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Exploring Knowledge Models with Simulated Tutorial Conversation

Stephen Gilbert Taylor

A Thesis

in

The Department

of

Education

Presented in Partial Fulfilment of the Requirements
for the degree of Doctor of Philosophy at
Concordia University
Montréal, Québec, Canada

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ABSTRACT

Exploring Knowledge Models with Simulated Tutorial Conversation

Qui docet, discit.
He who teaches, learns
Comenius

Stephen Gilbert Taylor, Ph.D.
Concordia University, 1999

This research project started from the idea expressed by Comenius that an individual learns more about a subject matter through teaching it to another person than from participating in conventional learning activities. The idea was studied through the design, development and testing of a theoretical model of the tutoring-learning process in which self-tutoring and the development of knowledge and understanding is based on both using educational resources and on explaining the structure of knowledge to another individual. The theoretical model, the *Knowledge Modelling Approach*, incorporates constructivist learning theory with the concept of a mental model, and applies Pask's conversation theory. The theoretical model was then tested through the development of a simulation of tutoring, the *Virtual Tutee System*, that casts the real student user into the role of tutor, while the tutee resides within the computer simulation software. This is a reversal of the roles generally found in computer aided instruction. A text similar to a college biology chapter was developed to serve as an educational resource for the students. The subject matter chosen for this test case was the topic of photosynthesis as taught in college level biology courses. Fifty Québec college students participated in a laboratory demonstration of the simulation. Eighteen of these students studied the text guided by study questions to learn about the subject matter, while thirty-two students used the computer based tutoring method. Pretest and posttest comparisons indicate that the users of the simulation achieve similar results to those using the text alone. Users of the simulation also responded favourably to the software on an attitude questionnaire following their session. These results provide a validation for the use of the *Virtual Tutee System* as an instructional method. The system is presented as a contribution to educational technology as a prototype of a novel conversational learning system. The *Knowledge Modelling Approach* is thus presented as a new theoretical model for the design of instructional systems.

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CHAPTER 1: INTRODUCTION

Qui docet, discit.
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Comenius

A current problem in education is motivating high school and college students to become active participants in the development of their own learning. While young children are extremely eager learners, many adolescents seem to have been conditioned to adopt a passive approach to their academic work during the high school years, and this makes their post secondary studies more difficult. Few students become involved sufficiently to fully understand or demonstrate mastery of a body of knowledge. Although there is a number of causes that can be posited to explain this situation, it is more useful for educators to develop ways to help students to overcome the tendency to be passive and to become active learners again. Schank (1994) proposes that learning needs to be connected to doing and suggests several ways of developing educational software that promote active learning. His approaches include using simulations and case studies, producing incidental experiences to promote learning, and providing opportunities for reflection and exploration. There is another way, as well. It has long been realized that people learn about a subject through the activity of teaching it to others.

Comenius, more than 350 years ago, was recommending the introduction of teaching exercises as a way to improve student learning in *The Grand Didactic* (Keatinge, 1910). There is much anecdotal evidence to support this strategy and many teachers report that they really began learning about their subject matter only after they finished their studies and began teaching it. Although little seems to be known about what happens when one individual sets out to teach another, it appears that the repeated activity of explaining and answering questions posed, from several different perspectives, promotes a deeper knowledge and better understanding of a subject matter. As such, it appears that a teacher is actively participating in a mastery learning situation. This suggests that students could receive a real benefit from adopting a teaching role with respect to the subject matter that they are presently learning. Thus, a learning through teaching strategy could be added to Schank's suggestions.

The classroom teaching environment is a complex milieu with many interacting factors that might influence the learning of the subject matter by the teacher. While producing a simulation of this environment would be beneficial for teacher training, most students do not become formal classroom teachers and would not benefit from this type of experience. However, there is a substantial body of evidence provided by studies of peer-tutoring and close cross-age tutoring indicating that in the one-to-one tutorial situation the tutor benefits as well as the tutee. Thus, one way of providing students with a teaching experience is to have them do peer tutoring.

The current research project focused on the design, development and testing of a theoretical model of the tutoring-learning process in which self-tutoring and the development of knowledge and understanding is based on both using educational information resources, such as a textbook, and on explaining the structure of the knowledge to another individual. This model was then tested through the production of a computer based simulation of peer tutoring. The tutoring-learning model integrates cybernetic theory and methods, and incorporates constructivist learning theory as a current approach to the study of the phenomena of learning. It also uses a concept of a mental model as a metaphor for the internally constructed representation of experience, and draws on Pask's conversation theory to explain learning gains through a tutorial conversation. This tutoring-learning model has been named the *Knowledge Modelling Approach.*

The simulation used to test the model reverses the roles generally established in computer-based tutorials. It features a *virtual tutee* as the computer-based participant, while the student user adopts the role of the tutor. The real student studies the required subject matter content and then provides tutoring assistance to the *virtual tutee* who makes statements, poses problems and asks questions of the student user, now situated in the role of the *tutor.* A third participant, also computer based, called the *virtual professor* monitors the activities of the *tutor* and the *virtual tutee.* The computer simulation is named the *Virtual Tutee System.* Through the tutorial conversation students become involved in an exploration of the knowledge models inherent to the subject matter and consequently develop or remodel their personal mental models of that subject matter.

The subject matter chosen for the test case followed the objectives and content of the chapters from a typical college biology textbooks about photosynthesis. The subject matter knowledge waselaborated by analyzing theconcepts, their relationships, and the structure of the knowledge about the topic as presented in several textbooks by following a combination of an approach known as DACUM (Designing a Curriculum) and concept mapping. Using the completed maps as knowledge models for photosynthesis, a set of objectives for the lesson was established and a series of test questions for subject matter competence was written in order to assess the benefits to the student users. A printed study guide, similar to a textbook chapter, and containing the basic information about photosynthesis was also written to provide student users of the simulation with a knowledge reference source. College students were recruited to participate in a test of the simulation, as a relatively controlled experimental situation. An analysis of the data accumulated in this test case, while not providing definitive evidence, generally supports the validity of the use of the *Virtual Tutee System* as an instructional tool. This evidence then is interpreted to justify the application of the *Knowledge Modelling Approach* to the design of future intelligent tutoring systems.

Educational Technology is concerned, among other things, with the design, development and testing of environments and instructional systems that support the learning of subject matter domains. Duchastel (1994) defines learning environments as "...the interfaces in which learning occurs through the interaction between the learner on the one hand and the instructional resources and activities on the other." Hannafin and Land (1997) discuss technology enhanced student centred learning environments and point out that these "...emphasize constructing personal meaning by relating new knowledge to existing conceptions and understandings: technology promotes access to resources and tools to facilitate construction." Robert Taylor (1980) described three general uses for the computer in the school as a tutor, tool and tutee. Much of the development of computer-aided instruction has centred on the concept of using the computer as a tutor to help students learn about and master a particular subject matter or skill. There are also many applications of the computer as a tool. Students currently use computer word processing, spread sheets and graphic design programs to complete assignments and prepare papers and presentations. Students also use computer simulations to study situations that could not practically be studied other ways. For example, a student may use a simulation to establish an ecosystem and, then, by changing some of parameters, observe the consequences of the change over an accelerated time frame. Taylor presented less information or insight about the use of the computer as a tutee, and focused his discussion on having students design programs that tutor other students. Mann (1994) explores the application of computer based technology to the development of learning environments for gifted students. Drawing on Taylor's book as background, she describes applications that accomplish the first two uses but does not provide any examples of the use of the computer as a tutee.

The *Knowledge Modelling Approach* is presented as a contribution to the expansion of educational technology by providing a theoretical model of the tutoring-learning process as a method for the design of such environments and associated instructional systems. In addition, the *Virtual Tutee System*, as a computer simulation based on this approach, is presented as a prototype of an instructional system that is a novel approach to creating a teaching and learning environment using the computer as a tutee. This project also furnishes an exemplification of parts of Pask's Conversation Theory by providing an operating example of a process that he named *teachback*. This strategy and the simulation may be used to further investigate how one individual teaches a subject matter to another, and may have applications in the field of teacher training. The contributions to knowledge arising from this work should subsequently provide a basis for further improving tools for teaching and learning as well as the environments in which they are used.

CHAPTER 2: SURVEY OF BACKGROUND LITERATURE

The initial inquiry into the question of how the process of teaching causes improved learning in the teacher lead to a review of literature about teaching and tutoring. The development of the *Knowledge Modelling Approach* also drew on sources in the literature of constructivist learning theory, systems and cybernetics, and Pask's conversation theory. The evaluation of the proposed model of tutoring and learning required a review of literature relevant to the evaluation of intelligent tutoring systems. The sections of this chapter provide a brief survey of this diverse literature.

TEACHING AND TUTORING

Many of the things that humans do are the result of learning. It appears that humans have developed in particular two unique capabilities in the course of the evolution of the species: the use of tools to facilitate or extend human capability and the use of symbolic communication as a means of transmitting information from one generation to another. These developments have reduced our dependence on genetic evolution to modify behaviour patterns, and have led to cultural continuity and cultural evolution which depend on the transmission of information through teaching. This also permits individuals to learn by vicarious experience without having to re-learn all the behaviour patterns in each generation by direct experience. Smith and Smith (1966) provide a short overview of how this evolution of human learning is related to the central processes of education.

Pickering (1991) argues that there is an instinctive nature to teaching. He provides four reasons as evidence to support his hypothesis. First, many people give up worldly goods, recognition and conventional success to pursue teaching. Second, he reports on the widespread ability to teach. His third piece of evidence is the selective advantage, from an evolutionary standpoint, for having parents that can teach the helpless infant become an adult. Finally, Pickering reports on the constancy in the way that teaching is carried out. While this article was designed to stimulate thought about teaching at the beginning of a new academic year and might not be taken too seriously from a scientific viewpoint, it has some implications for the study of teaching as a process. If teaching is a natural human activity, then Pickering points out that more research should be directed at correcting "teaching pathology" and giving substance to some of the intuitions that are felt about teaching.

Teaching and Learning

The processes of teaching and learning, working together, may be considered as two sides of the same issue. Every individual is both a teacher and a learner, and is often both at the same time. A person can learn about the world through the efforts of another's teaching and but also by teaching himself or herself. In addition, one appears to learn about a subject through teaching it to others. Another way that learning occurs is through practice under the guidance of a more experienced individual. (Gharajedaghi & Ackoff, 1985)

A thorough search of the literature reveals very little research into how the practice of teaching a subject improves the knowledge of the teacher. Along this line of investigation, however, Wilson, Schulman and Richert (1987) report on their studies into the development of subject matter knowledge in novice teachers, and provide evidence that teachers learn about the subject as they teach. They point out that the teacher acquires a pedagogical knowledge about the subject or an approach to teaching the topics to students. Based on the comments of one of their research subjects they propose that the teacher also acquires a very large number of perspectives on a given subject matter. From their studies, they observe:

> ...In making the transition from student to pedagogue, novice teachers struggle with finding ways to explain the content of their disciplines to high school students. In their struggle to communicate understanding, they are forced to examine their personal understanding of the content. Subsequently, they generate representations of the subject matter that will facilitate the development of understanding in their students. These representations or transformations of the subject matter take many forms -- metaphors, analogies, illustrations, examples, in class activities and homework assignments....
>
> ...We begin with the idea that a teacher holds a specific, favored representation of particular ideas for her own purposes. In the course of becoming a fine teacher, she further develops the capacity to introduce variations on the schema, alternative representations of the subject matter. These representations are alternative for both the teacher and the students: the teacher actively creates multiple representations; the learners, in turn, are stimulated to invent their own as they experience the representational activity of the teacher. We use the general term 'transformation' to designate the set of activities engaged by the teacher to move from her own comprehension of a matter, and the representations most useful for that understanding, to the variations of

> the representation, narrative, example, or association likely to initiate understanding on the parts of students. As students are multiple, so representations must be various. As the multiplicity of connections renders understanding more durable and rich, so the range of variations produced by the transformations is argued, in principle, to be a virtue. Hence, teachers should possess a 'representational repertoire' for the subject matter they teach. And, as the representational repertoire grows, it may enrich or extend the teacher's subject matter *per se.*

Further, they propose that the generation and transformation of the representational repertoire is a cyclic process. Starting with a comprehension of a subject matter, the teacher transforms it to a representation for instruction by making critical interpretations and adaptations appropriate for the students. Following the instruction, evaluation of the effectiveness of the representation and reflection on the process leads to a new comprehension of the subject matter that is available for the next instructional event.

Along similar lines, Gess and Lederman (1991) followed ten preservice biology teachers through their final year of preparation to assess the content and stability of their knowledge structures of biology. The data suggest that these knowledge structures are extremely fragile and are strengthened by the opportunity to think about teaching the subject matter. They suggest that courses in science teaching methods should offer ways to study the subject matter that lead future teachers to reflect on the structure of the knowledge.

Tutoring as a Model of Teaching

There are several different approaches to teaching. For most of the past century much formal teaching has occurred in classrooms with one adult teacher directing the learning of several children. Joyce and Weil (1980) offer a brief description of probably every type of conventional teaching with the presentation and description of about 25 models. Perusing their book exposes one to the complexity of the subject and reminds the reader of the difficulty of making general statements about such a varied behaviour as teaching. One ideal model of teaching is individualised teaching through Socratic dialogue between a knowledgable instructor and a novice student. A strong case can be made for a return to this approach by citing literature from many sources regarding differences between individuals and their development across a wide range of variables, such as learning styles, experience, memory, intelligence scores etc.. Thomas (1992) presents an interesting survey of the arguments for individualising education and makes a point of improving our knowledge about it through more research. Studying individualised teaching also involves less complexity than studying teaching in a classroom environment where there is a multitude of variables influencing the transitions and transformations of teachers' knowledge structures.

There is a number of strategies that have been organized to provide individualised instruction, including programmed instruction, audio-tutorial systems, and structural communications. The recent trend of developing collaborative learning activities in the classroom is aimed at providing more feedback to the individual student through the conversations with peers. Brown and Palinscar created the concept of reciprocal teaching to improve reading skills in young students. In this scheme, the role of teacher is traded back and forth between two students reading the same text together. The students attempt to predict what will come next, summarize the content, generate questions for each other about the text and clarify concepts. Their studies have demonstrated improvements in understanding and comprehension in students employing this strategy (Brown & Palinscar, 1982, 1984; Palinscar & Brown, 1986). Rosenshine and Meister (1994) review sixteen studies of reciprocal teaching that generally provide support for the hypothesis that there are benefits for students using this approach.

Tutoring is a more common approach to individualised instruction. Here there are generally two individuals working together with the goal of mastering the subject matter. This process has often focused on students who were having difficulty with a subject matter as tutee, while the more experienced individual acts as the tutor. Teachers and other adults, parents, neighbours, friends and relatives such as older siblings have also provided tutoring formally or informally. However, since antiquity, students have helped other students, and today, this is commonly known as peer tutoring. In peer tutoring, the two individuals usually have the same relative social or developmental status but may be of different ages. There are many different formal approaches to the establishment of peer tutoring programs and some of these are reviewed by Frey and Reigeluth (1986). Also, there have been a substantial number of inquiries into the relative effectiveness of tutoring programs from both the vantage point of the tutee and that of the tutor.

Who Benefits from Tutoring?

Since often the intent of tutoring is to assist a student who is having trouble mastering a subject matter, one would expect that there should be a benefit to the tutee. However, consistent with the theme that people learn things through teaching, there is also a benefit that accrues to the tutor.

Cohen, Kulik, and Kulik (1982) present a meta-analysis of 65 independent evaluations of school-based programs to demonstrate that tutored students perform better than the control students on examinations and also develop more positive attitudes toward the subject matter. In addition, these studies indicate that the students serving as the tutors also gain a better understanding of the subject matter and develop more positive attitudes towards the subject matter than their non-tutoring peers. Topping (1996) offers a review of the literature about the effectiveness of peer tutoring in higher eduction. This review also presents evidence that there are benefits to the tutor as well as the tutee. This author introduces studies by Hartman (1990) and Annis (1983) that demonstrate that just the preparation for peer tutoring enhances the learning of the tutor.

A research bulletin by Dillner (1971) reports on several studies of benefits from the tutoring process. While in most cases there are gains made by both the tutor and the tutee, there are also results that indicate that sometimes the tutors have benefitted with few benefits gained by the tutees. She provides evidence to show that tutors do not have to be highly trained or successful students to have an impact on a peer tutee or to benefit from the experience of tutoring.

Further support comes from the writing of Allen (1976) who describes some of the benefits that tutors obtain. In addition to improved understanding of the subject matter and test performance, he reports an improvement in over-all attitude towards school and social behaviour in children involved in a helping relationship with their peers. He explains these apparently beneficial effects of tutoring on the tutor as related to the adoption of the teacher role and the subsequent delegation of responsibility, increase in status, attention and rewards from adults, as well as respect from younger children and the increased understanding of another person's point of view on a subject.

Kerwin-Boudreau and Woodruff (1980) helped to establish a student-centred tutoring program at a Québec CEGEP (Collège d'Enseignement Général et Professionnel) that has served as a model for other peer tutoring programs at community colleges. An extensive study of the effectiveness of the program reveals that both the students acting as tutors and their peer tutees benefitted from the tutoring activity (Woodruff, 1984).

Annis (1983) investigated the processes and effects of peer tutoring in college students by arranging an experiment with five conditions. College students were asked to read an article about an historical event. Some students only read the article, while others were asked to prepare to teach other students about the subject matter content. At the end of the reading period, some of the subjects were asked to become tutors, and others were asked to be tutees. Five experimental groups were established: students who only read the text; students who read the article to teach, but did not teach; students who read and taught others; students who read and were taught; and students who were taught without reading the article. A short test was given to determine learning gains of each group. Annis found that test scores for students who were only taught were significantly lower, than those in other groups. Students who read and experienced teaching performed significantly better particularly in regard to questions testing for application, analysis, and synthesis. Annis speculates that the reading and teaching students became more involved in the subject matter.

More evidence that teaching produces learning in the teacher is provided by Whitman (1988). His title, *Peer teaching: to teach is to learn twice* continues to state this theme. This book is a review of research into the use of students as teachers in institutions of higher education. Peer teaching is used as a general term for students teaching other students. As such, he includes other approaches, such as the use of undergraduate student teaching assistants, with tutoring. In reviewing the benefits to the peer teacher he lists affective and cognitive benefits. Three of the latter are particularly salient to knowledge gains:

> (1) The teacher must review the material....(2) The teacher must organize the material to be presented....(3) To teach the subject, the teacher may need to seek out its basic structure and , in so doing, may gain a better understanding of it. (p. 5)

Goodlad has done extensive research into peer tutoring and his book written with Hirst (1989) is subtitled as "A Guide to Learning by Teaching". This book describes and documents the success of several approaches to peer tutoring. The authors propose that: "tutors have to reflect on what they have learned to be able to represent it to their tutees and thereby master it better."(p. 57) They also write that:

> Tutors should benefit from peer tutoring by:
>
> - developing their sense of personal adequacy.
> - finding meaningful use of the subject matter of their studies.
> - reinforcing their knowledge of fundamentals.
> - experiencing being productive.
> - developing insight into the teaching/learning process.

An interesting variation on the theme of peer teaching and tutoring was carried out by Assinder (1991). She set up a successful peer teaching situation to promote English language learning for students from diverse linguistic backgrounds who intended to continue on to post secondary education. The small class was split into two groups and each group was given a videotape from which they prepared a lesson for the other group focusing on language skills and vocabulary. Each group then took the teaching role while the other adopted the student role. She reports learning gains accompanied by an increase in positive attitudes in the teaching group.

Additional evidence that there is a benefit to the tutor in a peer tutoring program is provided by several other studies and only a few are mentioned here. Franca, Kerr, Reitz, and Lambert (1990) found that junior high school students with behavioral problems showed improved scores on achievement tests as well as improved attitude and social interaction when involved in a peer tutoring situation. Guskey (1980), discusses the use of peer tutoring to promote mastery learning and bring about greater individualised learning in a typical classroom situation. Peer involvement in language learning is discussed by Gaies (1985) as a way to increase individualisation, intensify drill and practice and increase communication opportunities. He also points out potential socio-affective benefits that result from this strategy. Berliner and Casanova (1990) present a case for establishing peer tutoring within classrooms to promote the active participation of students in their school work. Their case is based on a more detailed study by Greenwood, Delquadri, and Hall (1989). Ellson (1986) gives examples of several successful tutoring programmes in a survey of ways to improve the productivity and quality of teaching. Semb, Ellis and Araujo (1993) also found benefits to tutors, and particularly found that in a study of long term memory that tutors retained more over a four month period than the tutees they had tutored.

Magin and Churches (1995) contribute a case study of the use of peer tutors to introduce students in a second year mechanical engineering course to a computer-aided design software package. Eighty-four percent of the tutors claimed that their tutoring experience had helped them to develop a deeper understanding of their own work. Seventy-seven percent considered that the opportunity to tutor another student had been worth the time involved. The authors did not carry out an evaluation to study the changes in knowledge in the tutors. Parker and Sharpe (1995) write about the benefits acquired by athletes on a college basketball team through the use of an adaptation of peer tutoring as a coaching strategy.

Reciprocal tutoring employs a changing of roles from tutor to tutee similar to that described above as reciprocal teaching. Gartner and Riessman (1994) add more support for having students teach each other in a report on a reciprocal tutoring program in a New York City high school. The students in this program showed improved achievement over those in conventional tutoring situations. Griffin and Griffin (1997) studied the effects of reciprocal peer tutoring on graduate students in an introductory course on educational research. Although their experiments indicate that the students involved in the tutoring performed at about the same level as those in the control group on tests of content, the tutoring students perceived the program as beneficial.

Donald Kingsbury (personal communication. February, 1993) while at McGill University established an interesting approach to providing students with a teaching experience. By pairing students into tutorial dyads. Kingsbury established small learning units within the larger lecture section and called each of these a learning cell. The learning cells operated in two different ways. In one mode, the individuals each read or worked with the same course content material and composed questions to pose to the other member of the team. In the other mode. each member of the dyad read different material and then taught it to the other student. Both of these modes of operation were successful in stimulating students to become more involved in their work and in developing a deeper understanding of the subject matter. Goldschmid subsequently applied this strategy to large lecture sections in psychology. and documents the success of this technique as an effective teaching method and indicates the benefits accruing to the teaching partner as well as the learner partner (Goldschmid. 1970. Goldschmid. 1971. Goldschmid. B. & Goldschmid. 1976).

A similar variation of peer tutoring is proposed by Thiagarajan (1973). Based on the reported gains that tutors make when involved in tutoring, he established a system that combined peer teaching and testing. Each student does three things for each unit in the course. First. the student learns the content from a peer tutor and passes a test administered and scored by a peer-tester. Second, the student becomes a peer-tutor and teaches another student about the content. This student is then tested by a peer-tester. Finally, the student becomes a peer-tester and tests other students on their mastery of the subject matter. Thiagarajan reports success with this method with high school students in India and college students in the United States.

It should also be noted that there are no studies in the literature reviewed that report any indications of harm or deleterious effects from student participation in peer tutoring situations.

CONSTRUCTIVIST VIEWS OF LEARNING

In order to explain how the activity of teaching may in itself produce learning in the individual doing the teaching, it is useful to consider a philosophical interpretation of knowledge and theories of learning related to it. There are several approaches to the study of learning that might be applied to this problem. However, a philosophy and learning theory currently driving research and development in the area of science education is constructivism. From this perspective, knowledge is believed to be built up internally in the knowing individual. Obviously, this implies an active process in which the student builds up an understanding of experience through an interaction with the environment. It also implies a continual change in the individual's personal knowledge as new experiences are integrated with previous ones. This internalizing of experience is explained by some as the construction of an internal representation of the environment. There is also a social dimension to the construction of the knowledge as it occurs through the interaction with an environment that includes other individuals and is most often conducted using language in humans. Constructivism also provides explanations that help to bridge the gap between biological enquiry into brain function and other philosophical explanations. As pointed out by Tobin (1993), constructivism is not a new theory that replaces objectivism, but rather is a way of thinking about knowing that allows for building models of learning and teaching. Kant, Piaget, Pask, von Glaserfeld, Bruner, Maturana and Varela have contributed to this view of knowledge and its development as well.

Jones, Knuth, and Baxendale (1993) state that

> The design of instruction that results in meaningful learning must be based on learning research. Otherwise, instruction becomes a trial and error affair or worse, retains the status quo of teacher delivery, instructional strategies, and teacher-student and peer-peer relationships. Learning research can be divided into two major categories: research about the learning process, that is, about the factors that are involved when learning occurs. In general, these can be discussed in terms of cognitive, metacognitive, affective and social theories. The other area is concerned with views, or metaphors, about the learner. In other words how do we conceptualize the learner? This includes perspectives from cognitive, philosophical, and metacognitive views in addition to new ideas about intelligence, brain research and aptitudes. (p. 315).

Their paper then provides a brief review of learning process research from cognitive, metacognitive, affective and social perspectives as well as a summary of research about the nature of the learner. They list five assumptions that have influenced the development of cognitive learning models:

> (1) learning is seen as an active, constructive, goal oriented process; (2) higher level processes which monitor and control learning play an important role in learning; (3) learners bring prior knowledge to bear on the learning task; (4) knowledge takes the form of cognitive representations; and (5) the analysis of tasks and performance leads to an understanding of cognitive processes. (p. 321)

These assumptions are similar to those of the constructivist approach to learning. Robertson (1994) provides a concise review of the literature of constructivist learning theory. He describes the theory as based on two principles, as stated by von Glaserfeld. One, that knowledge is not something passively received but is actively built up by the cognising individual; and two, that cognition helps the individual to organize experience and consequently to improve on the ability to adapt within the environment. The implication of this theory is that there is an interaction occurring within the individual between the previously constructed knowledge and the new material that is being presented to the learner. The way that the new material is received and interpreted is dependent upon the previously constructed knowledge structure and the way new concepts relate to this. In this regard the constructivist view of learning is consistent with the learning theory presented by Ausubel (1968) and promoted by Novak and Gowan in 1984. Although it appears that radical constructivism, as presented by von Glaserfeld, denies the existence of an objective reality existing separately from the cognising individual, the theory describes how that individual comes to understand his/her interactions with the environment. Several other authors have advanced less radical constructivist views about learning. Bartlett (1932) in work on memory proposed a theory based on a construction and reconstruction of the incidents being remembered. Much of his theory was based on qualitative observations of subjects reporting on their recall of short stories that were read and then reported upon immediately and after a delay. Bartlett was interested in how these stories changed over time and how other experiences interfered with the recall of them. A short review of Bartlett's experiments is provided by diSibio (1982).

Piaget studied the phenomena associated with learning and knowing from a developmental perspective, but his investigations and observations may now be interpreted to show that he had a liberal constructivist view. Summaries of these interpretations of Piaget's works are provided by Bodner (1986), Fosnot (1993) and Smith (1993). Bodner argues that: "Piaget was the first constructivist in the sense that his view that knowledge was constructed in the mind of the learner was based on research on how children acquire knowledge." (p. 874) He writes further:

> Piaget believed that knowledge is acquired as the result of a life-long constructive process in which we try to organize, structure, and restructure our experiences in light of existing schemes of thought, and thereby gradually modify and expand these schemes. Indeed his definition of knowledge as "invariance under transformation" has no meaning outside of the constructivist perspective. Piaget argued that objects appear "permanent" or "invariant" as a result of the individual's coordination of experiential data and the subsequent projection of these coordinations onto the world that lies beyond our senses. (p. 874)

Osborne and Wittrock (1983) proposed a generative theory of learning for science education in which the student must actively construct meaning in order to learn with understanding. Wittrock (1990) further describes this approach to learning:

> The essence of the generative learning model is that the mind, or the brain, is not a passive consumer of information. Instead, it actively constructs its own interpretations of information and draws inferences from them. People ignore some information and selectively attend to other information....Generation is a fundamental cognitive process in comprehension....generation is a process of constructing relations that contributes to comprehension and that can occur in reception learning and discovery learning, in laboratories and in lectures. (p. 349)
>
> ...To comprehend what we are taught verbally, or what we read, or what we find out by watching a demonstration or doing an experiment, we must invent a model or explanation for it that organizes the information selected from the experience in a way that makes sense to us, that fits our logic, or real world experiences, or both. People retrieve information from long-term memory and use their information processing strategies to generate meaning from incoming information, to organize it, to code it and to store it in long-term memory. (Osborne and Wittrock, 1983, p. 493)

A major contributor to the constructivist view is von Glasersfeld (1988, 1989, 1991 and von Glasersfeld and Steffe, 1991). He criticizes the concept of knowledge as a commodity and communication as a conveyance for it. He also proposes that knowledge and competence are products of our individual experience and are constructed as we try to make sense or understand the world. This sense-making or building of an understanding is a reflective process that also provides motivation and a self-generated reward for a cognising organism. The teacher's role is to guide the student in the organization of this experience. In his opinion, the teacher should have an adequate view of where the student is at the beginning and an adequate idea of the destination or result of the process. These may be considered as two models of the student: a model of his/her beginning state and a model of the student after instruction. The latter model may be considered as similar to a model of the expert's knowledge on the topic. In general, the ideas of von Glaserfeld are consistent with those of Piaget.

The constructivist approach to learning and the development of knowledge is consistent with the ideas of Maturana (1980), and Varela, Thompson and Rosch (1991), who have made links between biology and cognition. Their focus is on how cognition and the development of knowledge contribute to the autopoiesis (self-organisation) and adaptation of the individual organism surviving in a dynamic environment. Young (1987) also makes interesting links between neurological research and philosophy. Churchland (1995) integrates philosophy with recent advances in brain research and cognitive science to propose mechanisms of how the brain provides a way to internally represent the world.

Hendry and King (1994) provide an interesting synthesis of constructivist views of learning with advances in the field of neuroscience. They consider that knowledge is a spatio-temporal pattern of nerve impulses in our cerebral cortex, and provide a short summary of the evidence to support this claim. Edelman (1992) and Damasio (1994) each provide biologically-based theories of how the interaction of experience might influence central nervous system development and the consequent development of memory and personal knowledge. The details of these ideas belong to the domain of neuroscience and are consequently beyond the scope of the current project. However. Hendry and King discuss implications of their theory for education. and establish requirements for the development of these patterns of neural impulses that are similar to those provided by von Glasersfeld for the construction of knowledge. They point out the need to establish the current knowledge and ideas of the student prior to instruction in order to develop effective learning experiences. They recommend using teaching strategies that promote discussion in order to maximize a student's opportunity for knowledge construction. and they recommend the use of tests that require explanations of phenomena rather than the recall of specific knowledge items to demonstrate the development of understanding.

