revolution.
C_S = Systems chemistry, no War and Revolution.
$C_TW\&R$ = Traditional chemistry, War and Revolution.
C_T = Traditional chemistry, no War and Revolution.

Table 5
Classification of cognitive engagment among physics students, considering ability level

	W&R	No W&R All	No W&R HA
Self-Regulation	4	9	5
Task Focus	1	0	0
Resource Management	1	1	1
Recipience	0	6	2
Transformation			
High	5	9	5
Low	1	7	3
Acquisition			
High	5	10	6
Low	1	6	2

Note. n = 22.
W&R = War and Revolution.
No W&R All = No War and Revolution, all students.
No W&R HA = No War and Revolution, only high ability students.

Table 6

Selected response patterns on the Self-Regulated Learning Instrument

	Transformation			Acquisition	
	Selectivity	Connecting	Planning	Alertness	Monitoring
Exhibits only a specific component	LFTT	LMTS	LMSS		LMST
	HMTT	LMTT	HFST		LMT
	HMTT		LFT	HFTS (has acquisition but no transformation skills)	
Exhibits all other components	HFTW&R	LFTS	LMSS		
		HFTS	LFSS		
		LMS			

Note. H = high ability. L = low ability. M = male. F = female.
SS = systems chemistry and biology.
ST = systems chemistry, traditional biology.
TS = traditional chemistry, systems biology.
TT = traditional chemistry and biology.
T = traditional chemistry, no War and Revolution.
S = systems chemsitry, no War and Revolution.
TW&R = traditional chemistry, War and Revolution.

Appendix A

Name____________________ Class & Mods____________________

Self-Regulation Questionnaire

Think back to when you were reading the problem and trying to figure out what you were supposed to do. What were you thinking about?

1. Did you think about:
   a. the steps you would go through or the extra information you might need to do the problem? OR b. the very first thing you would do to get started?

2. Did you consider:
   a. what the problem was asking you to do overall? OR b. how you would work out the first part of the problem?

3. Did you think about:
   a. other school work that the problem reminded you of? OR b. whether other students in your group might be helpful to you in solving these problems?

4. Did you:
   a. keep track of some of the information in order to remember it better? OR b. read the information without doing anything special to make sure you would remember it?

In completing the problem, you had to do several different kinds of things - first you had to read the description of the problem, then you had to figure out what you had to do to solve it, and so on. During these different parts of the task, which of the following did you do MOSTLY?

5. Did you:
   a. plan how you would do each part of the problem as you came to it? OR b. pay attention to what others were doing or saying, to get ideas about how to do parts?

6. During various parts of the task, did you:
   a. consistently pay attention to the problem and what you were doing? OR b. try to pay attention, but kept losing your concentration?

7. Did you:
   a. compare the information in this problem to something you knew about already? OR b. see this information as new and keep it pretty much separate from things you knew already?

8. For parts of the task did you:
   a. create a drawing or other representation to help you understand, remember, or work with it? OR b. think about the information in just the way it was presented to you?

9. When you were working on the problem, did you:
   a. decide that some details given in the problem were not important for solving it? OR b. consider every bit of the information as important?

10. Did you find that you:
   a. sometimes double-checked to make sure you were doing it right? OR b. more or less just worked through the problems without needing to double-check things?

11. While working on the task, did you:
   a. pause to figure out the next steps you would need to take? OR b. work through the task without stopping to plan your next moves?

12. During the task, did you:
   a. think about whether you had a general understanding of things or not? OR b. just concentrate on solving the problem?

13. While working on the task, did you:
   a. focus on some parts or points more than others? OR b. concentrate equally on all the information?

Appendix B

Physics Problem

A late passenger, sprinting at 8 m/sec, is 30 m away from the rear end of a train when it starts out of the station with an acceleration of 1 m/sec^2. Can the passenger catch the train if the platform is long enough? (Note: This problem requires solution of a quadratic equation. Can you explain the significance of the two values you get for the time?)

Appendix C

Name ______________________________ Class ______ Date ______________

Mercury in the Environment

Several decades ago, the people of Minamata, a small coastal town on the southernmost island of Japan, witnessed some strange events. Birds would suddenly drop from the sky, almost as if someone had shot them. Cats were seen to spin around and "dance" in frenzied convulsions, usually to their death. Then in 1956 physicians there began to investigate a mysterious human illness—a disease thought to be possibly associated with the "dancing cats" and one that probably had been present in the population for a long time. Person after person developed unusual neurological symptoms, including the inability to walk or talk correctly.

After testing for and ruling out many possible diseases, the baffled medical authorities, suspecting an environmental cause, focused on the biggest industry in this town, a chemical plant that produced plastics and petrochemicals. Although the company vigorously denied charges of being responsible for this strange disease, the company doctor secretly began to perform his own tests by feeding waste material produced by the plant to laboratory cats. In October of 1959, he discovered the culprit: After ingesting wastes containing mercury, cat number 400 underwent seizures and began to spin around at great speed, crashing into laboratory walls. The doctor deduced that mercury poisoning was affecting members of the population, animal and human, exposed to water contaminated with wastes from this chemical plant.