Yarusso (1992) raises the issue of the relationship of constructivism to that of objectivism. Carried to its extreme. radical constructivism implies a relativity of knowledge as it is constructed within the cognising individual. This initially seems at odds with concepts of scientific knowledge that have been established using a positivist-empiricist or realist view of knowledge. This problem can be resolved by applying the constructivist approach to descriptions of the nature of scientific knowledge. Driver and others (1994) summarize this concisely in their essay on developing a constructivist approach to classroom teaching. They posit that scientific knowledge is both partly symbolic and largely socially negotiated. To this end, they describe the concepts used to model and/or describe the various domains of scientific knowledge as constructs that have been invented and imposed on the observed phenomena in attempts to interpret and explain them. These constructs are named, written down and, if coherent, become the way of interpreting the natural world within the scientific community. As such, these may then be considered as the public knowledge of science, and are communicated through the culture of science. Although this appears to provide a relativist view of knowledge, Driver and her colleagues consider that "scientific knowledge is constrained by how the world is and that scientific progress has an empirical basis, even though it is socially constructed and validated". Giere (1979, 1988) advances a similar view of how scientific knowledge is constructed and reconstructed as further discoveries are made. This view is also supported by Bruffee (1993). For Driver, *et al.*, learning science involves being initiated into the ideas and practices of the scientific community and making these practices meaningful at the individual level. They point out the frequent conflict between scientific ideas and explanations of phenomena, and those generated by everyday or commonsense interactions. While they do not spell out pedagogical rules for teaching science, they emphasize the importance for students to have the opportunity for discussion and negotiation with a subject matter authority in the development of scientific knowledge.

Saunders (1992) discusses the implications of the constructivist approach for science education:

> Science learning is the acquisition of meaning, not the mere rote memorization of information, but rather cognitive restructuring in a direction such that one's internal world is more consistent with one's empirical data about the external world. Such restructuring clearly implies that learners need abundant sensory experiences with their external world and opportunities for reducing disequilibration [reconciling the conflict between prediction and observation]. What are important features of effective science programs in light of the constructivist perspective?...(p. 138)
>
> ...the ample use of hands-on investigative laboratory activities, a classroom environment which provides learners with a high degree of active cognitive involvement, use of cooperative learning strategies and the inclusion of test items which activate higher level cognitive processes. (p. 140)

An experimental test of the constructivist approach to science teaching was arranged by Lord (1997). Using two different sections of an introductory college biology class, he exposed one group to the course content using a constructivist approach that involved lecture and laboratory activities similar to those described above by Saunders. Lord presented the course content to the other section in the traditional teacher centred lecture format. When the students were assessed by the same examinations, he found that those students in the section with the constructivist approach achieved significantly higher test scores than those students taught in the traditional manner. This experiment is similar to many cited in the literature to provide evidence that students benefit from instruction designed based on the constructivist view of learning.

While the constructivist view of learning has gained popularity within the science teaching community, there are difficulties to the direct application of this theory to the design of instructional events. Airasian and Walsh (1997) point out some cautions in the use of the theory. In particular, they advise their readers to avoid confusing the constructivist approach as an epistemology of learning with an instructional method. They remind them that students construct their own knowledge and meanings regardless of the instructional technique employed. As a consequence, teachers and instructional planners should be more concerned with the concepts, facts, information and issues that they want their students to construct meaning about. In addition, they warn of some of the difficulties in evaluating the outcomes of constructivist instructional strategies. They urge teachers to face the problems of determining the relative truthfulness of students constructions and their actual meanings to those students. They add the important point that: "The role of the teacher is to challenge students to justify and refine their constructions in order to strengthen them."

Another author offering a critique of the application of constructivism to science education is Osborne (1996). He is also concerned with the apparent relativism in the construction of knowledge and consequent possible misrepresentation of the process and product of science. Although Osborne advocates another approach to the teaching of science based on realism, he does point out the contribution of the constructivists to moving beyond didacticism. He finds value in the constructivist focus on the learner as an active participant in the learning process. He likes the range of pedagogical innovations that encourage active learning and the large body of research that reveals the forms of scientific thought found in children. His caution is particularly aimed at avoiding the confusion of constructivism as an epistemology that describes how an individual knows about a topic with the general epistemology of science.

Perhaps the effectiveness of a tutor-tutee situation can be explained in part by the epistemology of the constructivist philosophy. Through the establishment of a dynamic discussion in which several events are occurring, one finds those events necessary for the cultivation or construction of knowledge within an individual. Both the tutor and the tutee present explanations of the subject matter, pose questions to each other, and evaluate the explanations and answers in terms of their own internally constructed knowledge and the knowledge provided by external sources such as a course teacher or textbook. This process involves a strong motivation in the tutoring individual to carefully examine the subject matter content, as previously constructed internally and/or as presented in the available materials such as a textbook. The relatively immediate feedback from another individual prompts each of the individuals to become active and more responsible for the construction and evaluation of his/her own knowledge. Inadvertently, the tutor is constructing and reconstructing his/her own personal knowledge through the process. As this happens, the necessary links are made to other previously developed knowledge, long term memory of the topics is improved, and the tutor actually becomes more secure in his/her knowledge of the subject matter. Subsequent testing of the tutor for subject matter competence should then produce better quality answers than might have been received through other study techniques.

SYSTEMS, CYBERNETICS, MODELS AND INSTRUCTION

The previous evidence presented supports the premise that students can improve their knowledge and understanding of a subject matter through tutoring and justifies further investigation of the tutoring-learning process. Based on this rationale, the central problem of this project was to elaborate a development oriented model of the tutoring-learning process and to test the feasibility of using this model through its application to an instructional situation.

There were several dimensions to the solution of this problem. First of all it was an instructional problem, and, considering that instruction is a planned intervention into the learning process of one individual by another, it was important to establish the goals and objectives of such intervention. Further, fundamental to educational technology is the view that instructional events or activities occur as part of a system, and that a systemic view must be taken in the design and development of instruction.

Ackoff (1971) defines a system as "an entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set." A system, in this sense, has attributes that result from these elements and the relation between them that is different from the attributes of the elements when taken by themselves. An opening step, therefore, in the application of a systems approach to the study of instruction is to identify the elements of the instructional system and the relationships among them. In addition to the key elements of the system, there may be important flows of information that provide for communication between the elements of the system. Some of the communication is directed at the learner to direct him or her to the learning activities. Other information serves to guide the development of the student's learning through feedback that serves to control the behaviour of both the instructor and the learner.

Cybernetics

Cybernetics may be defined as the science of communication and control. It is directed to the study of dynamic systems and how the flow of information controls their processes. To accomplish this end, cyberneticists attempt to model or artificially simulate the system under study. They may use mathematics to quantify data about the system in order to draw conclusions about how it works. Applying cybernetic methods is an iterative process in which models of the system under study are built, tested, revised or refined, and tested again. Classical cybernetics, or first-order cybernetics was particularly concerned with the study of homeostatic systems, those that attempt to maintain a constant situation under changing conditions. This type of system must be able to change to suit the new conditions while limiting the degree of structural change within itself. An application of first-order cybernetics is in the development of computer controlled mechanical systems such as robots or navigation systems. The study of the physiology of animals and plants provides other examples of how a cybernetic approach might be used. If internal change could not occur, a body would fail to adapt and thus be unable to persist in a changing environment. If external change occurs so rapidly that the body cannot adjust to it, the consequence is usually disastrous. Effectively, the nervous system, through the rapid flow of information, controls change within the animal body and maintains a steady state or homeostasis (Bung & Lansky, 1978).

Bung and Lansky continue their introduction to educational cybernetics with a rationale for its application to educational problems and provide examples of cybernetic studies of education. Boyd (1977, 1981) also provides a rationale for using cybernetics in the study of education, while Talyzina (1973) provides a rationale for using cybernetics in the planning and design of programmed instruction. The proposed study of the tutoring-learning process will follow a cybernetic approach in the development of a model and the use of simulations to test it. The use of this approach will also serve to integrate the concept of mental models, constructivist theories of learning, and Pask's conversation theory.

Models

Cybernetics requires model building and model testing. Models are representations of a reality. As such they are not necessarily strictly, accurate copies of the reality. A model may be simplified or abbreviated as in the case of the model instructional system proposed above. It may conveniently leave out variables or aspects of the reality to emphasize or call attention to others. There are several types of model. Scale models copy an original to some degree of reality and are generally thought of as physical entities in themselves. In planning a new building, architects develop a set of models of the place as scale drawings on paper. These may be converted to a three dimensional model that helps the owner visualize the building and its setting. These models are clearly not the reality and are missing attributes of the real building. However, they can be tested for a coherence with the original by measurements and direct observation. Mathematical models are more abstract models. A budget can be considered as a model of how money is to be spent by an individual or organization. The financial statement that follows the planned budget is a model of what happened and these two may be compared to determine their coherence. It is also possible to model a skill. An individual can get on a bicycle and ride along the street to show that it can be done. Conceptual modelling is more abstract. It is difficult to build models of concepts such as justice or peace, although we can build models of situations that illustrate the concepts or the lack of them. Pask (1975a, p 13) describes cybernetics in terms of the testing for isomorphism between models in order to determine the degree of coherence. Conant and Ashby (1970) established the importance of models to cybernetics in stating that a controller must have a model of the system that it controls. This is particularly true for feed-forward adaptive controllers.

Modelling Knowledge

Knowledge has a particularly evasive nature. One knows about certain subjects, or ways of doing certain activities, or even how to find out about something. However, it is difficult to actually define and/or measure what knowledge is, determine where it resides, or describe how it is internally stored. It is useful, then, to think of two categories of knowledge, private knowledge, internal to an individual, and public knowledge that is external and can be shared among individuals. The latter may be thought of as materialized or objectified into something quite tangible. In this process, the private knowledge of the individual is encoded into a set of signs and/or symbols that can be understood by another individual. It can then be said that the knowledge of the first person has been represented by the symbols and it is in the symbolic form that knowledge can be structured, manipulated and organized for transmission to another person. After it is received by the second person, it is translated from the symbolic to produce meaning. Since education is involved with the transmission of knowledge from one person to another, some of the issues of how knowledge can be represented are interesting to an educational technologist.

Mitchell (1982) takes the view that knowledge may be considered as a system. That is to say that for any particular subject matter there are concepts, procedures, criteria etc. which are organized such that meaningful relationships can be established among them. Thus, Mitchell advocates the building of models, that indicate the relationships among these various parts of the knowledge structure of a subject, as a part of the instructional design process. This, he points out in a later article (1988) is more than the elaboration of the behavioral objectives for a lesson or course. The modelling process should precede writing of behaviourial objectives and they should flow from it. In the same article, Mitchell also presents the possible view of learning as a conceptual modelling process, with the learner building his own representation of the subject matter as he participates in learning activities. Evaluation of learning can then be done by comparing the student's representation of a subject with that of the instructor. This comparison should then be the basis for feedback to both parties. Another benefit of subject matter modelling described by Mitchell (1982) is the establishment of multiple routes through any knowledge structure and the consequent variety of outcomes. This he sees as invaluable in the design of individualised instruction. Good (1987) lends further support to the use of modelling of subject matters by students, and instructors in applying artificial intelligence to instructional systems for science education.

Mental Models

A theory of mental processes has been advanced that uses models to explain the behaviour of people and, in fact, other animals. This theory proposes that the individual often behaves as if he/she has an internal model of the situation. Based on this model, the person makes judgements and decisions that are reflected in their outwardly observable behaviours. One of the best ways of illustrating this phenomenon to another person is to ask that person to count the number of windows in his/her childhood home. After a few seconds, the processes is interrupted by the question: are you inside the house or outside? If you are inside what room are you in? what colour is it painted? If you are outside, what side of the house are you looking at? what colour is it painted?

One theory of mental models is probably derived from proposals made by Craik (1943) who hypothesized that as processors of information human beings make use of three distinct processes:

1. There is a translation of external processes into an internal representation in terms of words, numbers, and other symbols.
2. It is possible to derive other symbols from these by an inferential process.
3. There is a re-translation of these symbols into actions, or at least a recognition of the correspondence between these symbols and external events.

He also wrote:

> ...If the organism carries a "small scale model" of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, and in every way to react in a much fuller, safer, and more competent manner to the emergencies which face it (Craik, 1943, p. 61).

Johnson-Laird (1983) took up the work of Craik and advances the explanation of mental functioning through the use of the concept of a mental model. He provides numerous examples of the building of models from which judgements are made and how various concepts may be represented internally. Johnson-Laird particularly uses the notion of mental models in studying the way that words are used in discourse. This approach to discourse analysis is further described and utilised by Garnham (1987).

Gentner and Stevens (1983) and Norman (1983) also consider the concept of a mental model and describe it as an evolving or developing internal representation of an environment with which a human is interacting. For these authors, mental models provide a basis for both the prediction and explanation of the interactivity. In their view, the mental model of any given situation is essentially unstable and incomplete, but through the interaction with the target system, which is modelled mentally, the model is revised and reconstructed to become more compatible with the reality of the situation.

Jih and Reeves (1992) also provide an outline of a theory and definition of the concept of mental models and advocate its application to the study of human-computer interaction in computer-based learning systems.

A further revision of the concept of mental models comes from Reingold (1985):

> "Collections of facts, memories, perceptions, images, associations, predictions, and prejudices are the ingredients in our mental models, and in that sense, mental models are as individual as the people who formulate them. This essential privacy and variability of the models we construct in our heads create the need to make external versions that can be perceived and agreed upon by others. Because society, a collective entity, distrusts the modelling done by only one mind, it insists that people agree about models before the models can be accepted as fact.
>
> The process of communication, therefore, is a process of externalizing mental models. Spoken language, the written word, numbers, and the medium of printing were all significant advances in the human ability to externalize and agree upon models. Each of these developments, in their turn, transformed human culture and increased our collective control over our environment. (p. 215).

Mental Models and Instruction

The theory of mental models has multiple uses in the study of the phenomena that surround education and the more specific activities of instruction. However, the concept of a mental model shall be considered as only a metaphor for the processes by which the central nervous system and the body represents experience and controls behaviour. By assuming, then, that a person grows an internal model of a situation, it is possible to consider an instructional system as a cybernetic system that guides the growth and dissolution of mental models. Although the model is internal to the individual, it can be used by that individual as a basis for outwardly observable behaviour that allows another individual to make inferences about the current state of the mental model and offer suggestions for its revision, modification or annihilation.

This has several implications for the design of instructional systems. Firstly, it makes it possible to define rather precisely the behaviours that should be observed if an individual has a mental model of a situation. As examples, the person with a mental model of the topic can:

- build an external model of the topic based on the mental model or describe the topic represented by the mental model.
- describe the internal mental model externally through the use of language or symbols.
- create analogies and metaphors by linking the focal model with other mental models and then reporting on these through the use of langauge or symbols.
- use the mental model to answer appropriate questions about the topic (Who, what, why, where, when?).
- make predictions based on the model and recognize whether these are valid or invalid.
- recognize misconceptions and false models of the situation.
- teach the model to another.
- question the validity of the mental model or test it against that of another individual or particularly that of an authority on the subject matter concerned.

It follows that one individual's mental model for a topic might or should be largely consistent with that of another individual, and thus, the overt behaviours listed above should also be consistent among individuals with similar mental models. This means that, since measures of coherence between behaviours may be established, the degree of coherence of the mental models behind them may be inferred. When there are discrepancies between the behaviours, one can infer that the mental models differ in some way. This makes it possible to determine the nature of the discrepancies, and/or what is preventing the individual from performing at the level defined/described above. Based on this information, one individual, usually the instructor, can suggest or prescribe corrective actions. It is therefore important to develop precise tests that can be used to measure and compare behaviours. The possibility of the interaction of other factors such as motivation, intentions, and distractions are disregarded here for the sake of simplicity.

Another feature of the theory as it applies to education is to consider that the mental models of complex subject matters are built of smaller elements that are in themselves mental models. These can then be described as prerequisites to having a fairly complete model of the topic. Diagnostic procedures can be carried out to determine if these models exist and remedial action can be taken to guide their development. For example, the mental model for the anatomy of the human body should include mental models of the various systems, i.e., the circulatory system and the digestive system. The mental model of the digestive system will then have to include models of the stomach and intestines. The extent of detail within such mental models will also vary. We would expect a medical doctor to have more detailed models of the human body than a designer of highways.

From a cybernetic perspective the concept of the mental model can be used as a basis of control in the study of a teaching-learning system. If the purpose of the teaching system is to communicate the mental model of the teacher to the learner, and, if as the learner builds and/or revises a mental model the behaviours described above should be observable and measurable, then criteria can be set to determine the degree of coherence between the teacher's mental model and that of the learner. Consequently, feedback from control mechanisms can flow to both the teacher and the learner to determine subsequent action.

Finally, it is necessary to consider that the process of building mental models is an iterative process. A model must be built, tested against the reality or the expert's model, and remodelled until adequate coherence is reached. Application of this theory to educational and instructional situations requires that there be opportunities for formative evaluation and mastery learning of subject matters in an educational situation. Adding this opportunity to an educational situation may also be instrumental in moving students from a passive approach to their learning to a more active participatory approach. Constructivist learning theory when combined with a theory of mental models provides an explanation for how these models may be developed, explored and revised during and through instruction.

CONVERSATION THEORY

Conversation Theory is the result of several decades of investigation into the communications occurring within a variety of learning systems by Gordon Pask and his associates. In studying the educational process, Pask applied a cybernetic approach, and noticed a parallel process to those occurring in a conversation. As a simple case, if one listens to any conversation, such as a street corner conversation about the weather, one can detect four aspects or components. Conversations take place between *participants* about a *topic* using exchanges in a *language* and generate *agreements*. Disagreements and distinctions may be seen as qualities of agreements.

Pask started to investigate human learning in his early work and sowed the seeds for what became conversation theory in the sixth chapter of a short book about cybernetics published in 1961. Pask considered the conversation as the basic unit of psychological observation and therefore saw it as an especially valuable unit to use in studying aspects of human learning (1976a, p. 3). A way of interpreting Pask's work is to observe conversations as modelling and model testing sessions. Using this approach one participant in a conversation offers a model of the topic and the other may agree, disagree, or add to the model proposed. Pask also proposed a scheme for explaining the model building and testing processes occurring within an individual, as well as those occurring among participants. True to his role as a cybernetician, he produced a variety of models of the educational conversation, some of which were expressed mathematically. He also developed several teaching devices and systems, such as Thoughtsticker and his Course Assembly System and Tutorial Environment (CASTE) to test and validate his models through simulation.

Components of a Conversation

Language and Protolanguage:

That a conversation must occur in language seems a fairly obvious statement. For Pask, language could be an oral and verbal language or a written symbolic language. Bodily movements, signs and signals also count as language. A mime acting out a particular situation is expressing himself in his bodily movements and is sending messages to the audience. Language is often metaphorical and allows the construction of analogies and allegories. A non-response must also be considered as part of the language signalling system. The language for a conversation provides for the flow of information among the other elements within the conversational system. This is the sending of signals or messages. In his study of the language aspect of conversations, Pask hypothesized that there is an underlying structure to conversational language that he termed the protologic that provides a useful manipulative power. This allows the language to support commands, questions, persuasions, obedience, answers, stories or accounts of a situation. Pask also hypothesized the existence of a primitive or protolanguage, based on the protologic that among other things allows an external observer to record and comment on the processes occurring within the conversation under observation. The human seems both to create an internal description of the world using language and to externalize this representation through the use of metaphors and analogies in language. From this perspective, language may be considered as a building set from which an individual constructs the models presented in a conversation.

Topics:

In a general conversation, the subjects discussed may vary rapidly over time. A transcript of a street corner conversation may show how the conversation discussed the weather, the neighbours, the state of the village or the health of family members. The conversation drifts around several topics. To make a distinction between these informal conversations and those that provided basis for his studies, Pask defined the "strict conversation" (Pask, 1976a, p.4). In this case, the conversation is limited to an agreed upon subject matter and is kept on track by a defined structure. The conversation will focus on testing models of the concepts inherent to the subject matter and the relations between the participants are defined in an almost contractual way to avoid divergence.

The topics discussed in a "strict conversation" may be recorded and diagrammed out in a visual form called an entailment mesh. This knowledge representation shows the concepts important to the subject matter as nodes with the relations between concepts described by arcs connecting nodes. The entailment mesh or comments associated with it should also indicate what the participant must do to indicate an understanding of the concept at any given node. This is considered a task and may include a description or an illustration of the concept, an explanation of the situation to which the concept refers, or static or working models that demonstrates the concept. From observation of the entailment mesh, it should be possible to map out various routes to "drive through knowledge". In diagramming the subject matter, possibly illicit or inappropriate routes that indicate misconceptions can be made more explicit. Entailment meshes for strict educational conversations are developed by subject matter experts, but may be modified or enhanced through conversation between teacher and student participants.

Agreements:

Again, at the simple level of the street corner conversation, agreements occur between the participants to assure themselves that they are discussing the same topics and that their descriptors have common meaning. In a conversation about a snow storm a skier and a non-skier may each describe the snowfall as nice. The non-skier may see it as a pretty sight; the skier may be anticipating a trip to the hills. To each the word nice implies something different and as the conversation continues this distinction may become obvious to each other or it may remain elusive.

Agreements in conversation theory are related to the understanding that may occur between participants. In a strict conversation, evidence of understanding must be present to establish that agreement exists between the participants. This evidence is two fold: first, one participant must describe the concept being tested to the other in similar terms and second must also demonstrate an appropriate use of the concept. The first aspect is normally accomplished by the use of verbal analogies that call upon concepts already assumed to be in the repertoire of each participant and about which agreement has been reached. The second aspect may be accomplished in a variety of ways, again in the form of the observable behaviour, including a physical modelling of the concept or the selection of exemplars. The appropriate use of a concept must also summarize the relationship of the concept with other concepts in the subject matter domain (Pask, 1976b p.14).

Two participants may disagree on the use of a concept but by their agreement to disagree, each individual has demonstrated to the satisfaction of the other participant how the concept is being used in this conversational exchange. In some cases, agreements to disagree are more meaningful than clear agreements would be. This is a particularly valuable aspect of teaching-learning conversations where novel points of view are being elaborated by each of the participants.

Pask designed a number of pieces of electrical equipment to record the agreements between conversational participants. These were produced in an era that predated the microcomputer and today the computers can be programmed to do this type of recording. The record of the agreements collected by a study of strict conversations provides data to indicate a relative degree of agreement about the meaning of a concept or set of concepts as they are used by the participants. A coherence index may then be calculated to compare these. Pask considered the accumulated coherence indices as the "hard data" of conversation theory.

Participants:

In a common conversation, the participants are generally people standing or sitting around speaking to one another in a common language embellished with body language or hand signals. The language supports the conveyance of information from one individual to another and the topics may vary widely. Pask described two types of individuals. There are m-individuals that are mechanical or biological entities that can be described in time and space. The human bodies seen talking to each other are both m-individuals. A computer engaged in information exchange with a human may also be considered as an m-individual. Although there are many aspects of the m-individual that can be studied and that can influence a conversational system, characteristics of m-individuals are not generally the concern of conversation theory. Rather, the integral participant of conversation theory is the psychological-individual or p-individual.

The p-individual does not have to have a physical or mechanically defined basis. The p-individual was defined by Pask as a self organizing system of concepts which is organizationally closed but informationally open. This implies that the p-individual can act on information impinging on itself, but it remains arranged in a particular way. Information can change the state of the p-individual, but only to the degree that it does not interfere in its plan of operations. This stability contributes to the development of permanently stable concepts that are difficult to change once formed. As well, Pask (1976c) identified two major learning styles, serialist and holist, that are inherent to the stability of the p-individual. He referred to this stability of concepts and learning style as cognitive fixity. It was surmised by Pask that there are a number of p-individuals that exist simultaneously in the brain of one m-individual human, and that different p-individuals may be called upon to perform different roles in different situations.

Pask's View of Learning

In order for learning to occur in Pask's terms, information transfer occurs and causes the development of new procedures for producing concepts. The presence of these concepts and the memories from which they are generated are tested by establishing an agreement or understanding as described above. The information transfer consequently reduces uncertainty or doubt about the topic and increases the probability of reaching an agreement on the understanding of a particular topic in the subject matter domain. Pask introduces the concept of the *coherence index* as a means of establishing an arithmetic value for the relative degree of agreement or understanding that exists between the conceptual structures of two conversational partners.

Thus, in an instructional situation, it is possible to assign a teacher and a student role to participants. Through the instructional conversation information is transferred to the student by the actions of the teacher. Most often the teacher also tests the student for understanding. The student has gained in capability by adding to his/her repertoire of concepts, and has also gained the confidence to use this new capability appropriately. After the instructional occasion, an interchange of dialogue between the two participants, the student is able to describe the concept and to use it effectively. An agreement could be noted and the student can move on to deal with another related concept in the subject matter domain. The teaching individual may also compute a value for a coherence index during each interchange. If the concept is truly understood, it should persist over time and interact with other concepts in such a way as to provide refinement or facilitate the acquisition of further concepts. It should be noted that the interaction may also interfere with the acquisition and use of new concepts.

As mentioned briefly above, Pask identified two distinct styles of learning that are embedded within p-individuals and these predispose an individual to adopt to a particular strategy when learning about new topics. The "holist strategy" refers to the way that some individuals need to see the whole picture or range of topics in a subject domain and build up their concepts and the relationships between concepts based on this global view of the domain. Other individuals, described as "serialists", build their knowledge in small step increments and have difficulty grasping the over all aspect of the domain.

The holist can establish many goals and working topics within an overall subject area. This type of learner can assimilate concepts from many subtopics almost simultaneously to acquire knowledge about the topic. Holists look for global descriptions and make generalizations readily. Amongst holists there are two categories: "redundant holists", that invent descriptions of the topic for themselves; and "irredundant holists" that are less descriptive and more apt to adopt given descriptors of the topic.

"Serialists", on the other hand, operate on a one goal at a time strategy. People of this type prefer to assimilate information by increments and adopt very little information from other topics in the subject matter. They are therefore limited in the view of the whole and have difficulty describing how each piece of learned information relates to the whole domain. They do not make generalizations that can be used to sort out information into categories, but are apt to learn rote information that has already been placed into categories for them. Their descriptions of a topic are narrower than those of the holist and their models of the subject are apt to be deficient to the degree that they do not see the relationships of the subtopics to the major topic.

Given a topic to study and a time for the task, serialists do not seem to learn as much about the topic as holists, although they may be able to provide more details about a few specific parts of the subject matter. It is important to keep this difference between individuals in mind in the design, implementation and evaluation of instruction and instructional materials. Pask (1976b) has demonstrated a significant decline in the effectiveness of instruction when there is a mismatch between an instructional strategy and the learning style of the participant. The above description of the work of Gordon Pask is a very abbreviated summary of many years of research and is based on several texts some of which have been cited. In addition, the reader is referred to other documents listed as Pask, 1969, 1972, 1975b, 1980 and 1984.

Tutorial Conversations and Teachback

Pask also observed in his studies of teaching and learning systems that the teaching participant is constantly improving his/her own capability and reducing levels of uncertainty about the topic. Pask hypothesized that the teacher is constantly refining his models of the subject matter as he presents information to the learner and evaluates the responses. The methods used to study conversation theory can make this observation more concrete and led Pask to propose that students teach in order to learn better. This can be realized through the process he named *teachback*. The student having established an agreement on understanding of a topic is asked to teach it to the teaching participant. This actually can lead to a third way by which agreement on understanding can be reached. If the student can teach the topic, he probably understands it. The concept of teachback and an example of how it was used may be found in a paper by Pask and Scott published in 1972.

Designing Educational Systems Based on Pask's Work

The paradigm of the educational conversation proposed by Pask provides support for the use of the "strict conversation" as a version of the Socratic dialogue as an ideal method of education. It also provides a methodology for studying instructional dialogue and consequently provides insights into producing automated systems to imitate it. The instructional system should be considered as a modelling environment where there are several models in use. The modelling opportunity must be extended to the student. These models should be tested against an expert model and the student should have the opportunity to remodel until there is coherence with the accepted model. This process would naturally lead to mastery learning of the subject matter. More effort must be put into developing methods for modelling concepts and complex subject matters.

Instructional designers should be working from several models. They should be modelling the subject matter with the advice of subject matter experts to produce refined models or knowledge representations of subject matters. Classroom teachers can also benefit from a modelling of their subjects. This exercise, when done with other teachers or subject matter experts, can be a great catalyst for serious conversations about a subject matter domain. New ideas for teaching and evaluation can be exchanged in such a session. Agreements among faculty teaching the same or related courses can come from such a process. The models can then be used for other phases in the instructional process: materials selection, production, and evaluation.

At the same time, the instructional designer needs to develop accurate models of the potential users. These models should include the prior knowledge and possible misconceptions of the student as well as the user's learning style. There is a need for very different instructional plans and materials for individuals of each style to assist in their improved assimilation of the subject matter.

Students need to have opportunities to teach. Pask's idea of *teachback* enhances learner outcomes. Students seem to organize their models of the subject matter through this process and they can remodel them through an interaction with a critical audience to refine personal concepts. Having students make class presentations is one way of providing this, but there is a need to incorporate student *teachback* into computer aided instruction.

Since the use of the Socratic dialogue between real students and teachers is difficult, if not impractical, there is a motivation to introduce simulated conversational instruction. Given the current state of computer technology, this is an almost impossible task. However, if Pask's work can be applied to the development of instructional systems that help human teachers furnish more individualised instruction and detailed feedback to students about their models of a subject matter, improved educational effectiveness may be realized.

ISSUES IN THE EVALUATION OF INTELLIGENT TUTORING SYSTEMS

Assessment and evaluation are essential aspects of instructional system design projects. As important as it is to establish the goals and objectives of a project, it is probably more important to establish that these have been met at the completion of it. The introduction of microcomputers into education has raised new issues and revived old ones about evaluation. The following pages discuss some of these issues and provide a basis for the evaluation process carried out to complete this project.

Formative and Summative Evaluation

Cambre (1981) offers a historical perspective to the use of this terminology and the development of methods of producing instructional materials using feedback from small groups representing the target audience for the material. She reports that the concept of formative evaluation was first used by Michael Scriven in 1967 to describe the evaluation done during the developmental stages of an entity as opposed to the summative evaluation done at the completion of it. She points out that the actual concept of formative evaluation is much older than its name, and has found evidence of the use of this type of procedure as early as 1921 in relation to the study of World War I training films. At about this time there was an expansion of the use of motion pictures in education and an accompanying call for quality control. Her paper also reports progress made in formative evaluation of programmed instruction and educational television.

Baggaley (1986, 1992) has recommended the extensive use of formative evaluation procedures in the design and development of instructional programs for health education. He has used the Program Evaluation Analysis Computer (PEAC) to record fluctuations in the impact of various programs as frequently as every quarter second. He has completed several studies that support the use of this type of process to make significant improvements to films, video and sound tapes. These improvements may mean the screening out of potentially offensive aspects of the materials, or the addition of items that make the materials of greater value to the target population.

Weston (1986) reviews approaches to formative evaluation of instructional materials, and provides common variants within this process. The first stage of formative evaluation is usually a self-critique of the producer's own work. This may be followed by an informal review by a trusted colleague and/or an informal trial run with students. Further evaluation may involve submitting the materials to one or more experts for review and recommendations. Intensive individual formal trial sessions with potential users may also be done. In this type of session, the user's responses to the program and his/her comments are collected by the observer. She reports a three stage model of trial and revision. First, materials are tried by small groups, and revised. Then they are field tested using samples from the population for whom they are devised.

Following a second revision, the final form is produced and released for general consumption. Another approach, known as Learner Verification and Revision, is similar to the three stage model, but continues the formative evaluation throughout the life of the materials. This guarantees continuing success or updating of instructional materials.

Byrum (1992) is one of few authors to describe the application of formative evaluation to the development of computer-assisted instruction. He laments the fact that this type of evaluation has not been widely used in the development of these materials, and offers several possible reasons as an explanation. He suggests that software producers do not have the time, or the money (profit margin), to carry out such an evaluation. He also suggests that there is little demand for evidence of this process by the purchasers of software, while a large amount of the time available is spent on cosmetic aspects of packaging and marketing the materials. He also points out that there is a lack of trained observers and that the producers are unsure of any possible method of formative evaluation. His paper reports on a study that shows that there were significant improvements on posttest scores when students used the computer assisted instructional packages that had been revised following formative evaluation procedures.

Mark and Greer (1993) also discuss the distinction between formative and summative evaluation as applied to research and the development of intelligent tutoring systems (ITS):

> Formative evaluation occurs during design and early development of a project and is oriented to the immediate needs of developers who are concerned with improving the design and behaviour of a system. It frequently addresses the ITS evaluation question "What is the relationship between the architecture of an ITS and its behaviour?" By contrast, summative evaluation is concerned with the evaluation of completed systems and the making of formal claims about those systems. Summative evaluations tend to address another important question for ITS evaluation: "What is the educational impact of an ITS on students?" (p. 130)

They then continue to provide a review of several methods that may be employed to carry out an evaluation of materials for computer-assisted instruction. These include proofs of correctness, proofs of concept, criterion-based evaluation, expert knowledge and behaviour, Turing tests, certification tests, sensitivity analysis, pilot testing, and experimental research. They then discuss the use or application of these techniques in reviewing aspects of computer software. From this perspective, they recommend that the review investigate the relative value, accuracy and depth of the domain knowledge base and the teaching knowledge component used in the software. They point out the need to assure the validity, reliability, objectivity and standardization of the tests of student knowledge that may be used within the program. As well, they see the need to evaluate the communications component to establish that the users are able to understand the information presented and how to utilize the interface. Included within this topic is an evaluation of how the computer system changes or adapts to the student user and how it is controlled. In addition, to the evaluation of the software, they also establish the need to study the impact of the interaction on the student users. Obviously, they advise evaluation of the student achievement in terms of the objectives elaborated at the beginning of the instructional design, as well as criteria related to achievement such as transfer, retention, learning time and completion rates. Finally they advise the review of how the program impacts on the users from an affective perspective. At this point the reviewer should investigate changes in attitudes, beliefs, and motivation towards both the subject matter and the program environment.

During this project, both formative and summative evaluation approaches were followed. Formative evaluation was carried out during the developmental stages of the text materials and computer software programming using individual students. A pilot test of the computer software, associated print materials and test instruments was completed with a group of third semester college students. Subsequently minor improvements and revisions were made to these items. Summative evaluation of the simulation was then completed and the results from this study are reported in the next few chapters.

Background Research in the Evaluation of Educational Software

There has been limited research into how computer based instructional systems should be evaluated. As this may be considered a new medium or instructional technology, there has been only a short time to accumulate data and begin to determine what should be a part of an evaluation.

Williams, Rice and Rogers (1988) consider computing to be included with various telecommunications systems as a new medium of communication and education. They have gathered together a number of strategies and tactics for developing research into the effectiveness of these new ways of teaching. They consider these media to have special features that make them particularly important. These include interactivity, the possibility of highly tuned or individualised messages for a particular situation, as opposed to mass instruction, and the asynchrony of detailed highly personalized communication. They suggest not only extending the current methods of study to the new media, but also recommend using multiple measures to provide triangulation of measurement.

Neuman (1989) makes a case for the application of naturalistic inquiry into the effectiveness of computer-based instruction. The naturalistic paradigm is based on the sense of multiple realities constructed in the minds of individuals. Computer-based instruction supports and allows individualisation at a level unlike any other medium of instruction and therefore needs to be evaluated more from the individual user's perspective. At the same time it is necessary to look at how the individual parts fit into a larger picture. One way that data is collected using a naturalistic inquiry is through the observation of the users of the software while they are interacting with it. Data collection might actually be built into the software by recording the keystrokes or mouse clicks of the user. A document analysis might be done on these recordings to discover certain trends or patterns. The naturalistic inquiry might also draw on interviews to explore the user's perspectives and ideas on a number of instructional issues.

Winne (1993) reviews issues in evaluating an adaptive learning system. He proposes five broad topics to be addressed in an evaluation study:

> 1. What is the system being evaluated?
> 2. What standards of worth and value are relevant in evaluating that system, and what justifies selecting those particular standards?
> 3. What data are to be gathered to describe the system?
> 4. What process(es) are used to gather that data?
> 5. What rules are used to filter data and to relate data about the system to the chosen standards of worth and value. (p. 309)

He then elaborates on the issues surrounding each of these topic areas and how they relate to the types of computer software that adapts to the individual user. He points out that interactive software raises some special problems, in that not all users of the software follow the same pathway through the program. Because of the individualisation of the presentation and interaction, it is difficult to interpret the results.

Shute and Regian (1993) also address some of the issues relative to the problem of determining how well intelligent tutoring systems teach what they intend to teach. They list seven principles that should be followed to design an evaluation:

(1) Delineate the goals of the tutor,
(2) Define the goals of the evaluation study,
(3) Select the appropriate design to meet defined goals,
(4) Instantiate the design with appropriate measures, number and type of subjects, and control conditions,
(5) Make careful and logistical preparations for conducting the study,
(6) Pilot test the tutor and the study, and
(7) Determine the primary data analyses as you plan the study. (p. 249)

It has been mentioned above that Mark and Greer (1993) call for improving instructional software through formative evaluation, and they review approaches to how this may be carried out. Seidel and Park (1994) provide a historical perspective on the design, development and evaluation of intelligent tutoring systems. They then propose a model for evaluation that includes evaluation along several dimensions. One dimension has three major stages in the use of an intelligent tutoring system: adoption, implementation, institutionalization. Another considers four target levels of possible uses and benefits of the program: community, school, classroom, and student. They also consider the dimension of the incorporation into the teaching environment. There are two processes at work here: one is assimilation of the new product into the teaching environment; the other is the accommodation of the teaching environment to the new innovation. When software is being evaluated and compared, useful data can be gathered through consideration of how it fits into their model.

While it might seem obvious to evaluate the software in terms of the potential users, this has not always been done. In many cases, software has been reviewed by expert reviewers or the planners of an instructional program. Reiser and Dick (1990) proposed a model of evaluation where the evaluator set the instructional goals or aims to be accomplished and then used a small group (15-20) representative members of the target audience to test the software. These students were pretested for subject matter competence, and then were observed as they followed the computer based instructional program. Posttests and delayed posttests were administered and compared with the pretests to determine if there were significant changes in the scores. This testing also brought to light other problems or aspects of the software that were liked or disliked by the student users. Zahner, Reiser, Dick and Gill (1992) present a simplified version of this approach by using only three members of the target population to one researcher/observer. Reiser and Kegelmann (1994) continue to describe the use of the student user as a participant in the evaluation of software. These student testers of computer programs should not only be observed and tested for subject matter gains, but also, their opinions, attitudes and reactions to the particular program should be studied.

Standards for Evaluation

Before embarking on an actual evaluation process, it is necessary to define the dimensions along which the software is to be evaluated and to set the approach to measuring these. This is consistent with the concept of assessment as means of establishing what the outcomes should be. The evaluation can follow this assessment to determine the degree to which these standards are met and the relative value of the software can be determined based on these standards.

Bloom's Taxonomy of Educational Objectives (Bloom, *et alia*, 1956) is particularly useful for categorizing much of what needs to be determined about any educational program or product. The division of the outcomes into the three domains of cognitive, psychomotor, and affective outcomes is a convenient way of assessing aspects that should be addressed when defining and determining some of the standards. Another approach to categorizing and studying instructional outcomes is that taken by Romiszowski (1984, ch. 4). In addition to content variables there are technical aspects relating to the computer hardware and the software as a communication medium that should be assessed.

Cognitive Domain

In this category are the objectives pertaining to knowledge about a subject matter. When individuals learn about a new subject, they must acquire certain concepts and a vocabulary for naming them. They need to know certain facts, principles, sequences, methods, structures, and/or theories. They must also demonstrate comprehension of the meaning of this knowledge, as well as being able to apply it. It may also be important to be able to analyze new information in terms of previously learned material. There may be a need to synthesize descriptions of the knowledge, in order to communicate it, and the learners should be able to evaluate their own or others knowledge of the subject matter. In evaluating the effects of computer software on the cognitive domain, one would use many of the same techniques used to determine knowledge gains from other educational experiences. Testing exercises including multiple choice tests, short answer questions, essays, structured interviews, concept maps, diagrams etc. could be designed to determine the depth and breadth of subject matter knowledge. White and Gunstone (1992) provide a summary of testing techniques to determine the degree of understanding that a person has about a topic. Balla and Boyle (1994) provide an interesting framework for determining student performance in academic and knowledge based situations that is based on a simple quality management model. It is also appropriate while dealing with objectives related to the cognitive domain for the evaluator to assure the factual accuracy of the subject matter content used in the software. As well, the evaluator should check the vocabulary used to be sure that ambiguity does not occur. Conventionally, the test subjects are given pretests and posttests of subject matter competence that have been based on the objectives. Comparison of these results allows the evaluator to infer the degree of effectiveness of the software experience

Affective Domain

There is less educational research about this domain, but it may be of great importance in the over all evaluation of the effectiveness of educational software as it is into this area that one categorizes objectives dealing with emotion, feeling, beliefs and attitude. Bloom also developed subcategories in this domain. Receiving or attending to the message being sent to the learner includes awareness, willingness to receive, and controlled or selected attention. If the learners are willing to attend, they may then also be willing to respond or participate in the learning process. Compliance in responding, willingness to respond and satisfaction in response are further subcategories of responding. Further, Bloom describes the aspect of valuing to include attitude and belief. Aspects of this subcategory include acceptance of a value or belief, preference for a value or belief, commitment to a value. A fourth aspect of the affective domain is the organization of a value or belief system. Finally there is characterization by value or value complex. In this part of the affective domain, are the controls on behaviours based on one's values and beliefs, as well as the development of an integration into a philosophy or world view. To study aspects of the affective domain, attitude questionnaires are usually employed. One of these may be administered prior to the test session to collect information about the way the subjects feel about computers and computer-based instruction. Another questionnaire might be given to the subjects after they have worked with the software under study to determine affective reactions to the software.

Psychomotor Domain

This domain includes the actual physical movements involved in carrying out behaviour, as well as actual behaviours executed. Most of Bloom's subcategories within this domain would be considered to be physical skills by the average person. Bloom also includes verbal (speech) and non-verbal communication in this category. Often in academic software there are no specific objectives that require the development of skills in this domain. In some types of simulations, a flight simulator for example, the major goal of the instruction may be to integrate skills of the psychomotor domain with cognitive and affective skills.

Technical Aspects of Software

In addition to the educational goals and aims of the software, there is the need for the evaluator to consider some of the technical features that can enhance or inhibit the individual user. The user interface is the part of the software that relates the human user to the computer program. Because instructional programming is still in its infancy, there are no well defined standards for the design of the layout of screens and the use of the various input devices. The evaluator must be a bit subjective about these features, but should ask test users appropriate questions to determine if they find problems that inhibit their interaction with the computer.

The screen design should be pleasant and not distracting. Colour can be used to enhance the text interchange, but one should avoid garish or conflicting colours. For example, white text on a blue or black background screen appears to be quite pleasant to the user. Likewise, blue or black text on white or pale yellow backgrounds are easy for the user to use. There should be a consistency of colour used for different purposes in the software. For example, if there is a help or tutorial mode connected with the software, it might have a different background/text colour scheme than the main instructional mode. Again there are no hard and fast rules about the use of various sizes and styles of text or the use of lower case versus upper case lettering on the screen, but the evaluator should be sensitive about checking how these are used. Icons should make sense to the user and not be distracting. A bright red stop sign allowing the user to quit from the software may become very tempting and lead the individual to stop prematurely. Inserts and windows that appear on the screen should follow similar conventions and the user should be aware of how to close or remove these features.

There is an increasing use of the mouse as the way to operate instructional software. While many people have adopted the mouse as a way to navigate through software, there are still those who prefer to use a standard QWERTY keyboard. One might investigate how the target users feel about this and how the mouse might be difficult for them to use. In some software, both options are provided by the use of arrow and tab keys.

Another technical aspect is the use of language and graphics. In recent years there is a move away from using the computer as a fancy way to turn pages in a book. More programs are adopting a multimedia approach by inserting short film clips, actual pictures and diagrams. Again there are no hard and fast rules about the use of these features. However, one does need to realize the reading level and vocabulary required for the text based materials or text on screen presentations. It may be important to consider important media variables that have been studied in the development and production of health education materials in print, film and television.

The evaluator should also investigate how long the program takes to process an input and return a response to the user. This is less a problem with fast processors, CD-ROMs and hard drives, but can still cause the user some frustration. The user should also be able to reverse certain decisions or inputs. It is important to determine how the user will be alerted to errors in input and how he/she can back up without restarting the program. Related to this is the study of the flexibility of the program and how well it adapts to a variety of users.

There may be a need or desire for a hard copy of the information. For example, in nutrition education the user may go away with a diet to try that has been tailored to the individual's specific weight, age and activity situation. If this is desirable, then one should determine if it is available and how well it works. Likewise, if there are subsequent sessions of use with the software, the user might need the data from one session to feed into another session. Consequently, there should be a way to store this information and reload it into the program at a later date. If there are tutorial or help provisions, the evaluator should determine how useful they are to the overall goals of the software.

Finally, one should be aware of the costs of the software in terms of the available resources. At this point, one must consider the time used by the participant as a cost. If the instruction can be delivered to an individual in another quicker and easier way, one must consider the possible benefit to be attained through the use of the software. One cannot ignore the financial costs either, in these days of budgetary restraint. Again there is a need to assess the expense of purchasing the program in light of the possible benefit that might accrue to the users.

Potential Confounds to the Assessment

There are several factors that can potentially confuse and confound the evaluation of this program and it is necessary to address a few of these issues in advance to establish a stronger link between the software and the performance measures. For this purpose, individual differences in the users, time on task, reading ability and the interaction with the computer itself will be discussed. The students who use the program will come to the experimental situation with a vast variety of educational and family backgrounds. It is assumed that a population fairly typical of today's college students can be obtained by recruiting a large number of students. This can be checked by asking the students to fill in a form asking for demographic data, such as age, sex, college program of study, number of semesters completed, general over-all average at college level, and mother tongue. Theoretically, the effects of these factors should be cancelled out by having a large number of students test the software, and by the random assignment of subjects to the different testing conditions. In addition, the interaction of these individual differences may be checked statistically after the fact to determine if there was some particular bias in the results obtained that had not been foreseen by the experimenter.

Bloom (1980) raises the issue of the time spent on the learning task in his discussion of alterable variables that can effect the quality of educational outcomes. There are really two components here, the time available and the time spent as active learning time, i.e. the "time on task". According to Bloom, raising the active learning time can be expected to improve the outcome. However, the maximum active learning time is usually constrained by the actual available time allotted to the learning activity. A timer may be included in the software to determine the time that the user spends on the various sections of the program and on the total program. In any experimental testing situation, there are real time constraints. The computer laboratory will have to close, and students will have to complete the posttests and attitude questionnaires somewhat before this time. By scheduling the test sessions properly, based on time estimates from the pilot testing, the majority of subjects should have sufficient time to interact with the software and complete the evaluation instruments. A study of the interaction of the recorded time with the outcome scores may be done to adjust for this factor. Another possible factor that might influence the results on the outcome tests is the general reading ability of the student subjects. The nature of the subject matter and its presentation depends on the ability to read and write the English language at least at the level expected for high school leaving. Because of the possible interaction of this ability with the outcome scores, a simple test of reading ability might be given to the students. Again the effect of this factor will be studied after the testing to determine if there are differential results for students with different abilities.

Then there is also the issue of the computer use itself. Putting students into a computer tutorial environment is a novelty that might well effect their motivation and interest in performing with this system. This is commonly called the Hawthorne effect. This is one of the factors that makes it difficult to actually establish an experimental design using equivalent groups, as users of the computer program are doing something completely different from the other subjects participating in the study. There are at least two levels of distortion. One is the use and presence of a computer in the experiment. Student attitudes to the use of computers are still variable. Although there is a shrinking number of them, there are a few students, who lacking access to computers, have little experience and, perhaps, even a fear of working with them. At the other extreme are students who enjoy working with any computer program and are quite willing to try anything, including trying to subvert the program or find out how it works. Questionnaires about experience with and attitudes towards computers in education can help to identify subjects who are at these extremes.

Another problem is described by Winne (1993) as the problem of the variable student performances being a function of the interactivity itself. Adaptive learning environments are designed to diagnose and react to individual differences in ways that are not foreseen by traditional comparative research models in education. In fact, if this type of computer program is successful, there should be somewhat varied treatments within the group using the system. However, as a result of participation in an interactive learning system, the individual outcomes should each be closer to the expected performance. Then, if the interactive system is valid and useful, one would expect to find considerable differences in the outcomes of the users when compared with non-users.

While it is difficult to overcome all of the obstacles operating against a valid study of instructional software, progress in the design and development of intelligent tutoring systems can only advance through a repetition of attempts at evaluation.

CHAPTER 3: A MODEL OF THE TUTORING-LEARNING PROCESS: THE KNOWLEDGE MODELLING APPROACH

This dissertation puts forward a theoretical model of the tutoring-learning process that offers an explanation for the improvement in the mastery and understanding of a subject matter in students who act as tutors for peers, and offers a basis for the design and development of instructional systems. The model presented is called the *Knowledge Modelling Approach* and integrates a constructivist view of knowledge and learning with the concept of mental models and the ideas presented by Pask's conversation theory. The *Knowledge Modelling Approach* is a cybernetic model of a learning system and is proposed for use in the production of intelligent tutoring systems. The model is based on the notion that a tutor-tutee relationship can establish a "strict conversation" of the type advocated by Pask, where precisely those events necessary for the construction of valid personal knowledge occurs.

Components of an Instructional System

Underlying this project was the belief that instruction is a planned intervention into the ongoing learning process. This intervention is usually made by one individual for another. As well, fundamental to educational technology is the view that instructional events or activities occur as part of a system. Therefore, as part of any educational technology approach to instruction, one must identify the elements in an instructional system and the relationships among them. Figure 3-1 represents an abbreviated model of an instructional system.

In this figure, two key elements of the system are the instructor and the learner. The instructor has an instructional intention upon which the intervention into the learning process is planned. This intention should be based upon the accepted knowledge models for the subject matter, a model of the learner's entry level capabilities, and a model of the intended outcome of the instruction. This third model may be developed as the goals, aims and/or the objectives of the system. The learner also enters the system with an intention. His or her intention is based on prior knowledge and experience that have produced incomplete models of the subject matter. As well the learner has goals and objectives of his/her own that influence the subsequent participation in the instructional system. The instructor's model of the student can be developed through diagnostic testing or from a history of the learner's experience. There is usually a discrepancy between the learner's models of the subject matter and those of the instructor that dictates a need for instruction in the first place.

The instructor arranges for a variety of possible learning activities, such as classes, readings, discussions, laboratory exercises, internships, films, videos, computer-aided instructional packages, etc.. The learner participates in the system through the learning activities and develops new capabilities through the process. The learner is considered to be building personal mental models of the subject matter at this time.

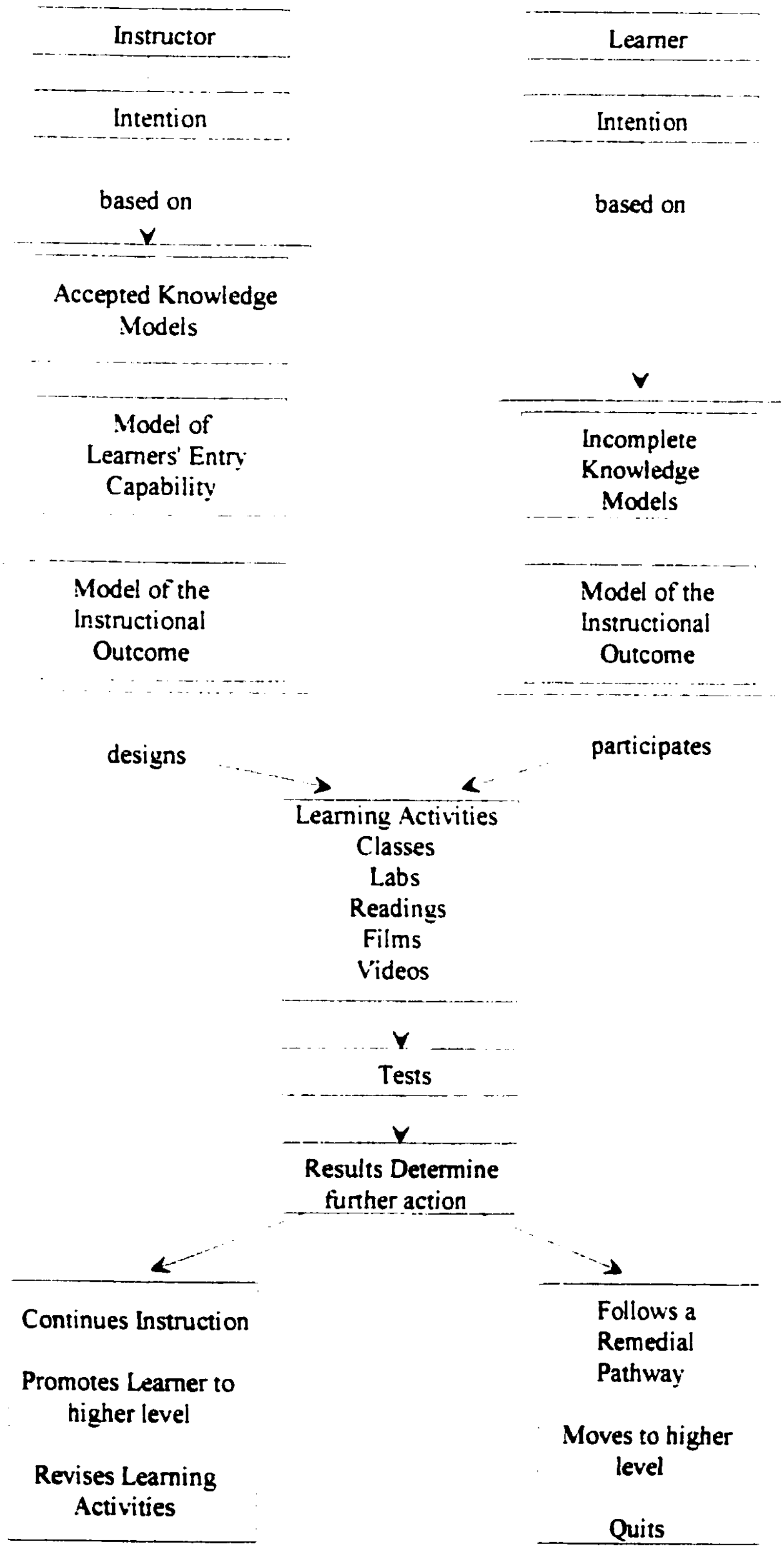

Figure 3-1: A Simplified Flow chart view of an Instructional System

Following these activities a comparison is made between the learner's newly acquired characteristics and the instructor's model of the outcome. This comparison is usually done through a form of testing as mentioned above. The results of the testing provide feedback, both to the instructor and to the learner, about how well the student's externalized models conform to the standard models that have served as the basis for the instructional intentions. The results also contribute to a rationale for further action. A remedial pathway may be indicated to correct mistakes or misconceptions. The learner may graduate or go on to a higher level system. The learner may also quit the system completely and move in a very different direction. Revision of the learning activities by the instructor may also be appropriate before exposing another student to the system.

This model instructional system is removed from its environment and consequently does not show all of the factors which usually impinge on such a system. This simplification has been made in order to focus on the key elements and processes involved in instruction. The model may be applied to several situations from high level training situations to individualised or self-directed lessons.

Further Elucidation of an Instructional System

Two central elements of an instructional system are the participants in the system, the teacher and the student. Another element is the actual knowledge domain. While each participant has internal private knowledge about the subject matter, there are external public sources of knowledge which can be shared among the individual participants. Within each of the participants similar processes are occurring that lead to the construction and reconstruction of personal knowledge. These three elements are illustrated in Figure 3-2. In addition, another element has been introduced in Figure 3-2 as the Modelling Space. This is the feature through which the participants can exchange and compare the externalisations of their personal models of the subject matter. This special environment may be concrete such as a written paper, or ethereal such as the spaces through which oral conversation travels. It should be remembered that these views of instruction are by their simplification incomplete. An aspect left out is the setting or environment of the instructional system. The environment imposes constraints on the system, provides resources as inputs, and receives outputs from the system. These views of instructional systems were developed from several sources of cybernetic literature and an educational cybernetics course as described by Boyd (1981).

Models and Paradigms in Knowledge Domains

Students in schools and early college settings are often presented with models of knowledge about specific subject matters, such as biology, chemistry, and physics. These models may be presented in a variety of ways including concept maps, diagrams, charts, tables, or as verbal descriptions of a situation. The knowledge models presented are based on and are consistent with those models and paradigms that have been established and accepted by the research community of the particular discipline. As

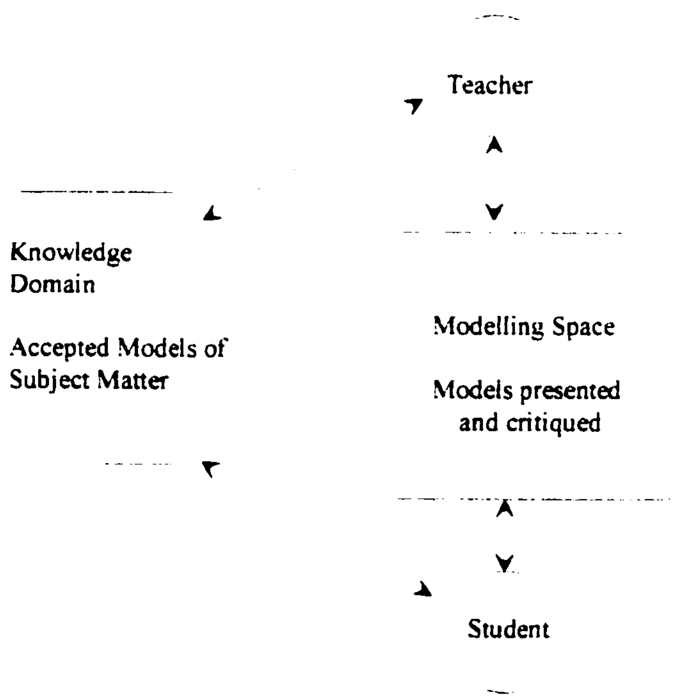

Figure 3-2: The Core Elements of an Instructional System

mentioned previously Giere (1979, 1988), Brufee (1993), and Driver *et alia* (1994) discuss the process of science and how scientific knowledge domains are socially constructed and reconstructed.

For teachers and students at lower levels of education, the accepted knowledge models of the subject matter may be considered as stable and can be used as the basis for assessing an individual student's competence in the subject matter. As such, they can also be used as the basis for controlling an instructional system aimed at development of mastery of the subject matter. The students are expected to study the presented knowledge models of the particular subject matter and to internalize them by building their own homomorphic mental models of the same subject matter. The competence of the students is then judged by tests and examinations that require them to externalise their models of knowledge without the aid of books, notes, charts, etc.. The tests may require the students to reproduce their models, answer questions about their models, solve problems based on their models, or act on situations based on their models. Through this testing process, parts of the students' mental models of the subject matter are externalised and may be compared with the standard knowledge models, and the model of teacher expectations. In higher level educational situations, such as graduate school or the education of medical specialists, the teachers and students may actually be involved in verifying, and validating the given knowledge models, extending or altering them, and/or proposing new models for consideration by the scientific community.

The Modelling Space

This aspect of the instructional system is proposed as the operating region between the participants in a conversation. Observable behaviours occur in this space. For the current purpose, the term conversation is used in the same sense as Pask's use and, particularly, as his idea of a strict conversation. The conversation is about a serious subject and uses a language, which may include spoken or written speech, or physical acts, such as gesturing and signalling. The units of the conversation are the concepts of the subject matter being discussed. The two participants operate in the modelling space in two conversational roles as presenter and critic. Generally, when one participant is presenting, the other participant adopts the role of critic. The critic provides feedback to the presenter, which causes the presenter to continue, stop, or take some other action. For example, a puzzled look on the face of the critic, may cause a verbal presenter to stop and clarify a concept in the presentation. As mentioned above, the modelling space may take a variety of forms. In a classroom environment, the modelling space may include the chalk board, overhead projector, and the physical space available to the teacher for a variety of physical demonstrations of the concepts involved. The modelling space may be considerably limited to an exchange of written communications as in some distance education situations. Electronic media such as radio, TV and computing provide opportunities to develop different types of interaction across the modelling spaces. The interface of an instructional computer program is considered to be its modelling space. The behaviours presented within the modelling space can be assessed and evaluated as inferences about the internal private knowledge of the participant.

Operations of Participants

Each participant is considered as a system unto himself or herself, and is therefore, a subsystem to the whole instructional system. Each participant operates externally in the modelling space, but has internal processes that can only be inferred from this behaviour. It is inferred that people construct, grow, or increase their knowledge by building and rebuilding internal representations as they interact with an environment that includes other individuals. The concept of mental models previously introduced in Chapter 2 provides a convenient metaphor for these internal representations. It was beyond the scope of this project to provide biological or neurological evidence for the existence of mental models. However, using this metaphor aids in explaining the behaviour of each participant and provides a basis for the design of instructional systems that are oriented to the building, testing and remodelling of mental models. It must also be kept in mind that humans are very complex and that there are many competing mental models driving the behaviour of an individual. The aspects of personal motivation and the interaction of belief systems should not be completely ignored, although they may not be included within the scope of a particular research project for sake of simplicity. The possibility that a particular material participant might embody several personalities and roles, or several of what Pask called psychological or p-individuals is also not to be forgotten. An interesting case is the truly self-taught person who performs both the roles of the student and the teacher within the same body while interacting with a specific subject matter domain. Figure 3-3 provides a simplified view of the operations of a participant in an instructional system.