Mercury, element number 80 in the periodic table, is a silver-white, heavy metal. It is one of only two elements that are liquid under normal conditions (the other is bromine). Historically, mercury, also known as quicksilver, has been associated with neurological disorders in persons exposed to it over long periods of time. In the nineteenth century, this metal caused mental illness in hatters, or hat makers, who used it to treat furs. In fact, the Mad Hatter in Lewis Carroll's *Alice's Adventures in Wonderland* is a fictional character based on the real victims of mercury poisoning in that profession. This poisoning can be caused by the inhalation of fumes produced by the substance, making it an occupational health hazard for such workers as mercury miners. It can also result from the ingestion of the metal. A serious public health disaster occurred in the southwestern United States during the late 1960s, when many individuals accidentally ate seeds that had been treated with mercury-containing fungicide and that were meant only for planting.

The victims of Minamata were poisoned by mercury dumped into the water. But scientists were confused by this at first. Mercury is not a reactive metal. It is only slightly soluble in water and does not react easily with other substances. Thus, it was long thought—until the late 1960s, in fact—that mercury discarded into the environment, especially into water, did not pose much of a threat or health hazard. Scientists considered it safe for industries to dump mercury into bodies of water because they believed the metal would simply settle down to the bottom and eventually be buried by layers of sediment.

Then, in the 1960s, scientists in Sweden were investigating the mercury levels in fish taken from mercury-contaminated water. They observed that the mercury found in the fish tissues differed from the inorganic, elemental form that had been dumped; instead, the mercury was present in an organic, and more toxic, form, called methylmercury. This "biotransformation" was shown to be brought about by microscopic life in the water. Microorganisms present in lakes, rivers, and other bodies of water transformed insoluble, elemental mercury into the very soluble and hazardous substance methylmercury. There is even some evidence to suggest that bacteria inhabiting the intestines of rats and humans also can perform this biotransformation.

This discovery changed the image of mercury as a relatively harmless waste product. The soluble methylmercury easily passes into the tissues of fish, and then into the brain, liver, and kidney tissues of higher-order organisms, including humans, that eat the fish.

Although case after case of this "disease of the dancing cats" was diagnosed, the chemical plant officials at Minamata maintained that no mercury was emitted from their plant into the water. They also believed that the evidence pointing to a natural formation of the hazardous methylmercury would relieve them of any responsibility for mercury poisoning anyway. The company doctor did not at first reveal his findings concerning the effects of mercury in the wastes from the chemical plant. But his work and that of scientists later showed that the

Name ______________________ Class ______ Date ______________

Mercury in the Environment (*Continued*)

chemical plant's waste did indeed contain levels of both mercury and methylmercury when it was discarded into the water. Finally, in 1973, a Japanese court ruled that the company was negligent in its actions, and ordered it to provide large cash payments and living and medical expenses to the mercury poisoning victims, who totaled 1,401 by 1979.

Besides the emission of this metal in industrial wastes, mercury contamination in the environment is also caused by the combustion of fossil fuels, especially coal. A large amount of mercury is released into the atmosphere each year by the burning of coal. Eventually it falls back to the earth, adhering to other particles. Some of it is then washed by rainfall into bodies of water. Scientists can only guess at how much mercury falls into water in this way, and then at how much is converted to the hazardous methylmercury form. Although they know that some biotransformation of mercury does occur, it does not seem significant enough to be a health hazard. Scientists do believe, however, that the sulfur and nitrogen oxides emitted by fossil fuel combustion, which are implicated in the acid rain problem (see the Societal Issues essay, Acid Rain on page 27-5), somehow increase this biotransformation process. As bodies of water become more acidic, the mercury levels in the fish there have been observed to increase.

Mercury is considered an "immortal" waste. Being an element, it is nonbiodegradable, that is, not broken down into less hazardous component parts by natural processes. Being an unreactive element, it is also not easily dispersed by natural processes either. In one situation, the land surrounding a factory in Virginia had toxic levels of mercury (used in the production of chlorine there) some ten years after the plant had been closed down. The mercury had not been eliminated by natural processes during this time.

The disaster at Minamata and other mercury poisonings have made it clear that corrective measures are necessary to protect the human population from mercury. The government has taken steps to reduce its levels in the environment. In 1971 the U.S. Department of Agriculture banned many fungicides containing this metal, and the use of mercury-containing drugs and paints has been greatly reduced. But the environmental problems created by past use of mercury are difficult, and expensive, to remedy. It is not yet known what kinds of procedures will be most effective for reversing mercury contamination of the environment.

Answer these questions based on your understanding of the article. Mercury in the Environment. Refer to the article as necessary. You may use sketches, graphs, or diagrams if they will help you answer the questions. Make your answers as complete and clear as you can

1. What is (are) the major reason(s) that it took so long to realize that people and animals can be poisoned by mercury in the environment?

2. What were some important discoveries that helped scientists understand mercury poisoning.

3 How is the amount of sulfur in fossil fuel (coal and oil) related to methylmercury in the environment

4. a.) If, starting today, no more mercury were released as waste into the environment, what would you hope a graph of the threat of mercury to people and animals might look like? (Try to make the time units reasonable.)

b.) How would you go about finding out if your "hoped for" graph is realistic or possible?

5. a.) How could the 1973 Japanese court decision affect environmental mercury?

b.) What could be some negative consequences of that court decision?

6. Oil spills and certain industrial wastes kill large amounts of microscopic life in the water On the other hand, pollution from sewage treatment plants increase microscopic life. If you were an environmental chemist trying to clean up mercury in the environment, which type of pollution would your study first. Explain your choice.

7 Since mercury is an element and therefore impossible to destroy, what are the aims or goals of those agencies that are trying to reduce the threat of mercury in the environment.