A Model of the Tutoring-Learning Process

The tutoring-learning process is a different case of a typical instructional system. The instructional intentions or goals are usually set by an instructor or teacher and are aimed at the development of knowledge, or mental models, of a particular subject matter based on accepted models specific to that knowledge domain. The learning activity in this case involves establishing a tutor-tutee relationship that subsequently leads to a dynamic conversation about the subject matter. The tutor and tutee are the participants in the instructional system, and may be considered as a tutoring dyad. They are usually both similar in age and/or experience with the subject matter, although the tutor is usually thought to be slightly ahead of the tutee. Traditionally, tutoring situations have been designed by instructors to improve the development of knowledge in the individual labelled as the tutee. However, based on the evidence provided in

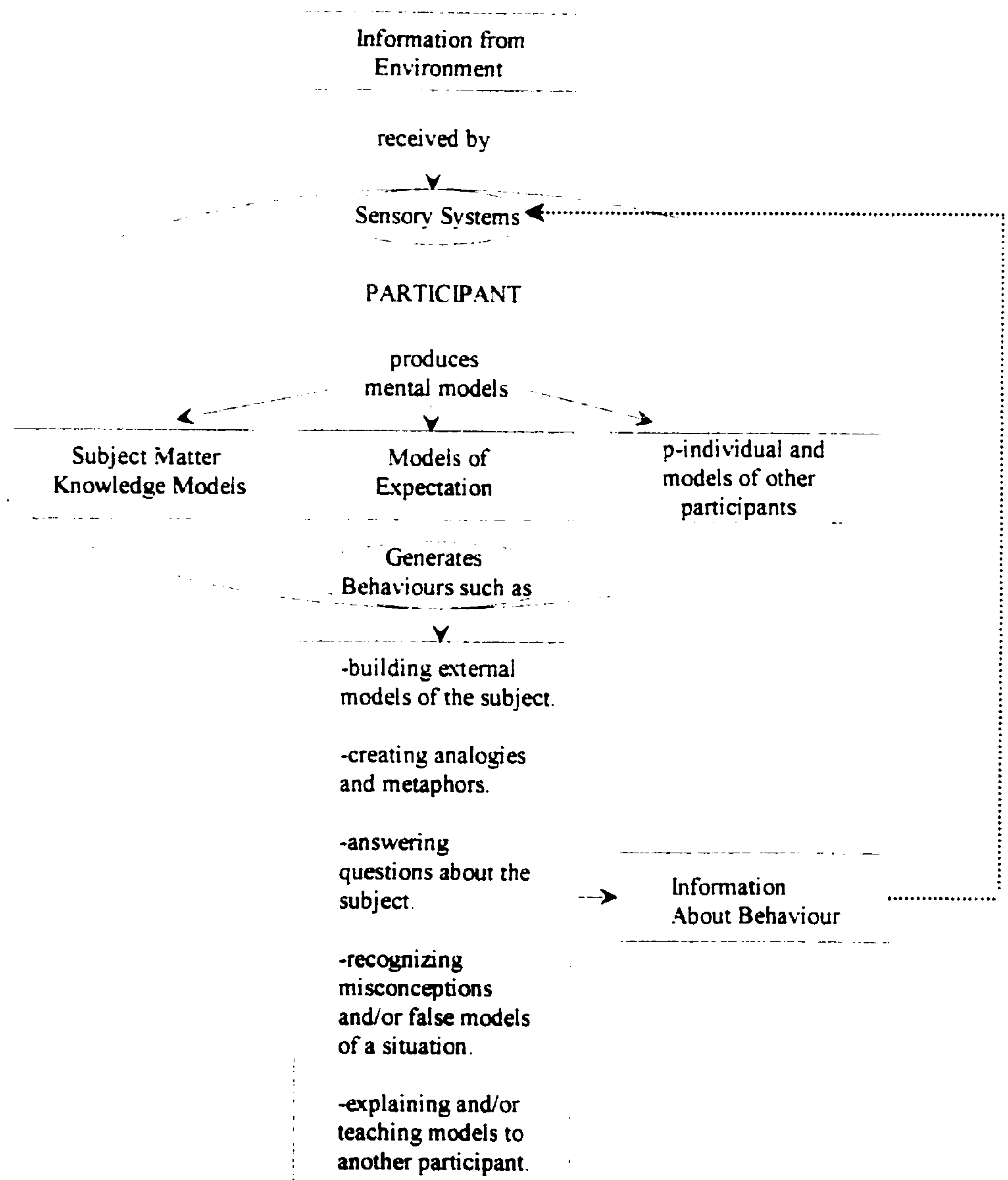

Figure 3-3: Simplified Model of a Participant in an Instructional System

Chapter 2, the tutor also gains in the process of tutoring, and, it seems that it may often be more beneficial to establish a tutor-tutee relationship for the benefit of the tutor. The *Knowledge Modelling Approach* postulates that a tutoring-learning situation establishes the conditions necessary for the construction of personal knowledge. There is an active cognitive involvement in both parties as each tries to explain the subject matter to the other across the modelling space. The process is further enhanced by the need to evaluate the explanation, comment on it, and ask questions about it of the other participant. In this way, an interaction is established where both the tutor and tutee are actively involved in the building and rebuilding of their personal mental models based on the standard subject matter models as defined by experts in the discipline. As mentioned above, these may be represented by text, charts, diagrams, visual aids, etc.. At the same time, the tutor should be overseeing the development of the tutee's subject matter models in terms of both the accepted expert models and the teacher's model of student capability to be developed by the instruction. Through the monitoring process, the tutor actually insures that both members are developing the capability for an adequate performance on tests of subject matter competence. This situation is represented by Figure 3-4 which is an alteration of Figure 3-2. In this figure, the tutor and tutee are shown as the participants, and a teacher has been added as the director or controller of the tutoring system. A model of expectations has been added to the system in parallel to the knowledge model.

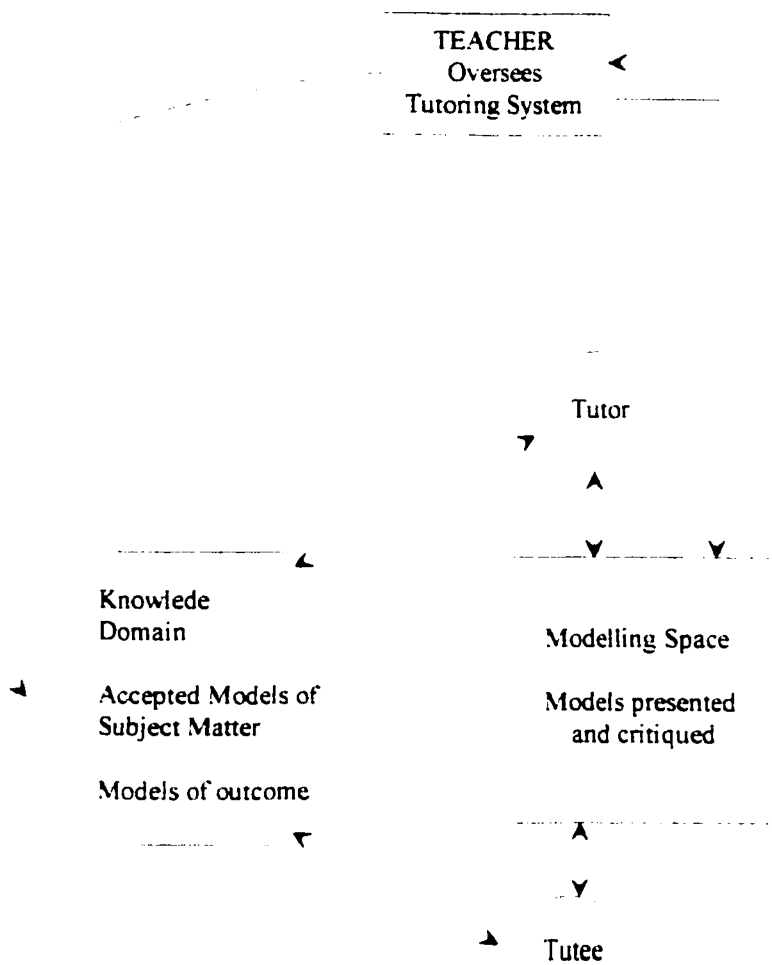

Figure 3-4: A Simplified Model of a Tutoring System

The *Knowledge Modelling Approach* to the tutoring-learning process also considers that there is an iterative process occurring with much subject matter model building and model testing occurring between the individuals involved. Through their interaction and involvement with the subject matter, each individual builds mental models of the subject matter. In addition, they are building models of each other and models of the expectations required for mastery of the subject matter, through these interactions. The models are tried out or tested on the other participant and each individual's models are consequently revised due to the rapid return of feedback coming from the other participant. This iterative process of successive interaction can be visualized as a double spiral in which each individual's pathway is represented by one strand. When the individuals enter the relationship at the bottom of the spiral, their subject matter models are relatively incomplete. Ideally, the models of each participant at the exit point should be coherent and congruent with each other and with those of the standard knowledge models and models of expectations as presented by the subject matter expert or the teacher. The conversational dialogue occurs across the modelling space which is represented by the blank spaces within the spiral's loops and these loops represent the transfer of dialogue from one participant to the other, as they explore and discuss their knowledge models. Figure 3-5 represents the iterative aspect of the *Knowledge Modelling Approach.*

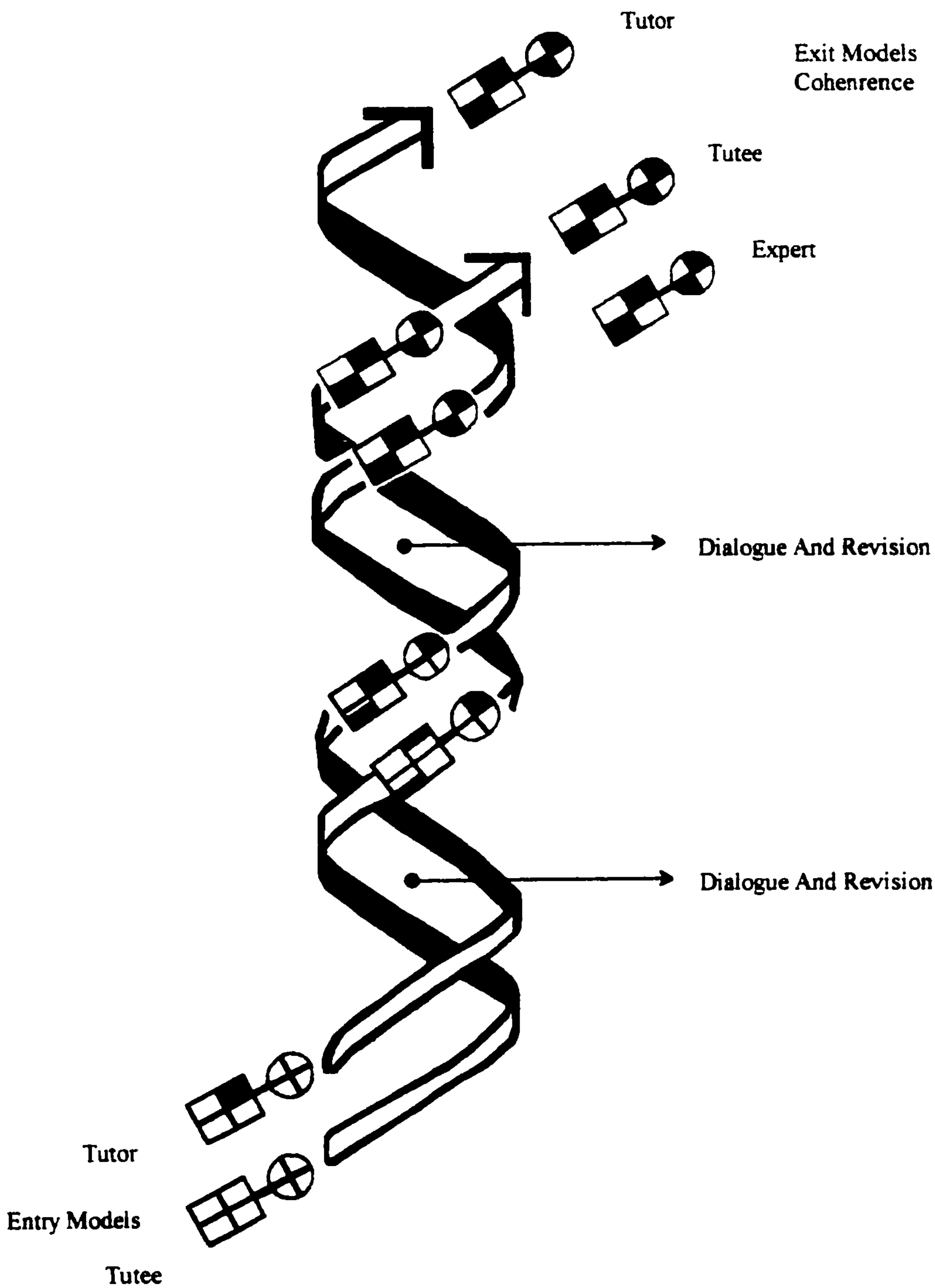

Figure 3-5: Parallel Coherence Model Building Process during Tutoring
as Posited by the Knowledge Modelling Approach

The *Knowledge Modelling Approach* illustrates how tutors and tutees can improve their overall knowledge and comprehension of a subject matter and of each other. However, it is important to study the issue from the standpoint of the tutor's potential gain. The tutoring individual enters the relationship in a different role than that of the tutee. The tutor is charged with the responsibility of guiding the knowledge development of the tutee. By definition, the tutor is regarded as having at least a slightly better command of the subject matter than the tutee. These factors probably combine to provide a strong motivation in the tutoring individual to become actively involved and more responsible for the construction and evaluation of his/her own knowledge. This, then, leads the tutor to carefully examine the subject matter content as presented in the available materials such as a textbook. The examination of the structure of the knowledge including the definitions of concepts and the relationships between them is a necessary prerequisite for the development of the tutor's explanations of the subject matter to the tutee. In addition, the relatively immediate feedback from the tutee, in the form of further questions and requests for clarification prompts the tutor to delve even more deeply into the knowledge models of the subject matter. As well, when the tutor asks the tutee questions, the answers from the tutee must be evaluated and explanations provided in terms of the accepted knowledge models. As this happens, the necessary links are made to other previously constructed knowledge, long term memory of the topics is improved, and the tutor actually becomes more secure in his/her knowledge of the subject matter. Subsequent testing of the tutor for subject matter competence should then demonstrate improved mastery and better understanding than might have been acquired through other approaches to studying the subject matter.

Applying the Knowledge Modelling Approach to Instructional System Design

The *Knowledge Modelling Approach* is presented as a basis for the design of instruction in general and for the design of intelligent tutoring systems in particular. It seems appropriate at this point to summarize the items that must be considered when this approach is implemented. Firstly, the instructional designer needs to consider the subject matter that the learner is expected to master. There are a variety of methods for establishing the knowledge and skills that the student should be able to demonstrate after instruction. Romiszowski (1984) describes some of these in his fourth chapter. Following this process, definite behavioral objectives and tests of competency may be developed. These may be considered as models of the expected outcome of instruction. At the same time, it is necessary to establish the background knowledge of learners who will use the system, and the prerequisite knowledge required before beginning to study the material at hand. Other factors such as the students' goals and objectives, aspects of the setting of instruction, and the students' motivation must also be considered. These steps are not unique to the *Knowledge Modelling Approach* but are the beginnings of most instructional design methods.

After determining the purpose and direction of instruction, it is possible to produce activities in an environment that will foster the development of the appropriate and desired mental models of the subject matter in the learners using the instructional system. These activities may consist of fairly traditional presentations, such as readings, lectures, videotapes, or slide-tape show. However, the *Knowledge Modelling Approach* demands that, in addition to these approaches, students become involved in a set of activities within the modelling space that provide the opportunities for several cycles of model building, model testing with feedback, and remodelling. The feedback should be arranged both to guide the learners in the development of satisfactory personal mental models of the subject matter, and provide control over the flow of the instructional system. Through this feedback the learners should be able to overcome various deficits their personal knowledge while developing it further. Although the *Knowledge Modelling Approach* is difficult to implement in a traditional classroom environment, it is more useful for the design of individualised instruction. Since it evolved from a study of the tutoring-learning situation, the *Knowledge Modelling Approach* has been tested through the design, development, and evaluation of a computer-based simulation of a tutoring environment.

CHAPTER 4: LABORATORY EVALUATION OF THE KNOWLEDGE MODELLING APPROACH USING VIRTUAL TUTORING

VIRTUAL TUTORING

The *Knowledge Modelling Approach* was tested through the design and production of a computer based simulation of a tutoring-learning system that provides the user with an opportunity to teach a subject matter. This simulation was designed to be consistent with Pask's conversation theory and serves an example of *teachback*. It also conforms to the conditions for intelligent tutoring systems (ITS) described by Mitchell and Grogono (1993). The design of the system was based on the models presented in the previous chapter. Models of the knowledge domain, in this case the biological process of photosynthesis, were established using a derivative of concept mapping technique. The models of expected outcomes were also set as behavioral objectives that serve as a basis for tests of subject matter competence. The *virtual tutee* was designed to imitate some of the behaviour a tutee operating in a real situation . A *virtual professor* was designed to remain mostly in the background and the real student users entered the system as tutors during the testing phase. The following pages provide details about the design and operation of the *Virtual Tutee System.*

Quasi-Intelligent Tutoring Systems

The *Virtual Tutee System* is presented as an example of an intelligent tutoring system (ITS). An ideal intelligent tutoring system, of course, would be two real students conversing about the subject matter and providing mutual benefits as described by Kingsbury's learning cells. In building a computer-based simulation of such a system, one should first look for the characteristics or requirements of such systems. MacKenzie (1990) asks the question in his title: "...where's the intelligence?" and then describes features of such a system. Firstly, the system has to have some capacity to learn and/or adapt to its surroundings. At minimum, the computer based tutorial system must be able to acquire information about the real student user and particularly about his/her progress in studying the domain. It might also acquire knowledge of the user's learning mode or style of interaction. MacKenzie considers that knowledge acquisition about the subject matter is more difficult to achieve for computer-based systems. Secondly, the system should accord the control to the user. He follows Scardamalia, *et alia*, (1989) who wrote:

> It is not the computer that should be doing the diagnosing, the goal setting and the planning, it is the student. The computer environment should be providing the knowledge and intelligence to guide learning, it should be providing a facilitating structure and tools that enable students to make the maximum use of their own intelligence and knowledge.

In addition, MacKenzie (1990) points out that an ITS should also tolerate human error and should provide a way of correcting errors made by the user. The system interface should be consistent so that it is easy for the student to learn to use it. The intelligent tutoring system should provide the student user with support for self evaluation and should provide resources for helping the student to move to higher cognitive levels.

MacKenzie leaves the reader with the idea that "intelligence" should be reserved as a descriptor of human qualities and that "sophisticated" may be a better descriptor of currently available software.

Along similar lines, Mitchell and Grogono (1993) provide five requirements for intelligent tutoring systems. First, there should be a subject matter that the student wants to learn or must learn, and this subject matter contains facts, statements, concepts, rules, etc., that can be written down or elaborated in the form of concept or knowledge maps, forming an expert's model of the subject matter. Second, the ITS should be able to build a model of the student user. This should include a model of how the student views the subject matter, as well as entry level capabilities and an assessment of the user's learning habits. Attributes and requirements for learner modelling are elaborated further in an article by Boyd and Mitchell (1992).

They list six key components necessary for producing a model of the student. The model should be able to acquire information about the identity of the student user. This should be more than just the user's name. Aspects of the student's personality, and approach to learning may be included. Using Pask's notion of a p-individual, it is useful for the student model building process to determine characteristics of the persona operating in the system. The second component of the student model is the facility to determine the user's expectation of the system. The third characteristic is the students entry level knowledge of the subject matter. Mitchell and Boyd's fourth component is the student's views of the working time available. This is related to the expectations and commitment of the student and affects their pacing and rate of achievement. The fifth component involves the students perception of the other individual within the tutoring dyad. If the real student is in the role of tutee, he/she will develop a model of the computer-based tutor. Their sixth component involves the learner's psychostructure, affective states, and preferences for various modes of communication.

Returning to Mitchell and Grogono's requirements, their third point is that an ITS should allow the student user to explore the various subdomains of the subject matter in a non-linear order. This should be determined by a combination of the state of the student's knowledge and the choices made at various stages of the interaction. Fourth, an ITS should pose problems, provide information when asked, and guide the learner towards a goal of mastering the subject matter. Their fifth requirement is that the result of the learning process should be an observable event or sequence of events that can be evaluated.

As there are difficulties developing truly intelligent simulations that conform to all of these requirements, it seems to be more realistic to call the *Virtual Tutee System* a quasi-intelligent tutoring system.

Developing Knowledge Models

A first step in the design of instruction is the development of models of the knowledge domain and the expected outcomes for the real students participating in the system. It was decided to develop the materials for the test case of the *Knowledge Modelling Approach* around photosynthesis. This is the process by which plants transform light energy into chemical energy. This subject matter is considered to be a fairly complicated topic in the study of biology. There are also several different levels of knowledge and accompanying detail between the knowledge and understanding of a novice and an expert. Several authors have written about various aspects of teaching photosynthesis at the high school and college level and the reader is referred to the work of Haslam and Treagust (1987), Eisen and Stavy (1988), Lloyd (1990), Amir and Tamir (1994), and Hazel and Prosser (1994) for more information.

An analysis of the concepts, relationships and structure of the scientific knowledge of this subject was carried out by building a "sticky paper knowledge web" for this domain. A web is constructed by using small pieces of pre-glued paper commonly called by their brand name, post-it notes. The technique is a combination of the DACUM method and concept mapping. DACUM is an acronym for *Designing a Curriculum* and is a way of recording a session in which a panel of subject matter experts describes the tasks, knowledge and skills required for a certain job to an instructional designer. During a DACUM session the items are written on cards that are posted on a large bulletin board or blank wall. These postings can be easily edited by adding to them and moving them. Gradually, a model of a course's content takes shape along with its prerequisites and sequence. The process is concluded by setting behavioral objectives, tests of competency and the building of actual lesson plans. More specific information about the DACUM method may be found in Romiszowski (1981).

Concept mapping is another tool that can be applied to developing the course content. It has been particularly used as a technique for recording the concepts and cognitive knowledge skills for subject matter domains containing a large volume of verbal information. A concept map is a chart showing the words that stand for the concepts in a knowledge domain. Lines connect the concepts to show the relationships and the hierarchy of concepts within the domain. Concept mapping has roots in the cognitive psychology proposed by Ausubel (1968) that views learning as an organisation and reorganisation of one's conceptual scheme. Novak and Gowin (1984) recommend a variant of this technique in the form of a "Vee Diagram" as a learning activity to help students build their cognitive structure. Rowntree (1981) recommends it as an instructional design method, and Duttweiler (1991) supports its use as a planning tool. The process of building "sticky paper knowledge webs" is described in an article by the author (Taylor, 1994).

In building the knowledge web for photosynthesis the author, a college biology teacher, examined several university biology textbooks, as well as several articles about photosynthesis. The concepts were recorded on the pieces of sticky paper which were in turn stuck to larger sheets. As more information was gathered, these were edited and rearranged to build a concept map of the subject matter domain and its subdomains.

The outcome of the analysis process is considered to be the expert's model of the subject matter knowledge. A copy of this concept map is presented in Appendix 1.

Following the analysis, a set of instructional objectives for the sample lesson was set down. They were developed following recommendations of Romiszowski (1984) and taking into consideration Bloom's taxonomy of educational objectives (Bloom, 1956). As a check on their validity, these were compared to objectives set for college biology courses by the Ministry of Education in Quebec and by the International Baccalaureate Organisation. Subsequently, a text about the subject of photosynthesis was produced as the basis of the subject matter model. This text, titled *Capturing Energy for Life*, is therefore similar to a chapter in a standard college level biology book, and is shown in Appendix 2. At the same time, appropriate objective test questions were developed to test subject matter competence about photosynthesis. The development of the test instruments drew on approaches to the measurement of understanding and mastery discussed by Entwistle and Marton (1994), Coker, White and Barton (1993), Holmes and Leitzel (1993), White and Gunstone (1992), Perkins (1991), Kember (1991), as well as Pask (1975a). These materials were examined and checked for accuracy by three college biology teachers. A copy of these objectives and a copy of the test instrument are included as Appendix 3.

The text and objectives provide the models of subject matter knowledge required by the tutoring learning system proposed in Chapter 3. They also meet Mitchell and

Grogono's first requirement for an Intelligent Tutoring System. The subject matter tests provide for their fifth requirement that there be an observable outcome of the tutoring events. The combination of the objectives and subject matter tests are considered to be the standards of success, required for the evaluation process described in the next section of this chapter. The test instruments can be scored in a manner similar to standard processes used in college testing. The individual's score can be used to infer the degree of congruence between the knowledge constructed by a student subject with the defined standards of success.

The Modelling Space of the *Virtual Tutee System*

A feature of the instructional model presented in the previous chapter is the modelling space through which the participants transmit the externalised personal knowledge models of the subject matter. As mentioned, this environment usually involves the use of a written or spoken language. However, a major difficulty with the current generation of personal computers is their inability to deal with a natural conversational language. Although some interfaces have been developed for the recognition of free flow conversation, and, more recently, there has been the introduction of software capable of recognizing spoken language, none of these is yet sufficiently developed to provide an adequate basis for instructional conversation about a sophisticated subject matter. Structural Communications is an instructional approach that provides a simulated dialogue, between the author of instructional materials and the user. The technique was developed in the 1960s by Bennett and Hodgson as a means of providing a higher level dialogue, between the author of instructional materials and their user, than the then popular programmed instruction could offer. A structural communication lesson consists of six parts. It opens with an **Intention** that locates the lesson in a curriculum or provides a rationale for its study. Objectives may be provided here and advance organizers may be added to assist the learner in finding a context for the lesson. A **Presentation** follows as a description of the course content on which the lesson is focused. This section is not unlike that of a typical textbook, although other types of presentations, such as film, video, slide-tape or a laboratory experiment may be considered as presentations. The third section, the **Investigation,** presents challenges or problems that involve students in an interaction with the subject matter. After thinking about a solution to the given problem, students use a **Response Matrix** to compose an answer to the problem. A response matrix consists of twenty to thirty items relevant to the problems posed in the **Investigation**. From this matrix, a student selects and arranges those items that provide an appropriate response. The student's selection is analyzed and a referral made to the appropriate **Discussion** item. The latter is a reply by the author to the student response which comments on discrepancies, and points out misconceptions or errors implicit in the particular choice of matrix items. Finally, the **Viewpoints** section may provide alternative ideas on the subject matter, and further explanations, while making links with subsequent lessons.

The philosophy and methodology of structural communications is described and documented by Egan (1976), Hodgson (1974), and Romiszowski (1986, 1988).

The strength of structural communications is that it provides some of the elements of a conversation by allowing the student to build a fairly sophisticated answer and by providing a reply relevant to that answer for the student. In the print format, however, structural communications is quite unsatisfactory. The author of a structural communications lesson must produce a number of paragraphs in anticipation of the types of response composed by students. The student is left to make an analysis using a grid system to select the appropriate paragraph as a reply. Also, any book written in this format contains much more written material than can or should be used by a particular reader. The use of a computer to mediate between the student's input and the feedback from the instructor makes structural communications an interesting way of establishing an instructional conversation.

The approach used in structural communications was adapted to design a modelling space across which the real student user and the *virtual tutee* could communicate. The Intention and Presentation elements of the structural communications lesson were incorporated into the textbook chapter about photosynthesis. The Investigation and Response Matrix aspects were adapted to create a series of message building kits. Each message building kit contains the items necessary to build a response to a question or provide information to the *virtual tutee*. Each message building kit contains fifteen items. The number of items needed for a message about a particular topic varies, but is most often five or six. The other items in the kit are considered to be distracters. These are, in fact, true items that might be useful to build messages about other related topics. The real student user selects the appropriate items from the kit and enters their numbers into boxes provided on the interface. By requiring the student to select five or six items from the list, the chance of developing a good answer to the question strictly by chance is considerably reduced. Since the order of the items is also usually important to the development of a meaningful message, the chances of sending a good message through random selection are even further reduced. Before sending the message to the *virtual tutee*, the real student can read the statements as he/she has assembled them, and has the option of revising the message before it is sent. The constructed message for the tutee is considered to represent the real student's model of the concept under discussion. This is sent across the modelling space and is used by the *virtual tutee* as the basis for a response, as posited in Chapter 3. The responses from the *virtual tutee* unite the Discussion and Viewpoints sections of the typical structural communications lesson plan. By selecting the help button on the message building kit interface, the student is offered two types of help. One type of help is centred on the process of selecting items from the message building kit and sending them. The other type is a vocabulary list containing most of the concepts used in the lesson. A simple definition for each is available to the user.

Although further details about the computer simulation are provided in the following pages, the reader may see examples of the message building kit interface in the figures included in Appendix 4.

The Computer Architecture of the *Virtual Tutee System*

Figure 4-1 provides an overview of the simulation's basic components and is patterned after the model presented in Chapter 3 as illustrated in Figure 3-4. The virtual professor and the *virtual tutee* are resident within the program. The structural communication basis for the design of the modelling space and its message building kits have been discussed above. The computer simulation was developed using the hypertext programming environment, *Hypercard*, which operates on Apple Macintosh computers. This software allows the programmer to write scripts or programming routines that are executed when the user moves the mouse and clicks on appropriate buttons. The *Hypercard* environment is organized in sections called stacks, the units of which are called cards. The cards are shown on the screen of the computer, and the buttons allow the user to move within the environment which may mean changing cards or moving among several different stacks. Other routines and/or subroutines maybe programmed into the stacks themselves. *Hypercard* provides a suitable environment for building prototype systems and the scripts are executed quickly enough on the current generation of computers to provide a satisfactory flow of operation for the student users.

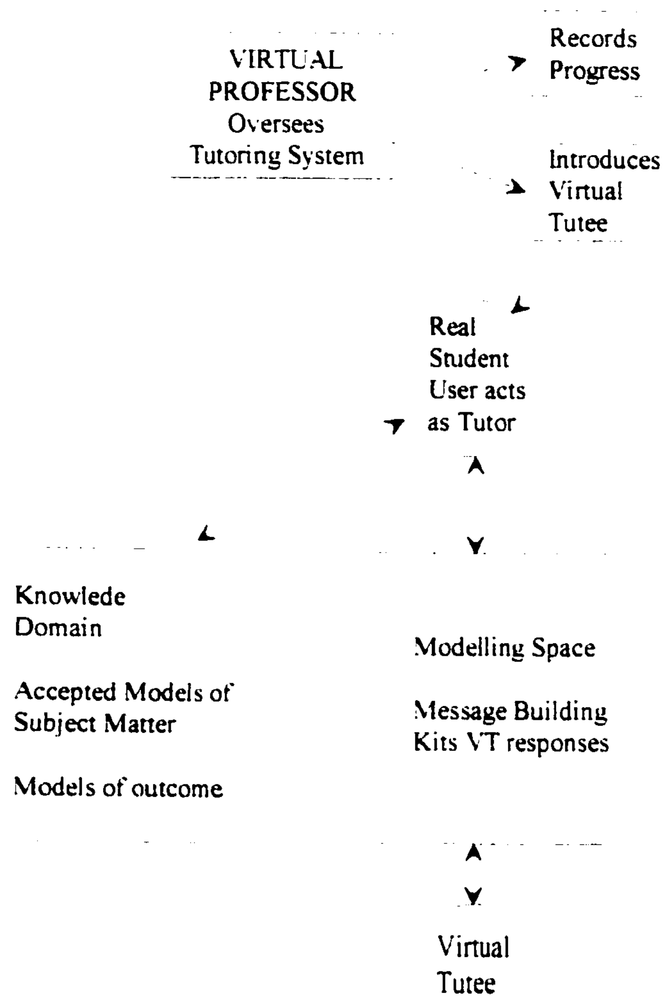

Figure 4-1: Basic Components of the *Virtual Tutee System*

The principal operating unit of the computer program for the *Virtual Tutee System* is the message building kit and its accompanying analysis processor. A message building kit is a Hypercard stack that provides the mechanism for the real student user to send a message to the *virtual tutee*. The stack contains an opening card with the question from the *virtual tutee*. This card's button causes the computer to draw the particular items from a data base stack and thus, develop a menu of message building units as described above. When the student has finished choosing the items, he/she clicks on the "Read and Send Message" button. The student is then shown the selection and is allowed to revise it before sending the message. At this point the real student user should determine that all of the items are relevant and that they are in an order that would make sense to another person. When the message is finally sent, it is moved to another stack for analysis. Figure 4-2 provides a simplified flow chart for a message building kit. The reader may also see the cards of a message building kit shown to the real student user by looking ahead to the figures presented in Appendix 4. The flow charts shown in this chapter are simplified for the purposes of illustrating program functions, and do not, therefore, show every step in the computer program script.

The use of the interface provides the computer program with a predictable range of inputs that can be processed by linear algorithms and, thus, overcomes the difficulties posed by relying on a natural language interface. The analysis processor stack contains the scripts and routines necessary for acting upon the student's selection.

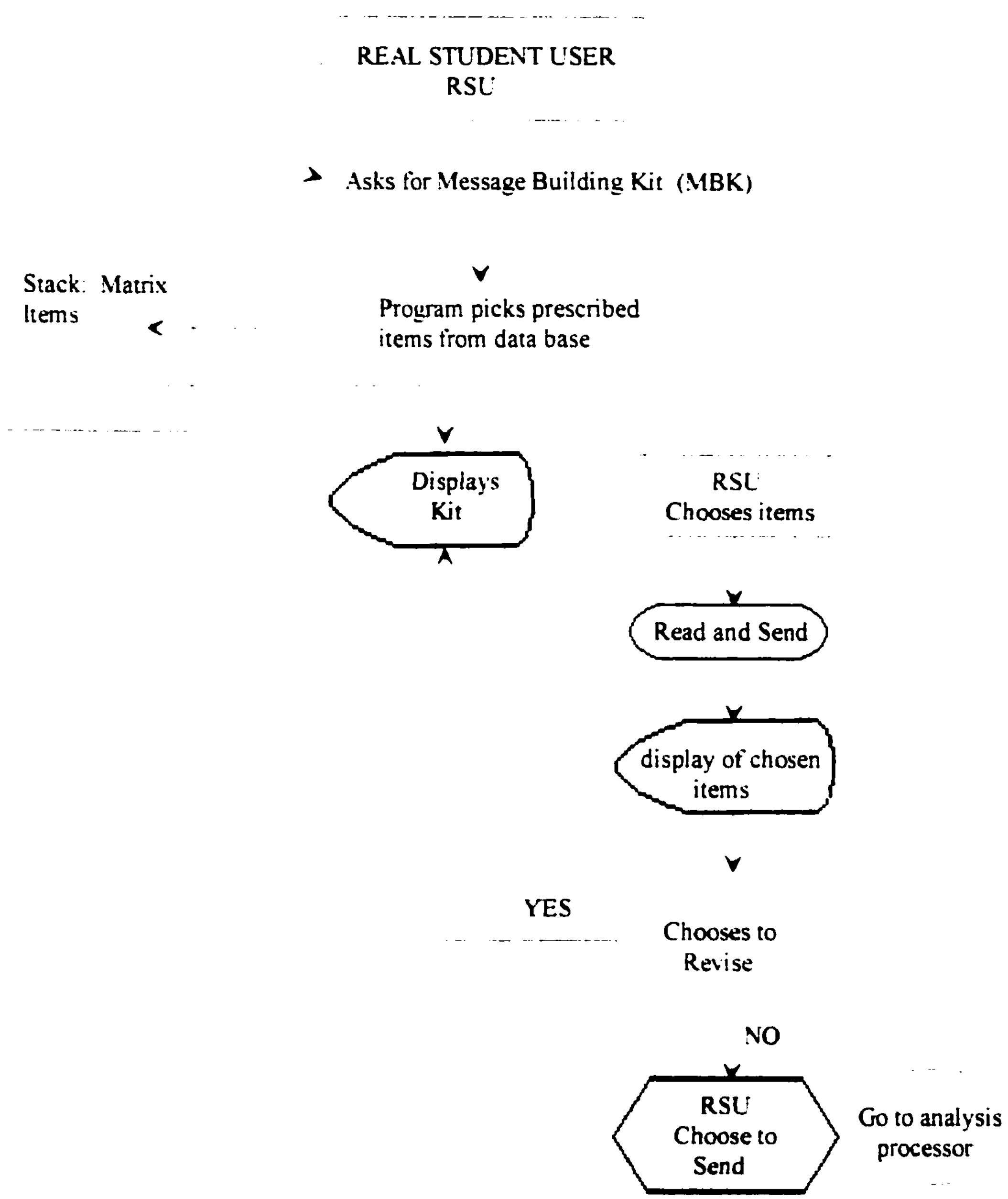

Figure 4-2: Flow Chart for Operation of a Message Building Kit

The user's selection from the message building kit is considered to be his/her model of the topic, and has been entered as a numerical sequence. As an input to the program, the numeric sequence is changed to an alphabetic pattern. The algorithm within the button script then analyzes the pattern and its elements. Based on the analysis, the algorithm in the program assembles an appropriate response from the *virtual tutee* to the real student user. If the input pattern is congruent with a pattern considered to be an excellent one, the algorithm produces a re-statement of the answer to the question asked and asks the real student to confirm its validity. If it is confirmed, the conversation moves on to another topic. If the pattern is slightly deficient, the user is directed to appropriate subquestions and their accompanying answer building kits. These operate in the same way as a message building kit and also have a associated analysis processor. The subquestions have been designed to clarify subtopics within the particular subdomain of the subject matter. When the real student user's input contains distracters, double items, or an unsuitable order, responses are generated that direct the user to return to the original message building kit to revise the message and then send it again before moving on to another topic. Figure 4-3 provides a simplified flow chart for an analysis processor. Again the reader may see the cards and examples of messages coming from the *virtual tutee* that appear by looking ahead to the figures shown in Appendix 4. The flow of messages between the real student user and the virtual

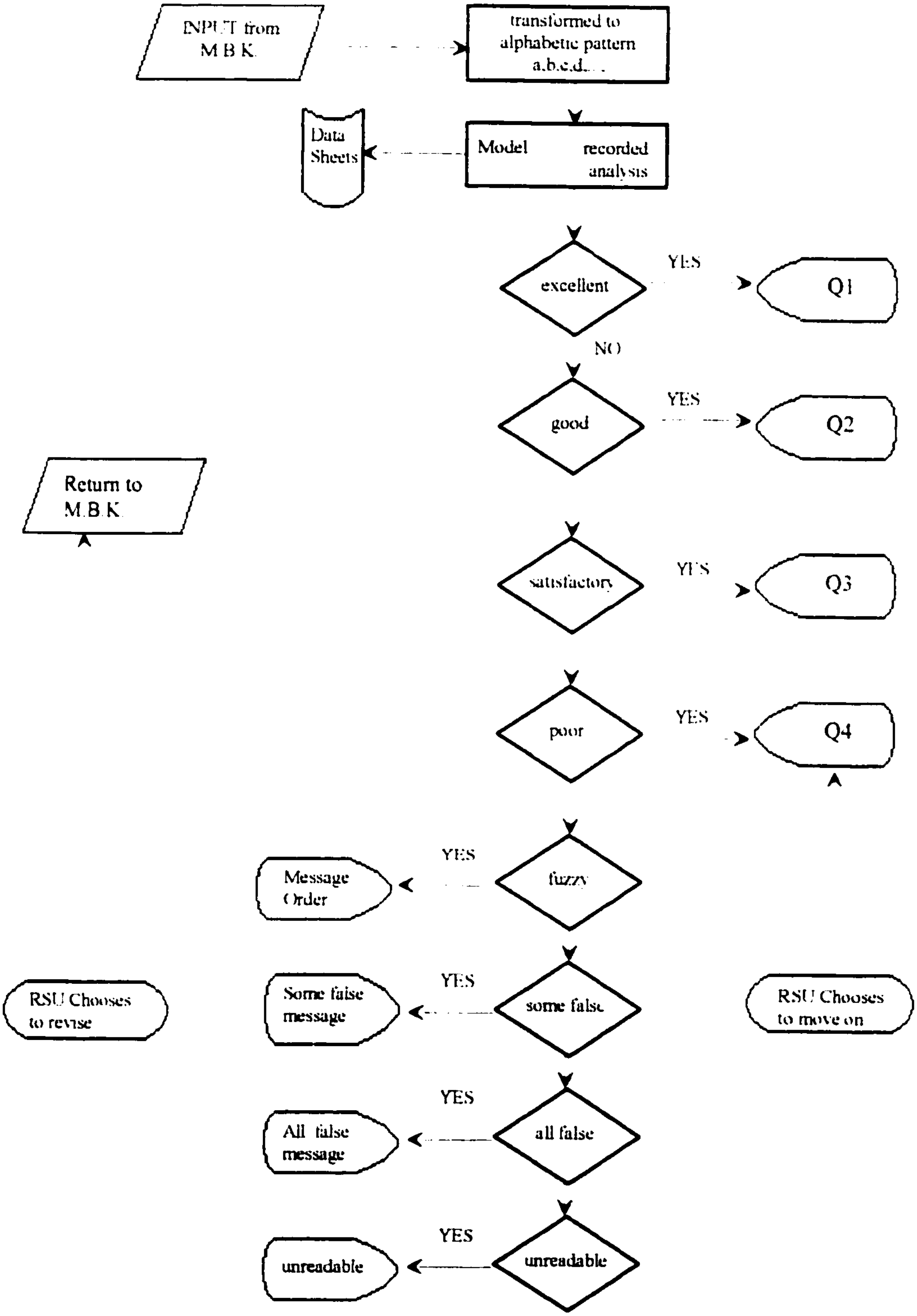

Figure 4-3: Algorithm used to Process a Message from Real Student

participants within the computer program occurs as text printed on the screen. This format has been designed to appear similar to that used in electronic mail communication.

The simulation is organized by modules, each of which is focused on a subdomain of the subject matter. Within each module, there are three Lead Questions, each asking for information about a particular topic within the subdomain. As described above there are four sub-questions associated with each lead question. Sub-question 1 always provides the *virtual tutee's* model of the subject matter and asks the real student to agree or add to it. When the real student's input message for a Lead Question is deficient in some regard, one of the other sub-questions appears as a response from the *virtual tutee*. These ask short questions that should cause the real student to review the prerequisite concepts within the subject domain. The flow is from sub-question 4 back to sub-question 1. This structure emulates the upward spiral of knowledge construction described in Chapter 3 and illustrated by Figure 3-5. Each Lead Question is considered to be a turn of the spiral. After the real student has worked with the three Lead Questions within a module, he/she is asked to quiz the *virtual tutee* by selecting questions. These are answered by the *virtual tutee* and the real student can indicate agreement with the reply or add information by sending a message. When at least some of the questions have been answered, the real student is given the option to conclude the module. Figure 4-4 represents a simple flow chart for the details of

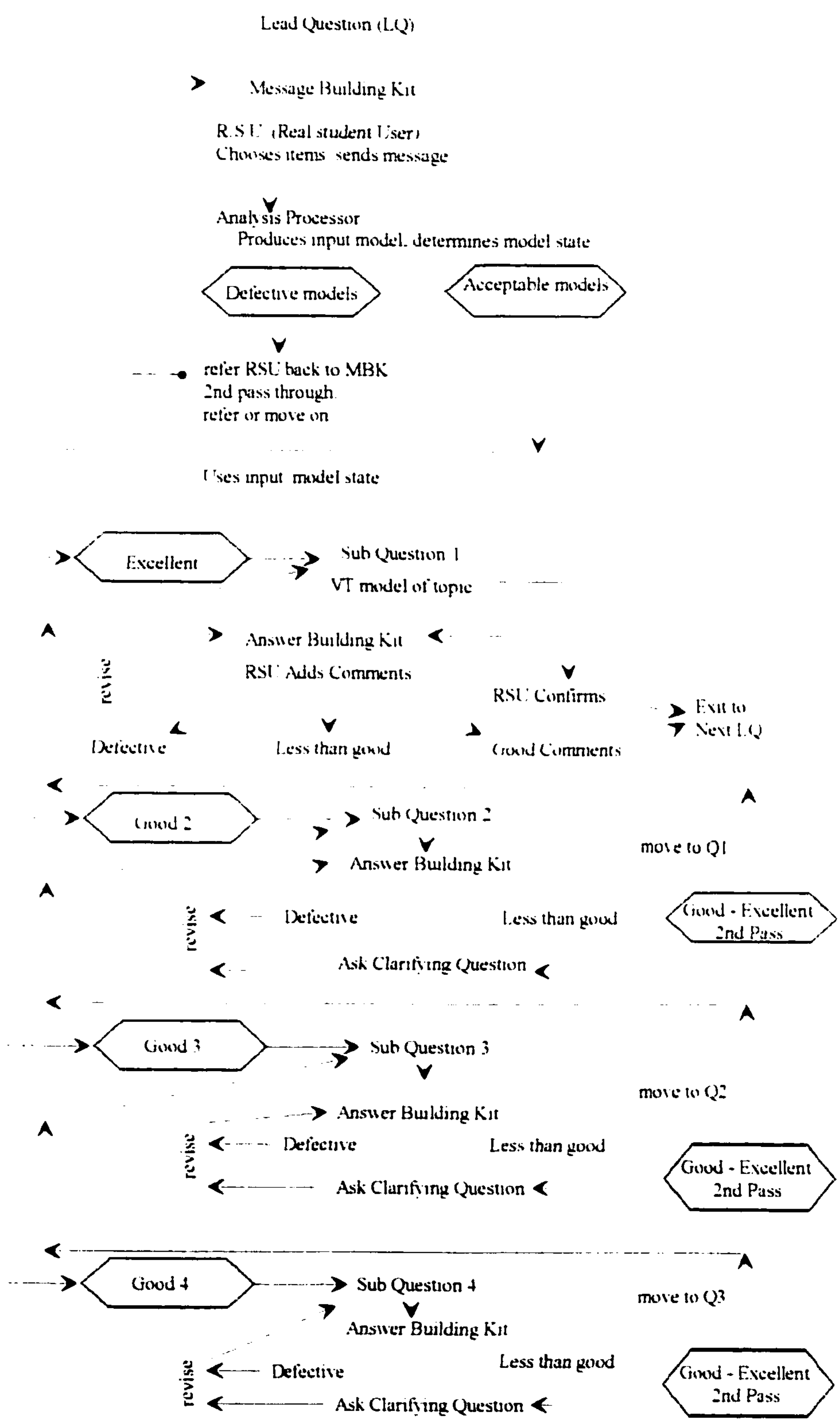

Figure 4-4: Flow Chart of Operations following a Lead Question of a Module

communication from a typical lead question through its associated sub-questions. Figure 4-5 represents an overview of the flow through a module of the *Virtual Tutee System*. Figure 4-6 provides details of the operation of the questioning aspect that ends the module.

The Participants in the *Virtual Tutee System*

Any simulation of the real student within a computer program can only be extremely limited. All of the mental processing that is occurring in that individual can only be inferred by the behaviours demonstrated. The real student participant within a tutoring system is a complex biological entity influenced by many internal and external factors. In Pask's terms this participant is also made up of several interacting p-individuals. The student is able to function in a number of languages, has mathematical skills, and already has background knowledge about the world in general and the subject matter at hand. However, as a consequence of this complexity, the real student has sufficient capability to react to the emerging situations that arise in the relationship with the tutee. Biological tutors perform several types of tasks in the tutoring situation. They provide short concise lessons about specific topics within the subject matter, and test the tutee for the presence or absence of certain concepts. By this process, they diagnose defects in the knowledge structure of the tutee and propose ways to overcome them. They provide encouragement to the tutee and reward the tutee for his/her effort. They may prepare for the tutoring session by reviewing their own

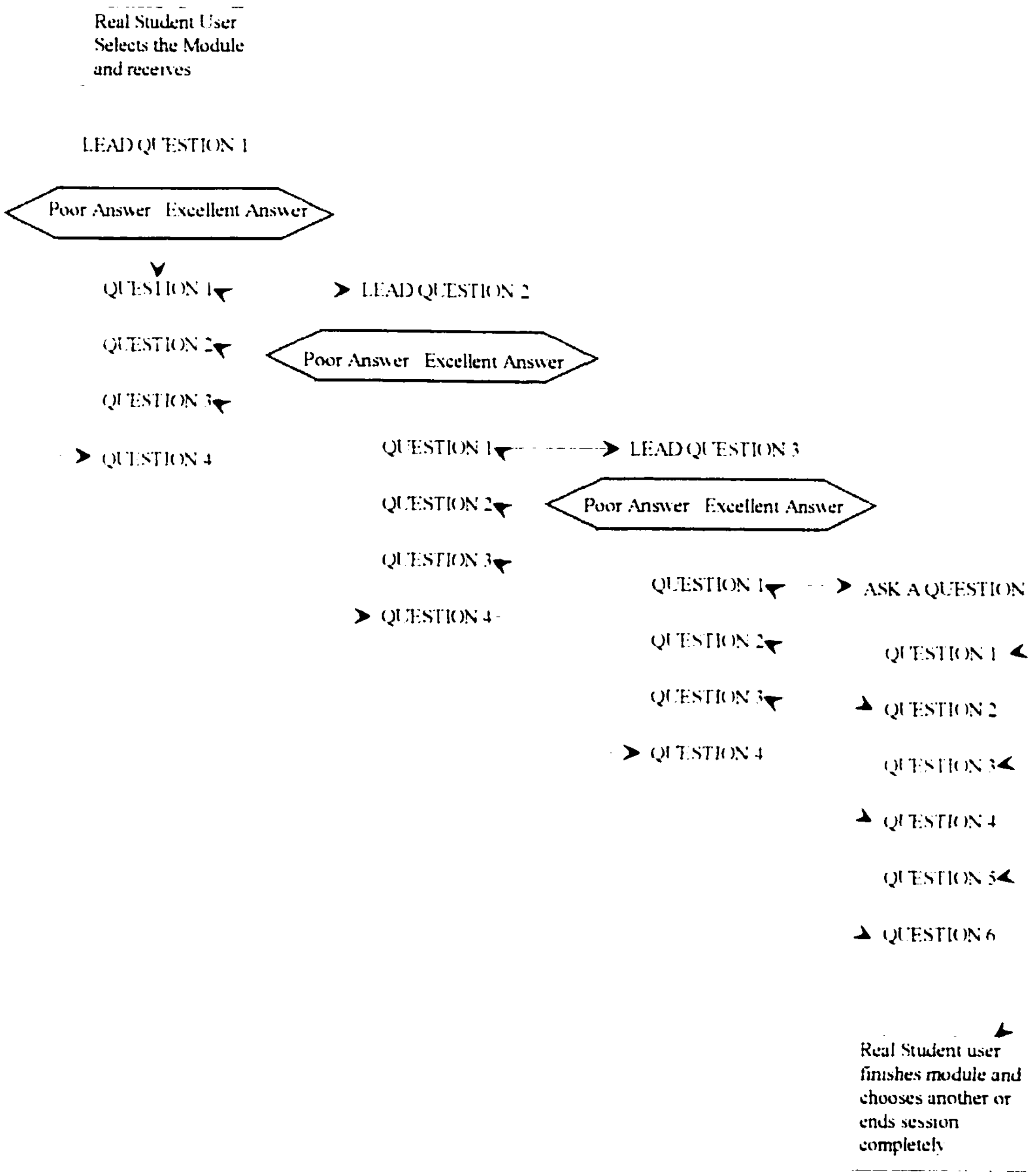

Figure 4-5: Flow Chart of Progress through a Module of the *Virtual Tutee System*

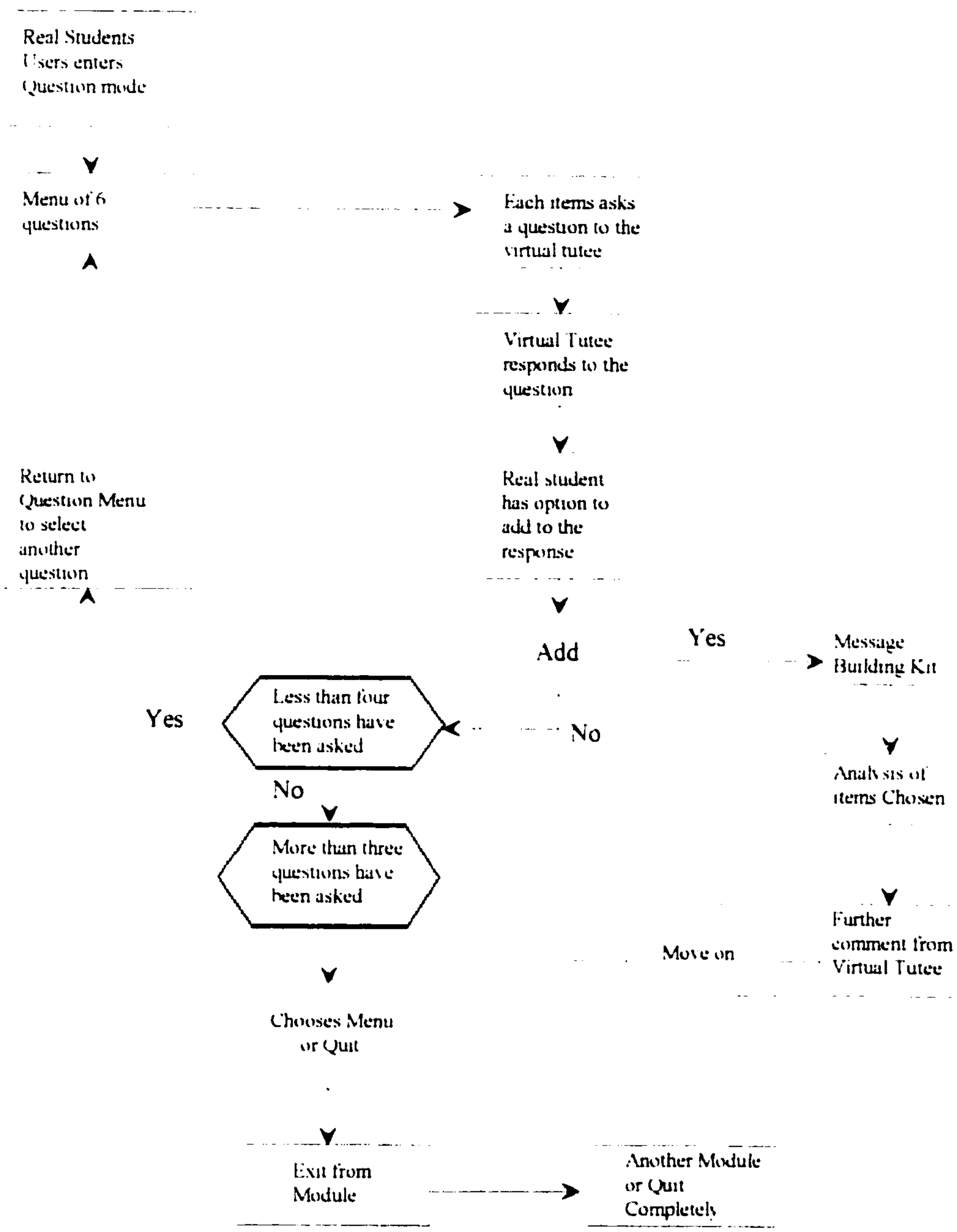

Figure 4-6: Flow Chart of Operation of Questionning Mode of the *Virtual Tutee System*

knowledge models and by looking up information about the subject matter in books. While participating in this simulation, the real student may explore the models of knowledge embedded in a text that is similar to a college textbook chapter about the subject matter, and to explore his/her own mental models of the subject matter by testing them against those of the virtual individual. Placing the real student in the role of the tutor requires him/her to do the diagnosing, goal setting, and planning mentioned previously by Scardamalia, *et al.*. The virtual student has been devised to make statements, pose problems and ask questions of the real student user as if he/she were a human tutee. Thus, the system provides a facilitating structure and the tools to draw on that students own intelligence and knowledge. This design also meets Mitchell and Grogono's fourth requirement that an ITS should pose problems, provide information when asked, and guide the learner towards a goal of mastering the subject matter.

On the other hand, all of the "mental processing" of the virtual student is a consequence of the computer programmer's design and plan. By its nature, the *virtual tutee* is missing such aspects as low motivation, poor self image, and lack of self-confidence. It has no biological aspects such as fatigue, hunger or thirst. Of course, it really has no background knowledge of the world or the subject matter at hand. Any appearance of knowledge is a functional extension of the programmer's knowledge. The Hypercard scripts, or programs and subroutines, built into each analysis stack have been written to simulate the tutee and to develop appropriate responses. By design, there are times when the *virtual tutee* appears to be smart, while at other times it appears to be less knowledgable than the real student. The flow chart in Figure 4-3 illustrating the analysis stack also provides an illustration of the typical operation of the *virtual tutee*. In some of the responses, strictly proper English grammar has been compromised to make the response more typical of that from a college student, although profanity and gross grammatical errors have obviously been avoided.

The introduction of the *virtual professor* into the tutoring dyad follows the suggestions and ideas of Stolurow (1965). This participant, monitors the activities of the real student tutor and the *virtual tutee*. This individual remains mostly hidden in the background of the program. He introduces the program and the *virtual tutee* to the real student at the beginning of the user's session. When the real student finishes the program the *virtual professor* comments on his/her performance.

Control of the Simulated Tutoring Program

There are several levels of control within the software. Consistent with the views of MacKenzie, Scardamalia, Mitchell and Grogono, the real student has the ultimate control over his/her participation in the simulation. Although the computing hardware available processes information in a linear fashion, the simulation allows the real student to explore the various subdomains of the subject matter in a non-linear order that is determined by a combination of the state of the student's knowledge and the choices made at various stages of the interaction. The student also has the option to exit from the program at various convenient points. The use of the real student's input model to determine the flow of the subsequent action removes some of the constraint imposed by the linear processing of the computer capability. In this way, the program is adapting to the real student user as indicated by Mitchell and Grogono's second requirement. The real student makes judgements about the messages coming from the *virtual tutee* and then chooses appropriate ways to respond to them. In this way the student becomes actively involved in the control of the process as described by Scardamalia above.

The control elements within the ITS monitor the changing state of the student's mental model of the subject matter through an analysis of the conversational inputs to the *virtual tutee*. While the computer-based model of the real student is actually hidden from the user's view, it forms the basis for the comments and questions coming from the *virtual tutee*. There is some feedback from the *virtual professor* to the real student. An additional component of the software that is hidden from the user is a recording of the user's inputs. This has been designed into the program to allow a researcher to study the pattern of development of the student's model of the subject matter. This aspect of the program also allows a researcher to re-construct the real student-*virtual tutee* conversation for later analysis. It also provides feedback to the program developer as formative evaluation of the simulation. In addition, a system of recording the time spent on each section of the simulation is incorporated into the data collection aspect that provides the researcher with data about the time spent by the real student on each subdomain.

Capturing Energy for Life Tutorial Conversation

The architecture of the actual simulation follows the general plans described above. Four modules were developed to cover the subject matter lesson. The first module explores the physical concepts related to energy and its forms that must be understood before one encounters the concepts of photosynthesis. The second module follows the text section providing an overview of photosynthesis. The third module is related to the text sections about the light dependent and light independent reactions occurring in photosynthesis and involves more detailed knowledge of biochemistry. The fourth module covers the advanced topics about the movement of protons through chemiosmosis and about the flow of electrons in reduction and oxidation reactions. Figure 4-7 shows a flow chart for the sequence of topics presented for discussion in the actual simulation. The reader is referred to the text chapter included in Appendix 2. For the purpose of illustrating the operation of the simulation for the reader. Appendix 4 contains printed versions of what the real student user sees on the computer monitor screen during the first module. This module introduces students to the general concepts relating to energy and matter. The presentation of these screen views follows the order in which they appear when the student enters certain inputs and clicks upon

Module I: The Nature of Matter and Energy

Lead Question 1: Definition of energy, forms of energy, kinetic and potential energy.

Lead Question 2: Definition of matter, atoms and molecules, transformation of matter in chemical reactions, energy and work in chemical reactions.

Lead Question 3: The sun as the source of energy for life, light and heat as forms of energy, light as a source of energy.

Module II: A Brief Overview of Photosynthesis

Lead Question 1: Transformation of light energy into chemical energy stored in carbohydrate molecules, splitting of water molecules and evolution of oxygen gas.

Lead Question 2: Cellular respiration and the release of the energy from carbohydrate molecules to provided the energy for life functions.

Lead Question 3: The structure and function of the chloroplast as the organelle responsible for photosynthesis.

Module III: A More Detailed View of Photosynthesis

Lead Question 1: Light dependent reactions of photosynthesis, light excites electrons in chlorophyll molecules and the energy of these electrons is used to split water molecules and produce the energy needed in the subsequent reactions.

Lead Question 2: Light independent reactions of photosynthesis, the fixing of carbon following the transfer of electrons, hydrogen ions and energy from the light dependent reactions through the Calvin-Benson Cycle.

Lead Question 3: Tracing the flow of matter and energy through the whole process of photosynthesis.

Module IV: Chemiosmosis and REDOX Reactions

Lead Question 1: Energy driving the flow of electrons and protons (hydrogen ions) across membranes, the establishment of osmotic gradients and production of ATP an energy transfer molecule.

Lead Question 2: The nature of oxidation and reduction reactions, the transfer of electrons through the electron transport chain.

Lead Question 3: A summary of photosynthesis from the perspective of oxidation, reduction and chemiosmotic actions.

Figure 4-7: Flow Chart of Topics Presented in Capturing Energy for Life the appropriate buttons. Examples are provided of complete entries as well as incomplete or deficient entries. A flow chart is provided at the beginning of the Appendix to guide the user through the appendix. In the current prototype format, the progression of the student is controlled to be in a linear fashion. The progression of topics moves from easier to more complicated ones and the quit button is not included in the message building kits. This was done to force the students to complete whole modules for comparison purposes during the testing phase of the project.

Any simulation of reality is incomplete. The *Virtual Tutee System* is limited by several factors. As mentioned above the biological and motivational factors are missing The real student has a limited variety of tutorial interactions by virtue of the structural communications message building kits. This in turn reduces the spontaneous nature of questioning and answering inherent in the real situation. There is also no room for conversation about topics other than those foreseen in the lesson, closely related or not. Although there is an occasional bit of humour coming from the *virtual tutee*, there are no jokes or plays on words. These factors may influence the learning gains inherent in the real tutoring situation through the development of a human-human relationship.

DESIGN AND CONDUCT OF THE EVALUATION STUDY

In order to assess the practical value of the *Virtual Tutee System* and the *Knowledge Modelling Approach* on which it is based, an experimental study of the simulation software was planned. This study was designed by integrating aspects of evaluation described in the literature cited in the previous chapter to provide answers to the focal questions of this project, as well as a general evaluation of the materials and the computer simulation. College students were asked to participate in the testing of the simulation, and data about their performance and reactions to the materials and software were accumulated to provide the basis for the assessment.

Focal Questions of the Study

There were three levels of investigation within this work. At the most general level, there was a study of the commonplace notion that "He who teaches, learns". The focal question at this level was:

> Do students who participate in the simulated tutorial conversation acquire a benefit through tutoring the *virtual tutee*?

A positive answer to this question would provide further evidence to support this widely held view of a teaching-learning situation.

At the theoretical level, a model of the tutoring-learning process was proposed. This model, called the *Knowledge Modelling Approach* and discussed in detail previously, posits that the tutoring-learning process for college students involves an exploration of the knowledge models that are part of the accepted subject matter knowledge base, and the development of mental models of the subject matter as internal representations of these models. This leads to a consequent structuring and restructuring of one's personal knowledge and a consequent ability to demonstrate mastery and understanding of the subject matter. When a student is joined with a peer tutee in a tutorial conversation, the opportunity is provided for the tutoring student to test his/her mental models of the subject matter in a non-threatening environment. Feedback from the peer tutee about these models, as well as further interaction with those of subject matter experts, will help the tutor to improve the accuracy of his/her mental models of the subject matter. The quality of the student's mental models can be inferred from tests of subject matter competence. The focal question at the theoretical level asked:

> How adequate are the mental models of a subject matter that are developed through study strategies that encourage students to examine the structure of the subject matter knowledge and teach it to another individual?

The answer to this question, based on the data from the tests of subject matter competence, would provide evidence supporting the general application of the *Knowledge Modelling Approach*. This is the central issue of this dissertation.

At the experimental level, the *Knowledge Modelling Approach* has been applied to a particular science education situation, the teaching of a college biology textbook chapter about the process of photosynthesis. The actual experimental design was derived from a protocol used by Byrd-Bredbenner and Bauer (1991) in the evaluation of computer assisted instruction in nutrition education. They adopted Solomon's Four-Group Design, one of the experimental designs proposed by Campbell and Stanley (1968), to study student test performance after using nutrition education software. The four group design was suggested by Campbell and Stanley as a means of overcoming the difficulties of non-equivalent groups. Students in two of the four groups were asked to use the computer software. Students in one of the other two groups completed a pretest followed by a posttest, while those in the fourth group completed only the posttest. These test only groups provide evidence to support the use of the posttest scores to infer a benefit from the treatment.

For the testing of the *Knowledge Modelling Approach*, further modifications of Solomon's Four-Group Design were made. Instead of the test only groups, it was decided to have two groups of students who would use the printed text and be guided in their study through the use of study questions, a common teaching and study technique. The use of these groups provides for a comparison of the novel *Virtual Tutee System* with a more conventional approach to independent study. The arrangement did not provide a means of compensating for the effect of the pretest on the posttest. Nor, did it provide a way for determining if the posttest can be successfully answered without the instructional events. These difficulties were overcome in three ways. Firstly, the same multiple choice questions appeared on both the pretest and the posttest. The difference between the tests was the order of the answers and the distracters. Secondly, there were questions written to probe for understanding of the topics at varying levels of knowledge and, although there were some relatively simple questions, most were of sufficient difficulty to make it very difficult for a non-participant in the planned instructional events to answer them correctly. Thirdly, for each type of instruction a test group of students was established who were not exposed to the pretest. They worked with the same materials and completed the same posttest as the students in the other groups who completed both tests. In this way, the outcomes of the pretested students could be compared with the outcomes of those students who only completed the posttest to provide support for the effectiveness of the instructional events. The design for this procedure is summarized in Table 4-1 on the next page.

The focal questions of the study at the experimental level asked:

> How adequate are the mental models of a subject matter that are developed through each study strategy as inferred from the tests of subject matter competence?

> Do the students interacting with the *virtual tutee* demonstrate a superior performance on tests of subject matter competence when compared with those using the study question strategy?

Positive answers to these questions would provide the evidence to answer the previous focal questions, and support the application of the *Knowledge Modelling Approach* to the teaching of specific educational topics through the simulated tutorial conversation. The test scores may be used as evidence from which to infer the relative

Table 4-1: Protocol for Test of the Knowledge Modelling Approach				
	Informed Consent Form			
Observation	Personal Information Sheet Pre-Questionnaire about Attitudes and Experience			
Group	A	B	C	D
Observation	Pretest of subject matter		Pretest of subject matter	
Treatment	Text with Virtual Tutee System		Text with Study Questions	
Observation	Posttest of subject matter			
Observation	Post-questionnaire about attitudes and reactions		Not Observed	

degree to which a student's model of the subject matter is consistent with that of the expert.

In addition to collecting data aimed at answering the focal questions of the study, questionnaires were produced to determine impacts on the student's attitudes to computers and computer use in education. As well, the users of the simulation were asked to answer questions to determine their reactions to this approach to learning about a subject matter.

Experimental Protocol

Fifty Québec college students were recruited to participate in the study and were assigned to four groups as described above and illustrated in Table 4-1. Group A received the pretest, participated in the simulated tutorial conversation and then completed a posttest. Group B only received the posttest after participating in the simulated tutorial conversation. Group C received the pretest, but was asked to complete study questions in place of the simulated tutorial conversation before completing a posttest. Group D also used the study questions strategy but only received the posttest.

All testing was done in the biology department computer laboratory at Champlain Regional College in St. Lambert, Québec. Individual students were assigned to the test groups upon arrival at the site by drawing playing cards. This somewhat random assignment was adjusted in the favour of having more participants assigned to groups (A and B) using the simulation to provide a greater number of software testers. The students read a document about the experiment and signed it to establish their informed consent to be participants in this experiment. Confidentiality of each student's data was assured by the assignment of a user number different from that assigned by the college. Demographic information, age, sex, semester in college, etc., was collected from each subject. Each student then answered the preliminary questionnaire that asked the questions about their experience with tutoring, and experience with computers. Within this questionnaire, are also items about attitudes towards computers and computers in education, as well as items asking about preferences to different study approaches. Group A and C students then answered the pretest with questions about the subject matter. Following the work period, during which the students in Groups A and B were working with the simulation, and students in Groups C and D were answering study questions, all students completed a posttest. The process used to develop these tests has been discussed above. The reader is referred to Appendix 3 to see a copy of the tests. The questions are grouped in a sequence consistent with that of the text chapter and the presented modules in the simulation. Group A and Group B students, the users of the simulation, were also asked to respond to a questionnaire about the simulation following their completion of the posttest. This post-session questionnaire asked questions about the study guide or text chapter, the tests, and the software components. A few questions were included to serve as a modified Turing test, a check on the perception of the possible reality of the virtual or simulated tutee. Other questions were arranged to determine student perceptions about the learning experience and their views on the issue of teaching another as a way to enhance one's own learning. The simulation software also records data about the choices made at each question, the progress of the user through the various modules and components, as well as the time spent on each module. This additional data provided a basis on which to evaluate technical aspects of the software and the student reaction to it.

Statement of Experimental Hypotheses

The author predicted that:

H1: The students who use the *Virtual Tutee System* will demonstrate both a mastery and a consequent understanding of the subject matter as measured by the tests of subject matter competence.

H2: The students who use the study questions approach will also demonstrate both a mastery and a consequent understanding of the subject matter as measured by the tests of subject matter competence.

H3: The students who use the *Virtual Tutee System* will demonstrate superior performance on the tests of subject matter competence compared to those using the study questions approach.

CHAPTER 5: RESULTS AND DISCUSSION OF THE LABORATORY EVALUATION OF THE VIRTUAL TUTEE SYSTEM

The experimental test of the *Virtual Tutee System* was designed to study both how the use of the computer simulation affects the student subjects and how the students view the approach used in the software. The major aim of this test was to provide support for the use of Knowledge Modelling Approach and to provide support for the concept of using simulated tutorial conversation as an instructional strategy. The test was carried out as presented in the previous chapter and the data generated from it are presented with a discussion of them in this chapter.

Fifty students participated in the experiment. All of these were recruited from classes at Champlain Regional College in St. Lambert, Québec. The students were scheduled for three hour testing sessions over a period of ten weeks during the Spring of 1998. All testing was done in the computer laboratory of the biology department using Macintosh computers. This chapter opens with a description of the sample population, and then presents the results of the tests for impacts in the cognitive domain. This is followed by a discussion of the affective impacts of using the Virtual Tutee System. The chapter continues with the results of the student evaluation of the materials and the software, and closes with a discussion of the how these results address the focal questions and hypotheses of the over-all investigation.

DESCRIPTION OF THE SAMPLE POPULATION

Table 5-1 illustrates demographic features of the population of students recruited to participate in the testing. All students were volunteers and were rewarded by the researcher with a simple food snack. Based on the general population features several subgroups were defined for the purpose of the assessment. There are the four groups described by the protocol and labelled as Groups A, B, C and D. Group A and Group B students used the simulation software and text to study about photosynthesis and are described as "users". Those students assigned to Group C and Group D used the same text but employed a study questions approach to learning about the subject matter. These students are described here as "readers".

The groups were fairly evenly divided by sex and age. In general, students were in their second or fourth semester in college. Students in the reading groups had been in college about one year less than students in the user groups. There were more students from the health and pure and applied science programs than from other college programs. This was an intentional consequence of the way subjects had been recruited. The initial request for volunteers was made in two senior biology classes in mid-February at about the third week of classes of the winter semester. The recruitment was done this way because students in these classes were more representative of the target population for instruction in photosynthesis. In addition, these students could gain an academic benefit from their participation as they would be studying photosynthesis later

Table 5-1: Description of the test population and groupings							
		Test Group					
	All	A	B	C	D	Users (A+B)	Readers (C+D)
Total Number of Subjects	50	13	19	8	10	32	18
Female	26	8	9	3	6	17	9
Male	24	5	10	5	4	15	9
Average Age	18.4	18.4	18.3	18.4	18.6	18.3	18.5
Semester in College							
1	4	1	1	1	1	2	2
2	23	3	7	6	7	10	13
3	1	0	1	0	0	1	0
4	17	8	8	0	1	16	1
>4	5	1	2	1	1	3	2
Average	3.0	3.5	3.3	2.4	2.5	3.4	2.5
Biology Level							
None	1	0	0	1	0	0	1
High School or Non-science college course	25	4	8	6	7	12	13
1 College Science course	8	2	2	1	3	4	4
2 College Science courses	7	3	4	0	0	7	0
3 College Science courses	9	4	5	0	0	9	0
Program in College							
Business Administration	3	0	1	1	1	1	2
Commerce	2	0	0	0	2	0	2
Computer Science	2	0	0	2	0	0	2
Creative Arts	5	0	2	1	2	2	3
Social Science	11	3	5	2	1	8	3
Health Sciences	19	8	8	1	2	16	3
Pure & Applied Science	8	2	3	1	2	5	3
Tutoring Experience							
Tutored another person	29	7	12	4	4	19	10
Never tutored	21	6	7	4	6	13	8

in the semester. A second call for volunteers was done in introductory biology and in three humanities classes in April at about the tenth week of classes. This call recruited students from a variety of programs with more varied biology backgrounds.

Another consequence of this selection of students is the uneven distribution of students to the user and reader groups. Initially, there was an intentional assignment of the senior biology students into groups A and B as users and testers of the software. This grouping served as a second pilot test of the computer simulation, assuring its proper operation. It was also intended to have a larger group of users for the purpose of having a sufficient number of student opinions about the *Virtual Tutee System* itself. Had more students volunteered to participate, and, had those who had volunteered actually reported as scheduled, there would have been a larger and broader population of student subjects. As a result, then there would have been a more even distribution across the various groups.

Based on the distribution of students and their varied backgrounds, three sub-groupings were made for the purpose of analyzing the results and assessing the software from several perspectives. The subjects are divided into two levels of biology. Senior biology students are those taking at least the second level college biology course, together with those taking a third level course. Low level biology students are those currently enroled in their first level college course and those with only a high school biology background. The third comparison grouping used in the students' evaluation of the software includes those students who reported having had some experience acting as tutors for another student. Slightly more than half of the subjects are in this group. The vast majority of students had extensive experience with the use of computers and consequently, there were no comparisons made based on these criteria.

During the testing sessions the author was present in the computer laboratory and watched the students at work. Students assigned to Groups C and D, "readers" completed their work in the same room as the computer users, but sat at other lab tables without computers. There were very few questions asked by the students about either the software or the text. The author observed the test situation and particularly watched the way the software program was operating.

THE IMPACT ON STUDENTS -- COGNITIVE DOMAIN

A major aspect of the evaluation study was to determine the impact of the use of virtual tutoring on the learning outcomes of those students participating in the test of the computer simulation with respect to topics about photosynthesis. In addition, the design of the study included a comparative study of the simulated software with the more conventional study questions approach. As mentioned earlier a pretest and a posttest were developed to provide objective measures of these learning outcomes. Referring to the study design shown in Table 4-1 in the previous chapter, students assigned to Groups A and B used the software; while students in Groups C and D were exposed to the text and study questions.

Students in Group A and Group C completed the pretest before beginning their work on the subject matter lesson. The pretest is a parallel form of the posttest, as mentioned earlier. Table 5-2 summarizes the results for this test. ANOVA F tests were done on the pretest data using the method of unweighted means recommended by Keppel (1982) for situations with unequal sample sizes. Comparing Group A to Group C no significant differences were detected. However, when the results for students with more courses in biology (Senior Biology) were compared with those with less experience (Low level Biology), the pretest mean for the senior biology students is shown as 8.7 points higher than that for the Low level biology group. This difference is statistically significant at the $p < 0.05$ level, and might be expected based on the more extensive general science background of the senior biology group. The values reported for the effect size in these comparisons also serve as an indicator that the groups are similar. The purpose of administering the pretest was to determine the background knowledge about photosynthesis of the student participants. It was only administered to Groups A and C in order to provide evidence that the pretest did not bias the performance on the posttest.

As the topics about photosynthesis for the simulation were organized in a series of modules, further investigation of the pretest results was then done by module. The subject matter for each module has been described in Table 4-7. The difficulty and level of detail increases in each successive module. The results by module are shown in

Table 5-2: Pretest scores out of 100					
	Experimental Group		Other Groupings		
	Group A	Group C	Combined Groups A & C	Senior Biology	Low Level Biology
Highest	74	67	74	74	67
Lowest	42	37	37	57	37
Mean	58.2	52.8	56.1	61.9*	53.2*
SD	8.7	9.4	9.4	5.3	9.6
Effect Size	+0.2	-0.4	-	+0.6	-0.3
Number	13	8	21	7	14

*Between these groups ANOVA F:$p<0.05$

Tables 5-3 to 5-6. and were accumulated by studying the performance on those test questions pertinent to each module. No significant differences were found on Group A-Group C comparisons. Nor, were there significant differences detected between the Senior biology group and the Low level biology group for Modules I, III and IV. Module I introduces students to general topics about matter and energy, and it appears that all of the student subjects had similar background knowledge about these topics. However, there is a differential performance between the senior biology students and those with a low level experience on pretest questions about the content of Module II which introduces photosynthesis as seen in Table 5-4. Again this seems to be consistent with the more developed scientific knowledge base of these students. The pattern does not continue into Modules III and IV. These modules cover subject matter considered to be more detailed and difficult, and it seems, from the relatively low means, that all the students had relatively less developed knowledge about these topics.

The most important aspect of the study was to determine if students actually develop their knowledge of the subject matter through the use of the simulation and reading assignment. When the over all posttest results were compared for the four experimental groups, the simulation users attained similar results to the text readers. The average for all students was 62.5 and the different groups showed similar averages, as can be seen in Table 5-7. ANOVA F tests were done on the posttest data again using the method of unweighted means recommended by Keppel (1982) for situations with

Table 5-3: Pretest scores out of 100 for Module I (Nature of Matter and Energy)					
	Experimental Group		Other Groupings		
	Group A	Group C	Combined Groups A & C	Senior Biology	Low Level Biology
Highest	100	95	100	100	95
Lowest	55	45	45	60	45
Mean	77.7	75.6	76.9	81.4	74.6
SD	15.3	18.3	16.5	12.5	17.8
Effect Size	+0.05	-0.08	-	+0.3	-0.1
Number	13	8	21	7	14

Table 5-4: Pretest scores out of 100 for Module II (A Brief Overview of Photosynthesis)					
	Experimental Group		Other Groupings		
	Group A	Group C	Combined Groups A & C	Senior Biology	Low Level Biology
Highest	77	69	77	77	69
Lowest	42	35	35	46	35
Mean	61.3	53.4	58.2	65.9*	54.4*
SD	11	13	12.4	9.9	11.7
Effect Size	+0.3	-0.4	-	+0.6	-0.3
Number	13	8	21	7	14

*Between these groups ANOVA F:p<0.05

Table 5-5: Pretest scores out of 100 for Module III (Detailed View of Photosynthesis)					
	Experimental Group		Other Groupings		
	Group A	Group C	Combined Groups A & C	Senior Biology	Low Level Biology
Highest	65	54	65	65	54
Lowest	12	4	4	15	4
Mean	34.0	26.4	31.1	37.4	28.0
SD	14.9	15.4	15.5	16.3	14.1
Effect Size	+0.2	-0.3	-	+0.4	-0.2
Number	13	8	21	7	14

Table 5-6: Pretest scores out of 100 for Module IV (Chemiosmosis and REDOX)					
	Experimental Group		Other Groupings		
	Group A	Group C	Combined Groups A & C	Senior Biology	Low Level Biology
Highest	71	59	71	71	65
Lowest	29	35	29	35	29
Mean	48.9	45.6	47.6	51.3	45.8
SD	12.5	8.7	11.3	10.8	11.2
Effect Size	+0.1	-0.2	-	+0.3	-0.2
Number	13	8	21	7	14

Table 5-7: Posttest scores out of 100					
	All Subjects	Experimental Group			
		Group A	Group B	Group C	Group D
		Simulation Users		Text Readers	
Highest	93	78	93	85	84
Lowest	36	36	43	41	47
Mean	62.5	62	62.7	64.6	60.9
SD	13.7	13.6	15.2	14.1	9.9
Effect Size		-0.04	+0.01	+0.15	-0.12
Number	50	13	19	8	10

Table 5-8: Comparison of Pretest and Posttest scores out of 100			
	Group A & C Combined		
	Pretest	Posttest	
Highest	74	85	
Lowest	37	36	
Mean	56.1*	63*	
SD	9.4	13.8	
Effect Size		+0.6	
Number	21	21	

*Between these groups ANOVA F:p<0.05

unequal sample sizes. No significant differences among the four groups were detected using this procedure. Calculation of effect sizes further indicates that there is little difference among the groups.

A within subjects ANOVA was performed to compare the pretest results for all students in group A and group C with their posttest results. The results, summarized in Table 5-8, indicate that there is a statistically significant difference at the $p < 0.05$ level between the performance on the pretest and the performance on the posttest. This implies that these students have acquired knowledge of the subject matter between the test administrations during the testing session. Again effect size calculations support this view. Since groups A and C were constituted to test the possible effect of the pretest on the posttest results, and since there are no significant differences detected among the four groups, one may conclude that the posttest observations are not likely to be the result of exposure to the test items through the pretest. Therefore, one may infer that the difference in performance between the two tests is a consequence of the treatments followed by the students in the four groups. That is to say, those students using the simulation software and those students using the reading and study question method all acquired a benefit from their study of the subject matter content. Table 5-9 shows the comparison between the overall posttest scores of users (combining groups A and B) and readers (combining groups C and D). Again there is little difference in the performance of the two groups and no significant differences were detected by the

Table 5-9: Posttest scores out of 100					
	All Subjects	Combined Groups		Other Groupings	
		Readers Groups C & D	Users Groups A & B	Senior Biology	Low Level Biology
Highest	93	85	93	93	85
Lowest	36	41	36	49	36
Mean	62.5	62.5	62.4	69.7*	59.1*
SD	13.7	12.1	14.6	13.2	12.6
Effect Size		0	0	+0.5	-0.2
Number	50	18	32	16	34

*Between these groups ANOVA F:p<0.01

ANOVA method. However, in this table additional data is reported about the comparison of students with low biology background with the senior biology students. The data for the senior biology students show a better overall performance by these students. This difference may be the effect of the difference in background knowledge, of these students as well as their motivation and interest in the subject matter.

One of the issues in the evaluation of student learning through computer aided instruction is the differential progress and routes through the program. Because each student user actually has a slightly different experience, it is difficult to make definite comparisons. To partially alleviate this problem, sub-scores based on specific groups of questions were taken from the tests of student knowledge for each of the modules as presented in the simulation. All the students using the simulation completed Module I which introduces basic concepts of matter and energy. The overall results are presented in Table 5-10 and again indicate a similar benefit for all students. Here the higher scores may also be a reflection of the time and effort invested in this section, as each student user spent more time, about 49 minutes, on this section than on any other module. Pretest and posttest comparisons, shown in Table 5-11, again show a significant difference indicating an effect from the treatments involved. Users and readers have similar results and the higher level biology students again perform significantly better than those students with a lower level biology background, as illustrated by the data shown in Table 5-12.

Table 5-10: Posttest scores out of 100 for Module I (Nature of Matter and Energy)					
	All Subjects	Experimental Group			
		Group A	Group B	Group C	Group D
		Simulation Users		Text Readers	
Highest	100	100	100	100	100
Lowest	35	40	35	65	50
Mean	84	81.5	88.2	85.6	78.5
SD	16.2	18.2	14.8	12.6	16.3
Effect Size	-	-0.2	+0.3	+0.1	-0.3
Number	50	13	19	8	10

Table 5-11: Comparison of Pretest and Posttest scores out of 100 for Module I (Nature of Matter and Energy)			
	Group A & C Combined		
	Pretest	Posttest	
Highest	100	100	
Lowest	45	40	
Mean	76.9*	83.1*	
SD	16.5	16.4	
Effect Size	-	+0.4	
Number	21	21	

*Between these groups ANOVA F:$p<0.05$

Table 5-12: Posttest scores out of 100 for Module I (Nature of Matter and Energy)					
	All Subjects	Combined Groups		Other Groupings	
		Readers Groups C & D	Users Groups A & B	Senior Biology	Low Level Biology
Highest	100	100	100	100	100
Lowest	35	50	35	80	35
Mean	84.1	81.7	85.5	93.8*	79.6*
SD	16.2	15.2	14.6	6.5	17.4
Effect Size	-	-0.2	+0.1	+0.6	-0.3
Number	50	18	32	34	16

*Between these groups ANOVA F:p<0.01

Similar comparisons were done for Modules II and III. Only 29 simulation users were able to proceed to work on Module II which introduces the student to basic principles of photosynthesis. Less time was spent on this module than on Module I with the average being about 35 minutes. Because it was considered that little could be gained by spending less than twenty minutes working on this module, the data for those students was eliminated from the study. This left twenty-two individuals who used the simulation to compare with the eighteen readers. Again no significant difference is detected across the four groups as presented in Table 5-13. Pretest to posttest comparisons indicate an improvement on the Module II scores as seen in Table 5-14. Users and readers again obtain similar results but as has been the pattern the senior biology students perform significantly better than their low level peers as presented in Table 5-15 for Module II questions.

For Module III there were only 13 users who spent more than 20 minutes working on more detailed information about the chemical reactions of photosynthesis. Table 5-16 indicates a similar benefit across the four groups, although the scores are considerably reduced when compared with those obtained in Modules I and II. Comparing the pretest to the posttest results (Table 5-17), one can assume that a benefit, has resulted from the experience. In this case, the users, readers, and both groups of biology students acquired similar benefits with no significant differences detected as shown in Table 5-18.

Table 5-13: Posttest scores out of 100 for Module II (A Brief Overview of Photosynthesis)					
	All Subjects	Experimental Group			
		Group A	Group B	Group C	Group D
		Simulation Users		Text Readers	
Highest	96	96	89	96	81
Lowest	39	62	39	46	50
Mean	65.4	75.3	60.8	68.8	58.8
SD	14.8	11.4	14.9	16.6	9.3
Effect Size		+0.7	-0.2	+0.3	-0.4
Number	40	7	15	8	10

Table 5-14: Comparison of Pretest and Posttest scores out of 100 for Module II (A Brief Overview of Photosynthesis)			
	Group A & C Combined		
	Pretest	Posttest	
Highest	77	96	
Lowest	35	46	
Mean	57.4*	71.8*	
SD	13.5	14.8	
Effect Size	-	+1.0	
Number	15	15	

*Between these groups ANOVA $F: p<0.01$

Table 5-15: Posttest scores out of 100 for Module II (A Brief Overview of Photosynthesis)					
	All Subjects	Combined Groups		Other Groupings	
		Readers Groups C & D	Users Groups A & B	Senior Biology	Low Level Biology
Highest	96	96	96	96	96
Lowest	39	46	39	50	38
Mean	64.4	63.3	65.3	74.0*	60.3*
SD	14.8	16.0	15.5	13.3	13.5
Effect Size	-	-0.07	+0.06	+0.6	-0.3
Number	40	18	22	12	28

*Between these groups ANOVA F:$p<0.01$

Table 5-16: Posttest scores out of 100 for Module III (Detailed View of Photosynthesis)					
	All Subjects	Experimental Group			
		Group A	Group B	Group C	Group D
		Simulation Users		Text Readers	
Highest	100	58	89	81	100
Lowest	8	30	8	15	15
Mean	45.7	41.5	46.7	46.2	46.6
SD	23.6	12.3	25.6	22.6	26.6
Effect Size	-	-0.2	+0.04	+0.02	+0.04
Number	31	5	8	8	10

Table 5-17: Comparison of Pretest and Posttest scores out of 100 for Module III (Detailed View of Photosynthesis)			
	Group A & C Combined		
	Pretest	Posttest	
Highest	54	81	
Lowest	3	15	
Mean	27.2*	44.4*	
SD	13.4	19.4	
Effect Size	-	+1.0	
Number	13	13	

*Between these groups ANOVA F:$p<0.01$

Table 5-18: Posttest scores out of 100 for Module III (Detailed View of Photosynthesis)					
	All Subjects	Combined Groups		Other Groupings	
		Readers Groups C & D	Users Groups A & B	Senior Biology	Low Level Biology
Highest	100	100	89	89	100
Lowest	8	15	8	27	8
Mean	45.7	46	44.7	53.4	43.0
SD	23.6	24.9	21.6	21.5	23.7
Effect Size	-	+0.01	-0.04	+0.3	-0.1
Number	31	18	13	8	23

Module IV focuses on the actual proton and electron movements that are important to the chemical process of photosynthesis. This topic area can be considered as an advanced topic and is conceptually difficult. Only four simulation users were able to move on to this module. Of these, three students spent more than twenty minutes and were able to score 29.4, 52.9 and 76.5 respectively on questions for this section. Two of these students were part of the senior biology group and one of these attained the highest score. The score of 52.9 was attained by a student considered to be in the lower level biology group. In fact the students with the two lowest scores were from non-science programs. No statistical comparisons were made on the data generated by these students. Unfortunately, the reduction of numbers proceeding to each successive module, limits the assessment of the complete simulation software package.

In studying the comparisons, it is important to remember that the subject matter of the modules becomes more technical and conceptually difficult from I to IV. Also, in an typical biology course, college students would not be expected to master a chapter on photosynthesis within a few hours of independent study, but rather, they would study this topic over three or four days and receive classroom instruction to assist in their study of the material.

For the reading students (Groups C and D), it was not possible to record the time spent on the various sections. These students were free to move through the chapter at their own pace. They were asked to complete the study questions found at the end of the chapter as a study strategy. Some students combined this strategy with other strategies such as underlining and highlighting. The reading students achieved higher scores on Module I than on any other, with scores falling off considerably as they move on to questions for Modules III and IV. Again this would be consistent with the increasing difficulty of the subject matter involved and probably more time and effort was invested in the material at the beginning of the chapter.

Because the learning tasks assigned to both the computer users and the readers required an involvement with written text, the students reading level or ability may affect his/her performance on the tests. Students in the lower level biology group were tested for reading level using the Nelson-Denny Reading Test. The results of this test indicated that most of these students were average or below average readers for their academic grade level. This made it difficult to determine if there is an interaction of reading level with posttest performance. The senior biology students were not tested for reading level. However, these students, based on their academic experience, have most likely developed the reading skills necessary for extracting information from textbooks and these skills aid them in achieving higher scores on tests. It would be interesting to investigate this issue more fully in subsequent experimental tests of these materials.

IMPACT ON STUDENTS -- AFFECTIVE DOMAIN

Another aspect that was considered in the study was the impact of the use of the simulation on the attitudes of students towards computers and their use in education. Students were asked five questions on the pre-questionnaire to determine these attitudes. The data shown in Tables 5-19 to 5-23, on the following pages demonstrate that almost all the student subjects (98%) expressed positive attitudes about wanting to know more about computers and considered being able to use a computer as an important skill. A considerable majority (84%) were also eager to learn new applications and about 78 percent felt content to spend time learning how to use a new computer program. Although the question about learning school subjects was put in a negative sense, 81.7 percent of the students disagreed with the statement indicating a positive attitude toward the use of computers in education. The attitudes expressed in the survey were similar across all the student groupings used in this study.

Similar questions were asked to the simulation users on the post-questionnaire and their responses for three of these questions are summarized in Tables 5-24 to 5-26. The opinions expressed by the users on these questions remain generally positive but decline somewhat. To compare the attitudes on the pre-questionnaire and the post questionnaire an index of attitudes was developed by averaging the replies to similar questions. This comparison is illustrated in Table 5-27 for all users. An analysis of variance for a within subjects comparison indicates a statistically significant difference between the attitudes at the $p = 0.01$ level. This decline in their enthusiasm might be connected to the effort involved and required to learn how to use the simulation and become involved enough in the subject matter to develop satisfactory answers to the tutee's questions.

On both the pre-questionnaire and the post-questionnaire, students were asked about study preferences. From the data presented in Tables 5-28 to 5-32, it appears that the majority of students do like to read books about subjects, a not unexpected finding, and like to answer study questions. The students in the reading group did show a somewhat lower interest in the book and study question approach than the users on the pre-questionnaire. Interestingly, although the users showed a slight decline in their enthusiasm for computers following their experience, the majority would not prefer to use the book and study question approach. Most users (80.7%) expressed their over all satisfaction with the simulation approach by agreeing with the statement: "I liked the computer-based tutoring as a way of learning about a subject matter" as shown in Table 5-32.

Table 5-19: Pre-Questionnaire item: I would like to know more about computers.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	27	54	11	61.1	16	50	9	56.3	7	43.8	10	52.6
Agree	22	44	7	38.9	15	46.9	7	43.8	8	50	8	42.1
Disagree	1	2	0	0	1	3.1	0	0	1	6.3	1	5.3
Strongly disagree	0	0	0	0	0	0	0	0	0	0	0	0
Total	50.0	100.0	18.0	100.0	32.0	100.0	16.0	100.1	16.0	100.1	19.0	100.0

Table 5-20: Pre-Questionnaire item: Being able to use a computer is an important skill in the modern world.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	43	86	17	94.4	26	81.3	13	81.3	13	81.3	15	78.9
Agree	6	12	1	5.6	5	15.6	2	12.5	3	18.7	3	15.8
Disagree	1	2	0	0	1	3.1	1	6.3	0	0	1	5.3
Strongly disagree	0	0	0	0	0	0	0	0	0	0	0	0
Total	50.0	100.0	18.0	100.0	32.0	100.0	16.0	100.1	16.0	100.0	19.0	100.0

Table 5-21: Pre-Questionnaire item: I am eager to learn about new applications of computer technology.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	14	28	5	27.8	9	28.1	5	31.3	4	25	4	21.1
Agree	28	56	10	55.6	18	56.3	8	50.0	10	62.5	11	57.9
Disagree	6	12	2	11.1	4	12.5	2	12.5	2	12.5	3	15.8
Strongly disagree	2	4	1	5.6	1	3.1	1	6.3	0	0	1	5.3
Total	50.0	100.0	18.0	100.1	32.0	100.0	16.0	100.1	16.0	100.0	19.0	100.1

Table 5-22: Pre-Questionnaire item: I am relaxed and content to spend time learning how to use a new program.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	12	24	6	33.3	6	18.8	2	12.5	4	25	2	10.5
Agree	27	54	8	44.4	19	59.4	9	56.3	10	62.5	11	57.9
Disagree	10	20	4	22.2	6	18.8	4	25	2	12.5	5	26.3
Strongly disagree	1	2	0	0	1	3.1	1	6.3	0	0	1	5.3
Total	50.0	100.0	18.0	99.9	32.0	100.1	16.0	100.1	16.0	100.0	19.0	100.0

Table 5-23: Pre-Questionnaire item: I do not like to learn about school subjects through computers.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	0	0	0	0	0	0	0	0	0	0	0	0
Agree	9	18.4	4	22.2	5	16.1	3	20.0	2	12.5	2	11.1
Disagree	28	57.2	9	50	19	61.3	9	60	10	62.5	11	61.1
Strongly disagree	12	24.5	5	27.8	7	22.6	3	20	4	25	5	27.8
Total	49.0	100.1	18.0	100.0	31.0	100.0	15.0	100.0	16.0	100.0	18.0	100.0

Table 5-24: Post-Questionaire Item: I am less afraid of computers after this experience.								
	All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	11	35.5	5	33.3	6	37.5	7	38.9
Agree	12	38.7	7	46.7	5	31.3	6	33.3
Disagree	6	19.4	2	13.3	4	25	3	16.7
Strongly disagree	2	6.5	1	6.7	1	6.3	2	11.1
Total	31.0	100.1	15.0	100.0	16.0	100.1	18.0	100.0

Table 5-25: Post-Questionnaire Item: I would like to know more about computers.								
	All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	13	41.9	5	33.3	8	50	7	38.9
Agree	15	48.4	8	53.3	7	43.8	9	50
Disagree	2	6.5	1	6.7	1	6.3	1	5.6
Strongly disagree	1	3.2	1	6.7	0	0	1	5.6
Total	31.0	100.0	15.0	100.0	16.0	100.1	18.0	100.1

Table 5-26: Post-Questionaire Item: I do not like the idea of learning about school subjects through computers.								
	All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	4	12.9	2	13.3	2	12.5	2	11.1
Agree	2	6.5	1	6.7	1	6.3	1	5.6
Disagree	17	54.8	10	66.7	7	43.8	9	50
Strongly disagree	8	25.8	2	13.3	6	37.5	6	33.3
Total	31.0	100.0	15.0	100.0	16.0	100.1	18.0	100.0

Table 5-27: Comparison of Attitude Index from Pre- to Post-Questionnaire		
	All Users Group A & B	
	Pre-Questionnaire	Post-Questionnaire
Highest	4	4
Lowest	2.67	1
Mean	3.45*	3.09*
SD	0.36	0.63
Number	31	31

*ANOVA F: $p<0.01$

Table 5-28: Pre-Questionnaire item: I like to read a book about a subject matter.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	5	10	3	16.7	2	6.3	1	6.3	1	6.3	2	10.5
Agree	32	64	7	38.9	25	78.1	12	75	13	81.3	15	78.9
Disagree	12	24	7	38.9	5	15.6	3	18.8	2	12.5	2	10.5
Strongly disagree	1	2	1	5.6	0	0	0	0	0	0	0	0
Total	50.0	100.0	18.0	100.1	32.0	100.0	16.0	100.1	16.0	100.1	19.0	99.9

Table 5-29: Pre-Questionnaire item: I like to answer study questions found at the end of a chapter to assist me in mastering the subject matter of a textbook chapter.

	All Students		Readers Group C & D		All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	12	24	3	16.7	9	28.1	6	37.5	3	18.8	7	36.8
Agree	24	48	7	38.9	17	53.1	8	50.0	9	56.3	9	47.4
Disagree	13	26	8	44.4	5	15.6	2	12.5	3	18.8	3	15.8
Strongly disagree	1	2	0	0	1	3.1	0	0	1	6.3	0	0
Total	50.0	100.0	18.0	100.0	32.0	99.9	16.0	100.0	16.0	100.2	19.0	100.0

Table 5-30: Post-Questionaire Item: I would prefer to read a book about a subject matter.								
	All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	3	10	1	6.7	2	13.3	2	11.1
Agree	7	23.3	3	20.0	4	26.7	5	27.8
Disagree	18	60	11	73.3	7	46.7	10	55.6
Strongly disagree	2	6.7	0	0	2	13.3	1	5.6
Total	30.0	100.0	15.0	100.0	15.0	100.0	18.0	100.1

Table 5-31: Post-Questionnaire Item: I would prefer to answer study questions found at the end of a chapter rather than work with a computer program.								
	All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	3	9.7	1	6.7	2	12.5	2	11.1
Agree	5	16.1	3	20	2	12.5	3	16.7
Disagree	18	58.1	10	66.7	8	50	11	61.1
Strongly disagree	5	16.1	1	6.7	4	25	2	11.1
Total	31.0	100.0	15.0	100.1	16.0	100.0	18.0	100.0

Table 5-32: Post-Questionaire Item: I liked the computer based tutoring as a way of learning about a subject matter.								
	All Users Group A & B		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	6	19.4	2	13.3	4	25	5	27.8
Agree	19	61.3	11	73.3	8	50	9	50
Disagree	4	12.9	1	6.7	3	18.8	2	11.1
Strongly disagree	2	6.5	1	6.7	1	6.3	2	11.1
Total	31.0	100.1	15.0	100.0	16.0	100.1	18.0	100.0

STUDENT EVALUATION OF MATERIALS AND SOFTWARE

Several of the questions on the post-questionnaire asked students to evaluate the materials used during the testing session. The data collected from these questions is discussed in the following pages.

The Study Guide

All students found the printed study guide that imitates a biology text chapter to be at least satisfactory, while 40 percent of them considered it to be very good. The data for these questions is presented in Tables 5-33 and 5-34. More of the senior level biology students, 56.3 percent, considered that it was in the very good category, while only 25 percent of the lower level biology students considered it to be at this level. The majority of the users, 75 percent, considered that it compared favourably with a typical college textbook. Again the lower level biology students were more likely to report that it differed. It should be noted that the study guide does differ from a college biology textbook by the absence of colour in the illustrations and diagrams. Another perceived difference might be that the study guide was inserted in a loose leaf binder rather than appearing as a bound book.

Tests

Tables 5-35 and 5-36 contain a summary of the data collected from questions about the pre-test and post-test. All students found the tests to be at least satisfactory as a measure of their knowledge of the subject matter. The senior level biology students

Table 5-33: How would you evaluate the printed study guide?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Good	13	40.6	9	56.3	4	25	9	47.4
Satisfactory	19	59.4	7	43.8	12	75	10	52.6
Poor	0	0	0	0	0	0	0	0
Not Satisfactory	0	0	0	0	0	0	0	0
Total	32.0	100.0	16.0	100.1	16.0	100.0	19.0	100.0

Table 5-34: How does the study guide compare with a general college text book?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Similar	8	25	6	37.5	2	12.5	5	26.3
Similar	16	50	7	43.8	9	56.3	8	42.1
Not Similar	8	25	3	18.8	5	31.3	6	31.6
Total	32.0	100.0	16.0	100.1	16.0	100.1	19.0	100.0

Table 5-35: How well did the printed test questions evaluate your knowledge of photosynthesis?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Good	14	45.2	9	60	5	31.3	10	55.6
Satisfactory	17	54.8	6	40	11	68.8	8	44.4
Poor	0	0	0	0	0	0	0	0
Not Satisfactory	0	0	0	0	0	0	0	0
Total	31.0	100.0	15.0	100.0	16.0	100.1	18.0	100.0

Table 5-36: How similar is the printed test to a college level test?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Similar	8	25.8	6	40.0	2	12.5	6	33.3
Similar	21	67.7	8	53.3	13	81.3	11	61.1
Not Similar	2	6.5	1	6.7	1	6.3	1	5.6
Total	31.0	100.0	15.0	100.0	16.0	100.1	18.0	100.0

evaluated them highly, while the lower level found them to be less than satisfactory. Students with tutoring experience also rated the test at the higher level. Most students in all categories reported the tests to be similar to college tests.

Simulation Software

The author was present in the computer laboratory and observed the thirty-two users as they worked at the program. At no time did the program crash, or stop working. The student users do maintain some control over the program operation. The program allows them to change their choices before sending them to Jack, the *virtual tutee*. Sometimes he asks them to revise their inputs when their input is not completely satisfactory, but also provides them with the option of moving on in the conversation after a few tries. Based on this trial run of the simulation no traps or endless loops appear to be built into the program. The record keeping option stored the inputs of the students and kept track of the time spent on the various sections of the program. These records were used as described above to indicate the degree of completion of the student's work on the task. The questions asking the users about aspects of the software generated the data presented in Tables 5-37 to 5-39.

All of the students found that the instructions for using the software to be at least satisfactory. In fact, the majority rated them as very good and this was consistent with the limited number of questions from users about how to proceed. Interestingly, most of the students found the Message Building Kit interface to be at least satisfactory.

Table 5-37: How useful were the instructions for using the program?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Good	23	71.9	13	60	10	62.5	15	78.9
Satisfactory	9	28.1	3	40	6	37.5	4	21.1
Poor	0	0	0	0	0	0	0	0
Not Satisfactory	0	0	0	0	0	0	0	0
Total	32.0	100.0	16.0	100.0	16.0	100.0	19.0	100.0

Table 5-38: How would you evaluate the message building kits?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Good	11	34.4	6	37.5	5	31.3	7	36.8
Satisfactory	19	59.4	9	56.3	10	62.5	11	57.9
Poor	1	3.1	0	0	1	6.3	0	0
Not Satisfactory	1	3.1	1	6.2	0	0	1	5.3
Total	32.0	100.0	16.0	100.0	16.0	100.1	19.0	100.0

Table 5-39: How would you evaluate the Help aspect of the program?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Good	3	25	0	0	3	50	1	14.3
Satisfactory	8	66.7	6	100	2	33.3	5	71.4
Poor	1	8.3	0	0	1	16.7	1	14.3
Not Satisfactory	0	0	0	0	0	0	0	0
Total Used Help	12.0	100.0	6.0	100.0	6.0	100.0	7.0	100.0
Did not use Help	20		10		10	0	12	0
Total	32.0	100.0	16.0	100.0	16.0	100.0	19.0	100.0

Only two students out of the thirty-two users reported these to be poor or not satisfactory. This high assessment of this aspect is important due to these as a unique approach to human-computer communication. Only twelve of the users commented on the Help Option. Again most of these found the option to provide satisfactory service and only one of these students reported it to be at the poor level. Taking into account the student reports of general satisfaction and liking the computer based tutoring approach, one can consider that they found the software to be satisfactory.

Turing Test

Alan Turing was an early computer scientist who was interested in developing what we now call intelligent systems. In 1950, in the British journal *Mind*, he proposed the imitation game, now called the Turing test. This test sets a human subject in a computer mediated conversational environment with both a computer and another human. If the human subject cannot differentiate the responses coming from the computer, from those originating with the other human, the computer may be considered to "think" as well as the human.

For the purpose of evaluating the realism present in the simulated conversation of the *Virtual Tutee System*, two questions, referred to as the Turing test questions, were asked of the computer users. The data for these questions is presented in Tables 5-40 and 5-41. When asked the first question: "While using the program did you ever feel that Jack might be a real person communicating with you electronically?" 72 percent of

Table 5-40: Turing Test Question 1: While using the program did you ever feel that Jack might be a real person communicating with you electronically?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Often	5	15.6	4	25	1	6.3	2	10.5
Sometimes	18	56.3	8	50	10	62.5	11	57.9
Rarely	6	18.8	4	25	2	12.5	5	26.3
Never	3	9.4	0	0	3	18.8	1	5.3
Total	32.0	100.1	16.0	100.0	16.0	100.1	19.0	100.0

Table 5-41: Turing Test Question 2: How likely is it that Jack is a real person communicating with you electronically?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very likely	2	6.5	2	13.3	0	31.3	1	5.6
Maybe	16	51.6	11	73.3	5	62.5	10	55.6
Not likely	11	35.5	1	6.6	10	6.3	6	33.3
Impossible	2	6.5	1	6.6	1	0	1	5.6
Total	31.0	100.1	15.0	99.8	16.0	100.1	18.0	100.1

the student users responded with often or sometimes. Interestingly, the higher level biology students were more likely to respond positively to this question than lower level students. Also interesting is that 68 percent of students with tutoring experience were willing to consider the possibility that Jack is a real person.

A second question presented later in the post-questionnaire also indicates the degree of realism present in the simulation. It asks: "How likely is it that Jack is a real person communicating with you electronically?" Again a majority of the users responded positively, 58.1 percent choosing very likely or maybe. As well, the higher level biology students were more likely to respond positively to this question than lower level students, with 87 percent of them choosing very likely or maybe. For this question 61 percent of those with tutoring experience considered there was a possibility of the *virtual tutee* being a real person.

The mainly positive responses to these two questions provide evidence that the simulation provides student with realistic responses and seems to provide satisfactory simulation of a conversational environment.

Learning through Teaching Questions

This project had its origins in the commonplace notion that individuals who teach a subject to another person learn about the subject. All participants in the experiment were asked to what degree do you agree with the statement: " Teaching someone else about a subject matter helps me to learn about it." The data reported in

Table 5-42 show that all the student subjects at least agreed with the statement and that the majority agreed strongly with it. This pattern is similar across the sub-groups of students used in the study. When the user groups were asked the same question on the post-questionnaire, the majority continued to express similar patterns of opinion with only a slight variation as shown in Table 5-43. These opinions provide further support to the anecdotal evidence that "to teach is to learn". In addition, they supply a rationale for the development of teaching opportunities for students, and for further research into this phenomenon.

Perception of Learning

The student users of the simulation were also asked a question to determine their opinion about their personal learning gains through the experience with the software. A strong majority also responded positively to this question as illustrated in Table 5-44. Ninety-three percent of the users at least agreed with the statement: "I have learned a lot about photosynthesis through using this approach." About one third agreed strongly. Only one or two students disagreed with the statement. Interestingly, the results shown in Table 5-44 indicate a slightly different pattern for those students with tutoring experience. A total of eighty-eight percent were in agreement with the statement. Forty-one percent of those users with tutoring experience actually indicated a strong agreement with the statement.

Table 5-42: Pre-Questionnaire item: Teaching someone else about a subject matter helps me to learn about it.

	All Students		Readers		All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Strongly agree	29	58	11	61.1	18	56	11	68.8	7	43.8	13	68.4
Agree	21	42	7	38.9	14	44	5	31.3	9	56.3	6	31.6
Disagree	0	0	0	0	0	0	0	0	0	0	0	0
Strongly disagree	0	0	0	0	0	0	0	0	0	0	0	0
Total	50.0	100.0	18.0	100.0	32.0	100.0	16.0	100.1	16.0	100.1	19.0	100.0

Table 5-43: Post Questionnaire item: Teaching someone else about a subject matter helps me to learn about it.								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	17	54.8	8	53.3	9	56.3	13	72.2
Agree	13	41.9	7	46.7	6	37.5	5	27.8
Disagree	1	3.2	0	0	1	6.3	0	0
Strongly disagree	0	0	0	0	0	0	0	0
Total	31.0	99.9	15.0	100.0	16.0	100.1	18.0	100.0

Table 5-44: Post Questionnaire item: I have learned a lot about photosynthesis through using this approach.								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Strongly agree	9	30	5	33.3	4	26.7	7	41.2
Agree	19	63.3	9	60	10	66.7	8	47.1
Disagree	2	6.7	1	6.7	1	6.7	2	11.8
Strongly disagree	0	0	0	0	0	0	0	0
Total	30.0	100.0	15.0	100.0	15.0	100.1	17.0	100.1

General Measures of Student Satisfaction

Students were asked three questions to assess their over-all reaction to the computer simulated tutoring. As mentioned above, one question asked them to rate how strongly they agreed with the statement: "I liked the computer based tutoring as a way of learning about a subject matter". The data for this question is reported in Table 5-32. About 80 percent of the users replied by agreeing or strongly agreeing with the statement. More individuals in the senior biology group and users with tutoring experience group reported liking the program than those in the lower biology level.

The same question was actually asked in a slightly different way a little later in questionnaire: "Over all how well did you like using the computer assisted learning package?" Slightly more students responded positively on this one as seen in Table 5-45. Even more students replied positively when asked to rate their satisfaction level in the question: "How satisfactory was this experience?" About 89 percent of the users regarded the experience as very good or satisfactory as shown in Table 5-46.

In general, then one can conclude that the students testing the simulation found their experience with the *Virtual Tutee System* to be satisfactory. The higher level biology students were to a slight degree more satisfied than the students at the lower level. Those students with tutoring experience were also slightly less enthusiastic about the computer based tutoring than the general population of users.

Table 5-45: Over all how well did you like using the computer assisted learning package?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very pleased	11	34.4	6	37.5	5	31.3	6	31.6
Pleased	17	53.1	8	50	9	56.3	10	52.6
Did not like it	1	3.1	0	0	1	6.3	1	5.3
Did not like it a lot	3	9.4	2	12.5	1	6.3	2	10.5
Total	32.0	100.0	16.0	100.0	16.0	100.2	19.0	100.0

Table 5-46: How satisfactory was this experience?								
	All Users		Senior Biology		Low Level Biology		Users with Tutoring Experience	
	n	%	*n*	%	*n*	%	*n*	%
Very Good	16	51.6	9	60	7	43.8	11	61.1
Satisfactory	12	38.7	5	33.3	7	43.8	4	22.2
Poor	3	9.7	1	6.7	2	12.5	3	16.7
Not Satisfactory	0	0	0	0	0	0	0	0
Total	31.0	100.0	15.0	100.0	16.0	100.1	18.0	100.0

Subjective Student Comments

In general, all fifty students left the test sessions in a satisfied mood and made positive comments about their experience. Most of the simulation users were positive towards the novel software approach and were happy to have played a role in the evaluation process. As a last question on the post-questionnaire, students who used the computer simulation were invited to write in comments. A selection of these comments is presented in Table 5-47. Students would have liked more detailed feedback from Jack, the *virtual tutee*, about what he did not understand in the messages they sent to him. One student expressed a preference for using the mouse rather than the keyboard to select items from the message building kit. Students also expressed an interest in using the system as a study or review aid rather than as a general learning tool. One of the students found the printed lesson more valuable than the computer program. Another would have liked to have had a few classroom lectures on the subject matter prior to using the system.

Cost-Benefit Analysis

Since the *Virtual Tutee System* was not produced commercially, there is no real indication of its market value and thus it is difficult to assess the materials from this perspective. The written texts, tests, and electronic program used in this study were produced over a period of three years and required more than 2000 hours of work time. Although students report satisfaction with the system and it has been shown that the

Table 5-47: Selection of Software Users' Comments
Negative Comments
There should be more guidance on how or what is missing in the choices or what is not right, what is mixing up Jack.
Using visual aids as part of the answer building kit would have been very useful. Long program. The program would have been far less frustrating if we would use the mouse instead of the keyboard. Very complete.
I acquired more knowledge from reading the sample lesson than from tutoring Jack. I think this tool is more efficient as a study guide than as a teaching/self learning tool. My ideal would be to learn from a book and study/practice with the program.
What I didn't like most is that Jack can't specify exactly what he doesn't understand. And scrolling through the kit is tiring which degrades the performance level.
Positive comments
This is a very good teaching device. This shows that teaching results in learning. (maybe jack knew too much from what I told him.)
Overall I liked the experience.
It was very long. It was very useful because it focused on the important aspects which are sometimes not very clear to the student. It was a very different approach (I like variety). Its a good tool as a revision before an exam to discover if the material is well known. Its a bit confusing when Jack asks a complex question & you only had 30 min prior to cover all of the entire process. Thank you. I've learned a lot. I hope I don't forget what I have learned today.
I think that if I had made the experience having had 1 or 2 lectures on the subject, I would of understand even more. Overall, I found it very interesting and easy to use.
I learned many things I did not know and confirmed the knowledge of things I was unsure of. Overall, a good new experience.
It is a good study tool (computer tutoring) but I would personally use it only to review material I had already studid in a textbook.

students learn about the subject matter through its use, it would be hard to justify this amount of work for the advantage acquired by students. However, the input effort may be justified by considering that the *Virtual Tutee System* is a prototype of an intelligent tutoring system based on the *Knowledge Modelling Approach*. Through further development of this approach and the accompanying virtual tutoring greater benefits with lower costs might be demonstrated.

EXPERIMENTAL HYPOTHESES AND FOCAL QUESTIONS

As described in Chapter 4, there were three levels of investigation carried out within this work. The results that have been discussed above come from the experimental test of the *Virtual Tutee System* and by implication of the *Knowledge Modelling Approach*. The *Virtual Tutee System* was specifically developed to assist students in their study of the biological process of photosynthesis. A major aspect of the experimental testing involved comparisons between the use of two study strategies, reading and the use of the simulation, and reading and study questions. The data presented support the first two hypotheses previously stated in Chapter 4 as:

> The students who use the *Virtual Tutee System* will demonstrate both a mastery and a consequent understanding of the subject matter as measured by the tests of subject matter competence.
>
> The students who use the study questions approach will also demonstrate both a mastery and a consequent understanding of the subject matter as measured by the tests of subject matter competence.

The test results presented previously as impacts on the cognitive domain of students do show that student users of the simulation demonstrate mastery and understanding of the subject matter as measured by the posttest questions. The users of the reading and study question strategy have similar results. The comparison of the pretest with posttest scores for experimental groups A and C indicate a positive change in the cognitive abilities as measured by the test questions. As no significant difference was detected across the four experimental groups A, B, C, and D, through the ANOVA testing, it can be assumed that all students have developed competence through their interaction with the subject matter. Comparisons using data derived from the questions focused on topics within each section or module reinforce this inference. When the student test scores are considered as an indicator of the degree to which their knowledge models are congruent with those of a subject matter expert, one can reply to the first focal question at the experimental level:

> How adequate are the mental models of a subject matter that are developed through each study strategy as inferred from the tests of subject matter competence?

It can be inferred that the majority of student subjects developed adequate mental models through their interaction with the subject matter to achieve satisfactory performance on the posttests in spite of the study strategy used.The third experimental hypothesis stated that:

> The students who use the *Virtual Tutee System* will demonstrate superior performance on the tests of subject matter competence compared to those using the study questions approach.

This hypothesis is not supported by the experimental results. Both the readers and the users of the *Virtual Tutee System* attain similar benefits. These results should not be surprising. It was probably optimistic to predict that the novel study strategy designed as the *Virtual Tutee System* would yield superior results for the student users. The printed text supplied to both groups was the same and had been developed through the same knowledge modelling process described in Chapter 3. The study questions for the reading group are very similar to the questions asked to the simulation users by Jack, the virtual tutee. The readers were using a very familiar instructional strategy and did not have to spend any time becoming familiar with the procedure. It would have been a surprising outcome if the readers had not produced fairly satisfactory results. On the other hand, the simulation users had to perfect the skill of selecting items from the message building kit, while engaged in attempting to learn about the subject matter and tutor Jack. Consequently, there is a negative reply to the second focal question at the experimental level:

> Do the students interacting with the *virtual tutee* demonstrate a superior performance on tests of subject matter competence when compared with those using the study question strategy?

At the theoretical level the project was organized around the design and development of a model of the tutoring-learning process. This model, the *Knowledge*

Modelling Approach, proposes that college students construct mental models as internal representations of their experience with a subject matter as they interact with the accepted models within the knowledge base. This process leads to a structuring and restructuring of their personal knowledge and the resulting ability to demonstrate mastery and understanding of the subject matter. Further the model proposes that the pairing of a student with a peer tutee provides an opportunity to test and revise the internal mental models in a non threatening environment. The focal question at the theoretical level asked:

> How adequate are the mental models of a subject matter that are developed through study strategies that encourage students to examine the structure of the subject matter knowledge and teach it to another individual?

Both study strategies involved the student in a process that encouraged students to examine the structure of knowledge and produce an explanation or reiteration of it. The study question strategy required writing down an answer based on the text material. The simulation users were composing a message for Jack by selecting items from the message building kit. Both can be considered as externalizing the mental models of the subject matter being constructed internally. Since both groups attained similar results on the testing, this focal question can be is answered by saying that the simulation users must have developed adequate mental models of the subject matter. In other words, the experimental results provide support for the theoretical model of the tutoring-learning process.

At the general level, the study was designed to investigate the commonplace notion that "He who teaches, learns". The focal question at this level asked:

> Do students who participate in the simulated tutorial conversation acquire a benefit through tutoring the *virtual tutee*?

The satisfactory posttest performance of the majority of students using the simulation indicates a learning benefit and provides support for answering this question positively. In addition, the fact that all student participants agreed with the questions about learning by teaching another student and that the users of the *virtual tutee* continued to agree after their experience also provides continuing support for the commonplace notion that to teach is to learn.

Limiting Factors in the Experimental Testing

The results of the experimental testing described and discussed in this chapter are limited by several factors. These include sample size, individual differences and the differential experience of individuals using the simulation. The time spent on the task and the effort invested by the student users is another limiting factor.

Fifty college students of diverse backgrounds participated in the experimental stage of this research project. Actually, about seventy-five students were initially recruited to be experimental subjects, but for various reasons twenty-five did not actually come to their test session or could not spend the three hours required for full completion of the experimental tasks. This left a relatively smaller group of subjects than planned and limits the ability to generalize the results for a wider audience. In addition, of those subjects that did participate as testers of the *Virtual Tutee System*, only three students were able to complete all four modules. There was a successive attrition of the software users as they passed through the program based on the relative time spent on each module. All thirty-two student users completed the first module about the nature of energy and matter. Only twenty-two of these were able to complete Module II that helps students to learn about the basic concepts of photosynthesis. Only thirteen were then able to continue on to the advanced topics of the third module. This attrition rate also seriously jeopardizes the ability to generalize the results of the experiment.

There are also problems of individual differences in background knowledge and experience that could confound the results. This problem is somewhat moderated by the pretest, posttest comparisons. A more difficult problem is that of the variations of experience built in to the individualised computer instruction, mentioned above in Chapter 2 as described by Winne (1993). This factor accounts for some of the attrition mentioned above as well as the variation in performance on the posttests. The examination of test sub-scores for the various topic areas represented in both the text sections and software modules helps to overcome this difficulty. Comparisons across the groups for topics included in Modules I and II are probably more valid indicators, than those made for Module III. Based on the small number of students left, no comparisons are offered for Module IV.

The time and effort invested in the various subsections could be counted for the users of the simulation. but this aspect was not studied in the readers. Perhaps readers had a broader experience with the subject matter than the simulation users. Some measure of the rate of progress might have been added to observations of their experience. Another aspect of the time problem was mentioned in the discussion of the cognitive impacts. College students would not be expected to study and master the amount of information contained in this lesson in one three hour block. Generally. students would have a combination of classroom instruction and reading assignments over several days. It would be more difficult to asses the impact of the software in that type of situation. It would also have been useful to ask the readers to respond to questions about their study experience and their opinions about the printed materials and the study questions themselves.

Based on the data accumulated in the evaluation stage of this project. it would seem that the project was successful in developing a simulation of the tutoring-learning situation that provides real students with a teaching experience. Evidence was acquired to support the use of this type of simulation and for applying the *Knowledge Modelling Approach* to the design of intelligent tutoring systems.

CHAPTER 6: SUMMATION

There were several facets to this research project. The major goal was to design, develop and test a novel model of the tutoring-learning process in which the development of knowledge is based on using educational information resources, such as a textbook, and on explaining the structure of knowledge to another individual. The *Knowledge Modelling Approach* was the result of this goal. The model of the tutoring-learning process was tested through the development of a computer simulation, the *Virtual Tutee System*. This quasi-intelligent tutoring system provides a student with an opportunity to explore knowledge models using tutoring as a learning strategy. Another aspect of the project was the design and implementation of an evaluation of the *virtual tutee* simulation that would provide evidence supporting its validity as a teaching-learning tool. The successful outcome of that evaluation of the computer simulation would also provide evidence supporting the validity of the *Knowledge Modelling Approach*. As well, the project, having had it origins in the traditional understanding that "to teach is to learn", sought to provide experimental evidence in support of this idea.

The Knowledge Modelling Approach

This cybernetic model of the tutoring-learning situation resulted from the synthesis of many ideas. An important philosophical consideration in its development was use of models and paradigms in knowledge domains in general and, more particularly, in the natural sciences. One can consider that a major aim of science education at the undergraduate college level is to motivate students to explore the accepted knowledge models as presented in lectures and readings, and to internalize these. The students are then tested to establish how well they have done this. Another influence on the development of the tutoring-learning model was the concept of a mental model. This concept, used as a metaphor for the internalization of representations of an individual's experience, avoids neurological considerations. Coupling the concept of a mental model with constructivist learning theory, one might say that science students are constructing their personal mental models of a subject matter while exploring the accepted subject matter models. Linking these ideas with an interpretation of Pask's conversation theory provided a basis for the development of the *Knowledge Modelling Approach.*

The approach posits that there are at least two participants within a tutoring-learning situation, a teaching or tutoring participant and a learner or student participant. Each participant has similar processes for building mental models of a subject matter and there is a knowledge domain consisting of accepted models of the subject matter that can be shared by each participant. The *Knowledge Modelling Approach* does not attempt to explain the internal processes, but rather focuses on the behaviours generated by the externalisation of these mental models. The approach introduces the concept of a modelling space in which each participant can build an external model of the topic under study. This space allows for an exchange of information, comparisons and critiques of the participant's subject matter model. In most tutoring situations, there is usually a teacher or professor who can interact with the participants and can act as an overseer of the process. Further the *Knowledge Modelling Approach* considers that through the continuing tutorial conversation there is an iterative process of model building, model testing, and remodelling that gradually reduces the marked differences and increases the likelihood of a congruence between the participants' personal models and the accepted models of the knowledge domain. This iterative process is represented in Figure 3-5 as an upwardly oriented double helix, where each strand represents the knowledge construction of a participant in the conversation.

The Virtual Tutee System

The *Knowledge Modelling Approach* was tested through the development of a computer simulation that emulates a tutorial conversation about the energy capturing process of photosynthesis occurring in plants. This is regarded as a complex subject matter with many concepts and principles, and is an important topic area in college biology courses. The accepted knowledge models relevant to photosynthesis were explored by the developer through the construction of a knowledge web, a modified concept map. A set of learning objectives was established, an appropriate sequence of the topics within the knowledge domain was determined, and a text chapter was written for students to use as a resource about the subject matter.

An important facet of the research project was to develop computer scripts in the Hypercard environment to implement the design of the *Virtual Tutee System.* During this phase several modifications in the system design and in the associated Hypercard scripts were made, so that the two evolved together. The architecture of the system was described in detail in Chapter 4. However, it is important to recall here a few salient features of the computer program. Firstly, it casts the real student user in the role of a tutor, rather than tutee. Secondly, it provides a modelling space as a series of message building kits, by which the user constructs his/her model of the topic as a reply to the *virtual tutee.* These message building kits were patterned after the methods proposed in structural communications. Thirdly, the topic sequence of the simulation was arranged to follow the double spiral of learning shown in Figure 3-5. The *virtual tutee* asks questions, gives answers or viewpoints on the topic under discussion and the simulation allows the tutor to ask questions to the tutee. The *virtual professor* introduces Jack as the *virtual tutee,* but remains in the background until the real student wishes to end the session.

Evaluation of the Virtual Tutee System

The data gathered from the experimental test of the *Virtual Tutee System* indicate that its use as a teaching-learning tool is as effective as the alternative text and study questions method. This evaluation was carried out as outlined in Chapter 4 and was designed by considering the issues of evaluation presented in Chapter 2. This meant that a fairly comprehensive assessment of the value of the simulation was done. An important component was to evaluate the impact of the simulation on students. From a cognitive perspective, this was examined through the use of subject matter test scores. At the beginning of the development of the materials, test questions were written as the subject matter was being analyzed. These questions were assembled into pretests and posttests through which the congruence between a student's mental model of a topic and the accepted subject matter model could be deduced.

The data generated by these tests have been presented and discussed in the previous chapter. These scores are interpreted as evidence to demonstrate that students learned about the lesson topics through their interaction with this program. A comparative study of the cognitive impact was done by having some students use only the text material with study questions to study photosynthesis rather than the simulation. The results of this comparison indicate that both groups attain similar results. While the author or creator of a novel tool for teaching and learning would prefer to have a superior outcome, it is encouraging to conclude that the tutoring strategy within the *Virtual Tutee System* is as successful as that of studying a text guided by study questions.

Another possible impact of an instructional event is on the affective domain. Questions were asked of the users to determine their attitudes towards computers in general and particularly their use in education. All students had had considerable experience with computers and were mostly enthusiastic towards learning more about them. They initially showed very positive attitudes towards the use of computers in education. There was a slight dampening of this enthusiasm following the use of the program, but the majority of the users continued to respond positively to the questions about their attitudes. All students replied that they would not prefer the text and study questions strategy as an alternate instructional method to the use of the simulation.

The users of the simulation were also asked questions to evaluate their experience with it. Extensive data from these questions have been presented in the previous chapter. The students consider the program and the associated materials to be useful and satisfactory. In addition, they seem to have enjoyed the experience and felt that they had learned a lot from using it. From a technical viewpoint, the program ran successfully with no disruptions, crashes or endless loops found by the 32 student users. Questions representing a Turing Test of the conversational software revealed that a strong majority of the students were willing to consider that the *virtual tutee* was a real person communicating with them electronically. This may be considered as evidence of the realism built into the computer simulation. Over all, one can conclude that the *Virtual Tutee System* was relatively successful from these standpoints, and consequently provides support for the use of the *Knowledge Modelling Approach*. To this end the major goals of the research project have been met.

Limitations to these Conclusions

The conclusion about the usefulness of the *Virtual Tutee System* and then the *Knowledge Modelling Approach* on which it is based is limited for several reasons. The major limitation, of course, is that the case described here is a single test of the theoretical model and the computer simulation based on it. The data and results gathered from the test of the simulation were also limited for the reasons described at the end of Chapter 5. Of these, an important consideration is validity of drawing major conclusions from the relatively small sample of thirty-two student users of the simulation and eighteen readers, for a total of fifty subjects. Related to this limitation was the reduction in the number of simulation users as they moved to successive modules with in it. An important consideration is the novel aspect of the *Virtual Tutee System* and the consequent possibility of a Hawthorne effect. Weller (1996) indicates the pitfalls of comparing different types of instructional delivery media. He mentions that subjects using novel approaches tend to devote more attention and effort to the task than those using more conventional approaches.

A greater limitation on the conclusions, however, is the general lack of interface, format and functionality standards in the field for the design, development and use of computer assisted learning packages. Currently, the instructional software developer must make decisions about screen designs, text fonts and sizes, help systems, use of colour, etc., as the package is being assembled with little or no guidance from a wider professional practise. This makes it difficult to determine if the effects generated from a software test are more a function of an intellectual process, a technical aspect of the use of the computer, or a result of the influence many other factors.

Likewise, a survey of the studies of the effects of computer assisted learning packages, reveals a lack of common evaluation methods. There is a wide discrepancy among the ways in which researchers and developers have proceeded in doing the testing. It appears that many of the programs currently in use in instructional settings have been marketed with almost no testing on a student focus group taken from the potential target audience. Other software has been tested only by subject matter experts, teachers, and graduate students in the subject matter domain. Both the standards and methodology issues are probably typical of a young field of research and development. Berson (1996) in a review of the literature about the effectiveness of computer technology in social sciences points out in his conclusion:

> Assessment of the integration of computers into social studies is still in its infancy and encompasses a dynamic process. The inherent difficulty of evaluating the effectiveness of computer assisted instruction is the perpetual modifications in goals and expectations for this technology. (page 496)

The problems of evaluating educational software have also recently been addressed by Tergan (1998) who predicts that a "second level of review" will emerge that involves paying more attention to factors concerning the user, the instructional method, and the situation and/or context of use.

Future Research and Development

Every research project stimulates more research. Educational research, like medical research or research in engineering, should be focused on solving practical problems. In the case of education, the goal is to improve the capability of the student, and the research should focus on the design and development of methods and techniques that accomplish this. This is particularly true of research and development within the field of educational technology. There is also a need in educational research to design and develop approaches to evaluation that provide evidence that the methods and techniques are successful.

The present study provides evidence that supports the use of the *Knowledge Modelling Approach* and the *Virtual Tutee System*. However, as mentioned above the data generated during the study is limited by several factors. It would be very useful to conduct further tests of the system under more tightly controlled conditions. Perhaps, it may also be useful to study the longer term effects through the use of delayed posttesting.

The present project may be extended in several directions. The *Virtual Tutee System* may be utilized for further studies of student learning about photosynthesis. An analysis of the input statements from the message building kits could provide data about the types of knowledge models being constructed by the students. Another experiment could use the chosen statements to focus on the study of misconceptions.

and their persistence and repair. The *Virtual Tutee System* could be tested over a longer time period, perhaps for a week during which the student testers would study the topics in class and from their own textbooks. This would address the suggestion made by some student users that this program be used as a way to review and consolidate knowledge in preparation for a test. It may be interesting to look at issues of gender within the tutorial relationship by establishing a parallel program with a "Jill" as the *virtual tutee* instead of Jack . An area not studied in the present research was the interaction of learning style or cognitive style and the *Virtual Tutee System.* As mentioned previously, the interaction of the student user's reading level with the experience could be studied further.

The *Knowledge Modelling Approach* has only been applied to the development of the materials used within this project. It would be very interesting to apply it to the development of other instructional materials. These could be text based materials or may include the production of another *Virtual Tutee System* for a completely different subject domain. Since the approach was based on a synthesis of several ideas, it might be applied to investigate some of the tenets of constructivist learning theory, or to further investigate Pask's conversation theory. This approach might also form a framework for the design, development and production of evaluation tools that are currently lacking.

Contributions to the Development of Educational Technology

We should not view instruction as the transmission of information, but rather, as the creation of environments in which learners are encouraged to construct and modify their own models of the world. Thus, the goals of educational technologists would include the design and development of successful tools for teaching and learning. Anderson *et alia* (1990) set two goals for research on intelligent tutoring systems. The first goal was the automation of education and the provision of tutoring at a relatively low cost. His second aim was the exploration of the epistemological issues concerning the nature of the knowledge being tutored and how that knowledge might be learned.

The *Knowledge Modelling Approach* is offered as a theoretical model of the tutoring-learning situation from which intelligent tutoring systems may be designed. This model can serve to provide a basis for studying the epistemological issues mentioned by Anderson *et alia*. Given the current technological limits, it is unlikely that we can build a system that is as intelligent as two real humans facing each other and discussing a topic, and, therefore, it may be better to refer to these computer-based systems as quasi-intelligent tutoring systems. The *Virtual Tutee System* is presented as a contribution to the field of educational technology as a prototype of such a system and as a novel tool for teaching and learning. Until now the designers of computer-aided instruction have usually used the computer as a tutor or has a simulator of complex situations. By reversing these roles to provide a real student with a simulated tutoring experience, the *Virtual Tutee System* may be considered to be a new and unique contribution.

This project has used systems theory, and particularly, aspects of cybernetics, and is therefore considered to be an application of these to educational problem solving. Based on this cybernetic approach, the project has drawn on Pask's conversation theory and has applied his theory to the development of a tutorial system that provides the student user with the opportunity to teach another about a subject. Pask frequently proposed the use of *teachback* as a way to have students learn about concepts and as a way to verify that the learning had taken place. Thus the development of the both the *Knowledge Modelling Approach* and the *Virtual Tutee System* may be seen as an extension of Pask's conversation theory.

Another contribution inherent in this research project has been the extension of structural communications to the development of a computerized instructional system. This method of instruction as proposed in the 1960s by Bennett, Hodgson and Egan has always been awkward in the print format. However, developing a computer approach for analyzing the input from the student and formulating a reply can improve this approach to instruction. There is also the possibility of arranging the *Virtual Tutee System* as a mechanized way of evaluating a students knowledge. As well, there may be other applications for this method in distance education and the development of internet educational communications.

Last Words

The *Knowledge Modelling Approach* was generated through an integration of the concept of mental models with constructivist learning theory and Pask's conversation theory. This approach is presented as a cybernetic model of the tutoring-learning process, and as a theoretical basis for the design of instruction oriented to the production of intelligent tutoring systems. The *Knowledge Modelling Approach* posits that a learner develops and redevelops his/her own personal knowledge as mental models of experience. The concept of a mental model is a convenient metaphor for the internal representation of that experience that avoids neurological details. As a learner explores a subject matter, there is an encounter with the existing knowledge models that serve as the foundation for the discipline being studied. In a traditional classroom or text based learning experience, the learner may be actively involved in building mental models and testing these against those knowledge models presented by the instructor or author of the book. There is rarely sufficient feedback to assist in the modelling, remodelling process. In the tutoring-learning situation, the tutoring partners are testing their personal mental models through conversational exchanges with each other. The comments and questions of the partner can be considered as feedback and cause each individual to more actively explore his/her own knowledge models as well as those presented by subject matter experts.

The *Virtual Tutee System* was developed as a simulation of the tutoring-learning process to test the *Knowledge Modelling Approach* and was evaluated as a prototype of a new approach to designing intelligent tutoring systems. The *Virtual Tutee System* places the student user in the position of a tutor and develops a simulated tutorial conversation. In this case, it was designed to provide instruction about the biological process of photosynthesis. Test data indicate that college student users of the simulation do learn about the subject matter through this approach. Also they expressed their over all satisfaction with the *Virtual Tutee System* as a teaching-learning tool. Their satisfaction with the message building kit approach to sending messages to the virtual tutee provides positive support for the use of this aspect of the software. The fact that thirty-two students used the software with no technical difficulties should also be considered to be a measure of success. Although the data gathered through the experimental evaluation may not be sufficient to support a definitive conclusion about the usefulness of these approaches, they do provide support for the concepts used in their development. There is evidence to support further studies of their use as indicated above. There is also support for conducting further research into the development of virtual or simulated tutorial conversation as the basis for the design of computer-aided environments that entice students to become active learners. Likewise, the evaluation study of the software provides some further empirical evidence to support the quotation from Comenius: "*Qui docet, discit*...He who teaches, learns".

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APPENDIX 1

KNOWLEDGE WEB FOR PHOTOSYNTHESIS

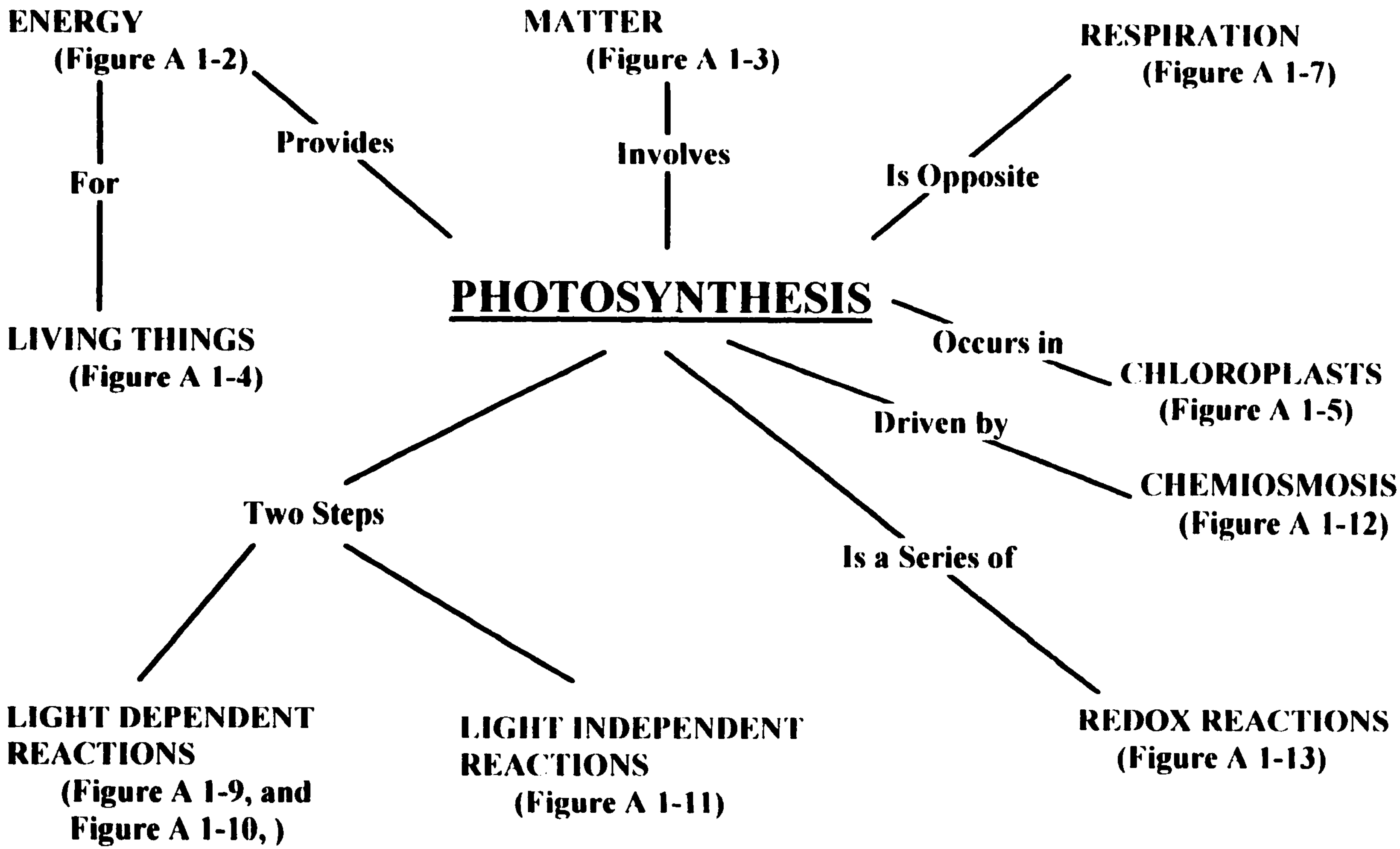


Figure A1-1: Knowledge Web for Photosynthesis: General Overview

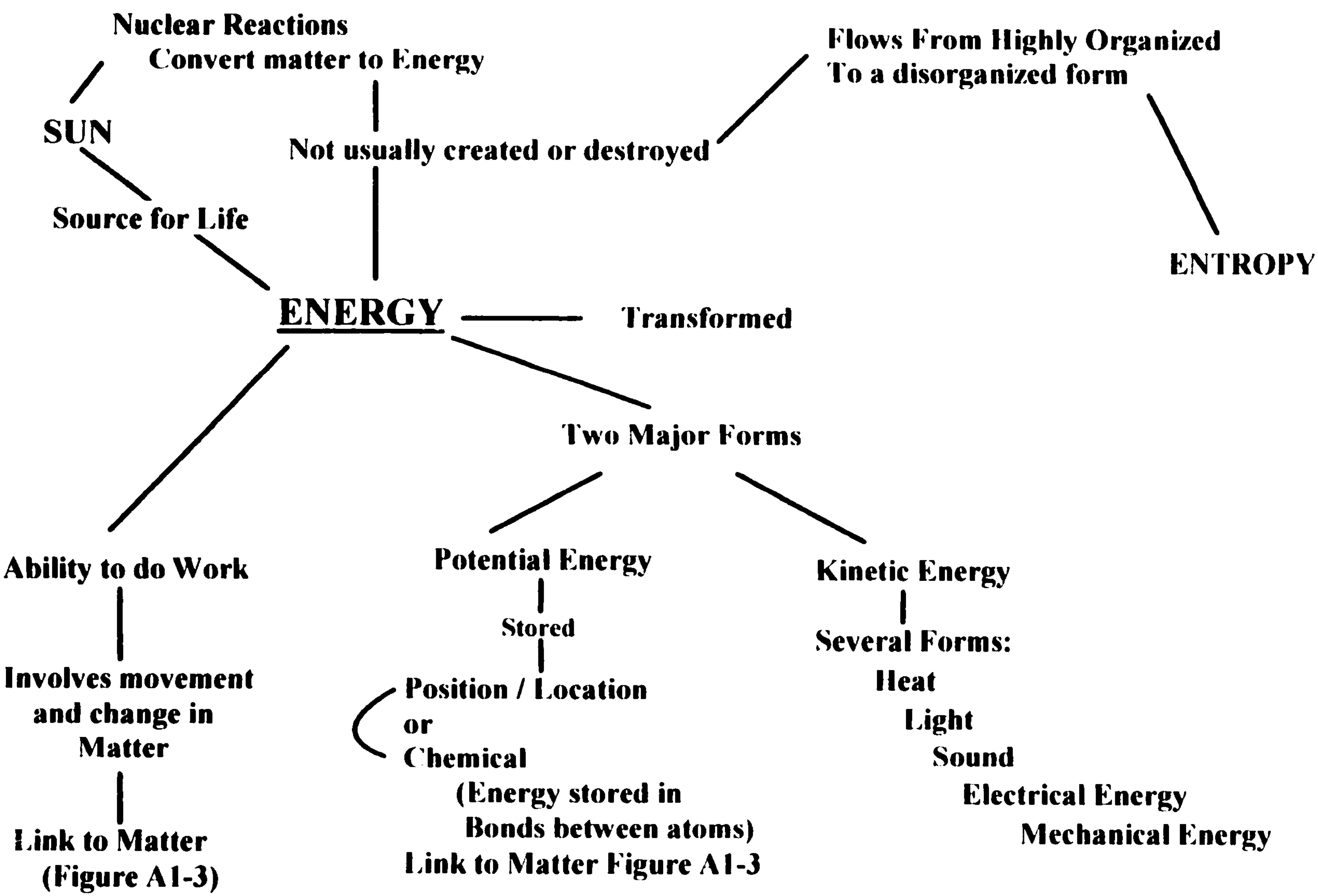


Figure A1-2: Knowledge Web for Photosynthesis: Aspects of Energy

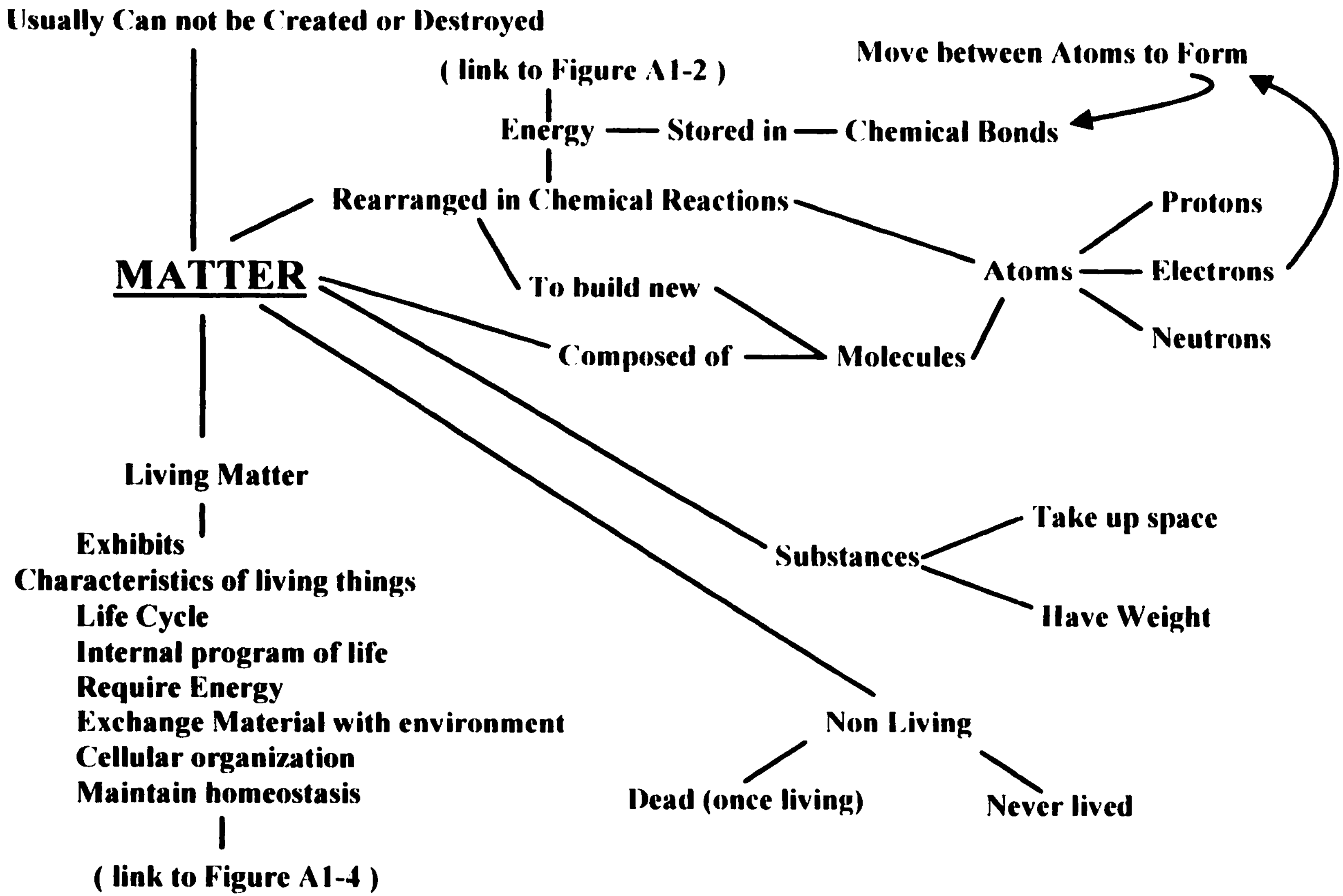


Figure A1-3: Knowledge Web for Photosynthesis: Aspect of Matter

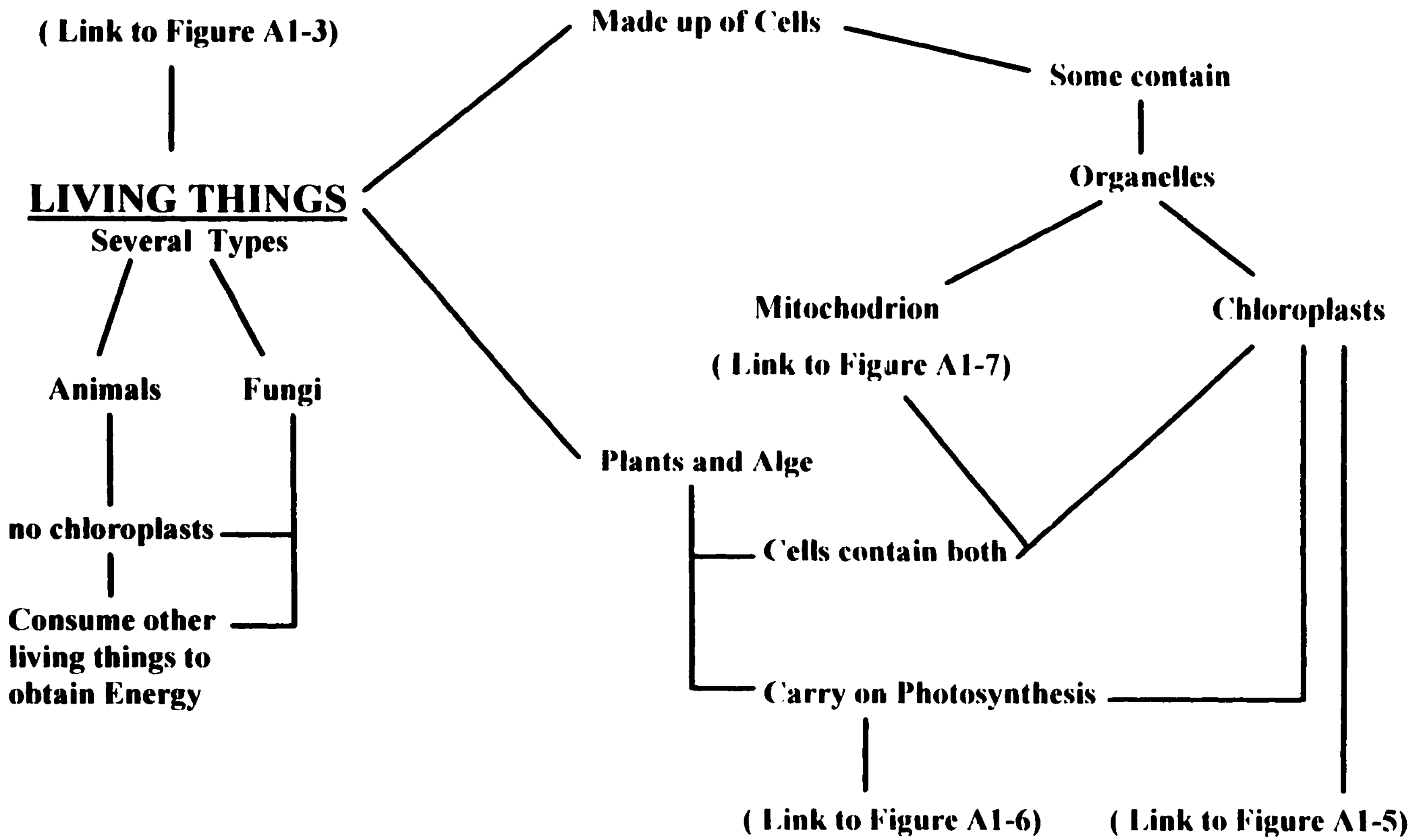


Figure A1-4: Knowledge Web for Photosynthesis: Aspects of Living Things

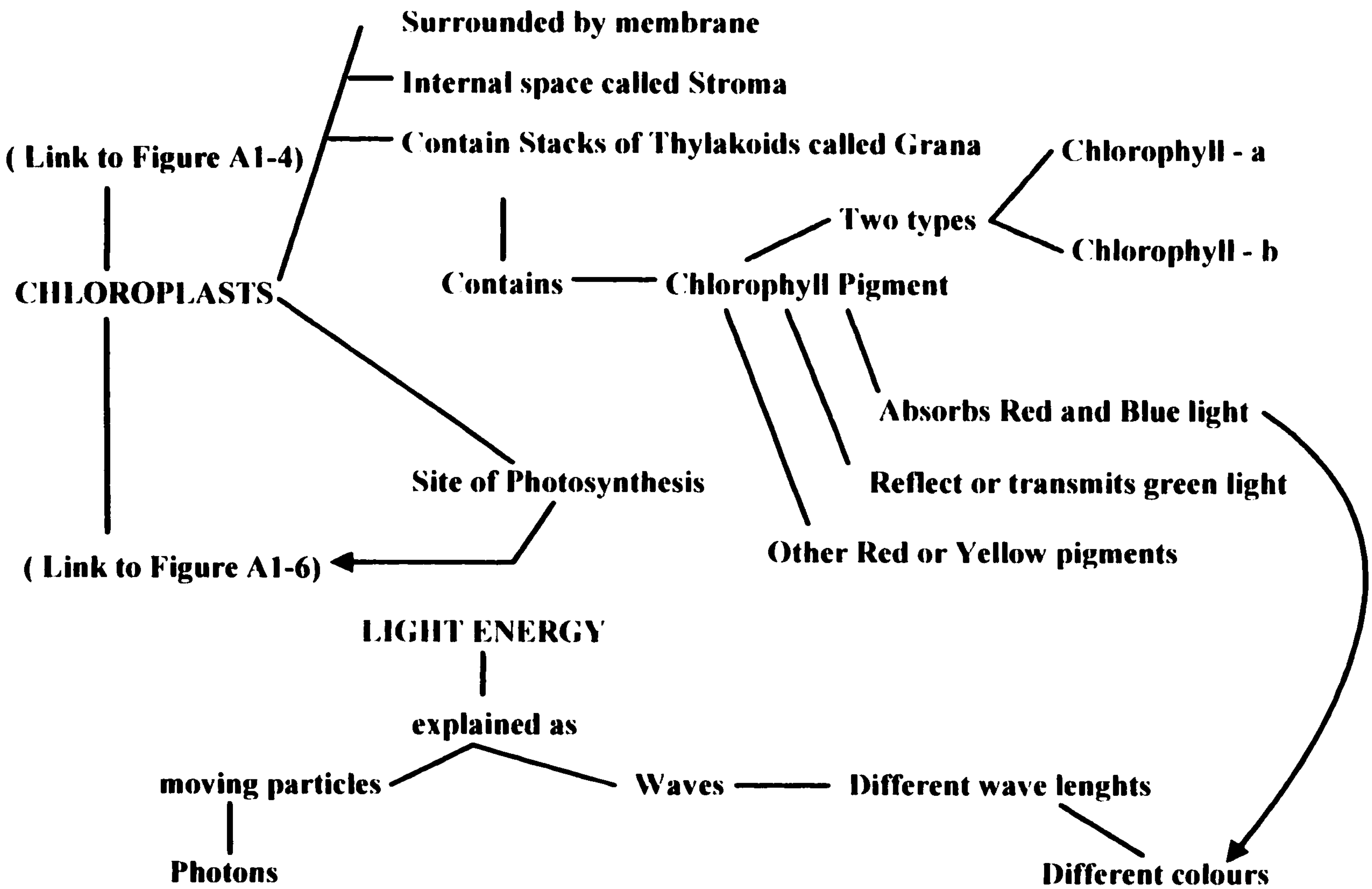


Figure A1-5: Knowledge Web for Photosynthesis: Chloroplasts

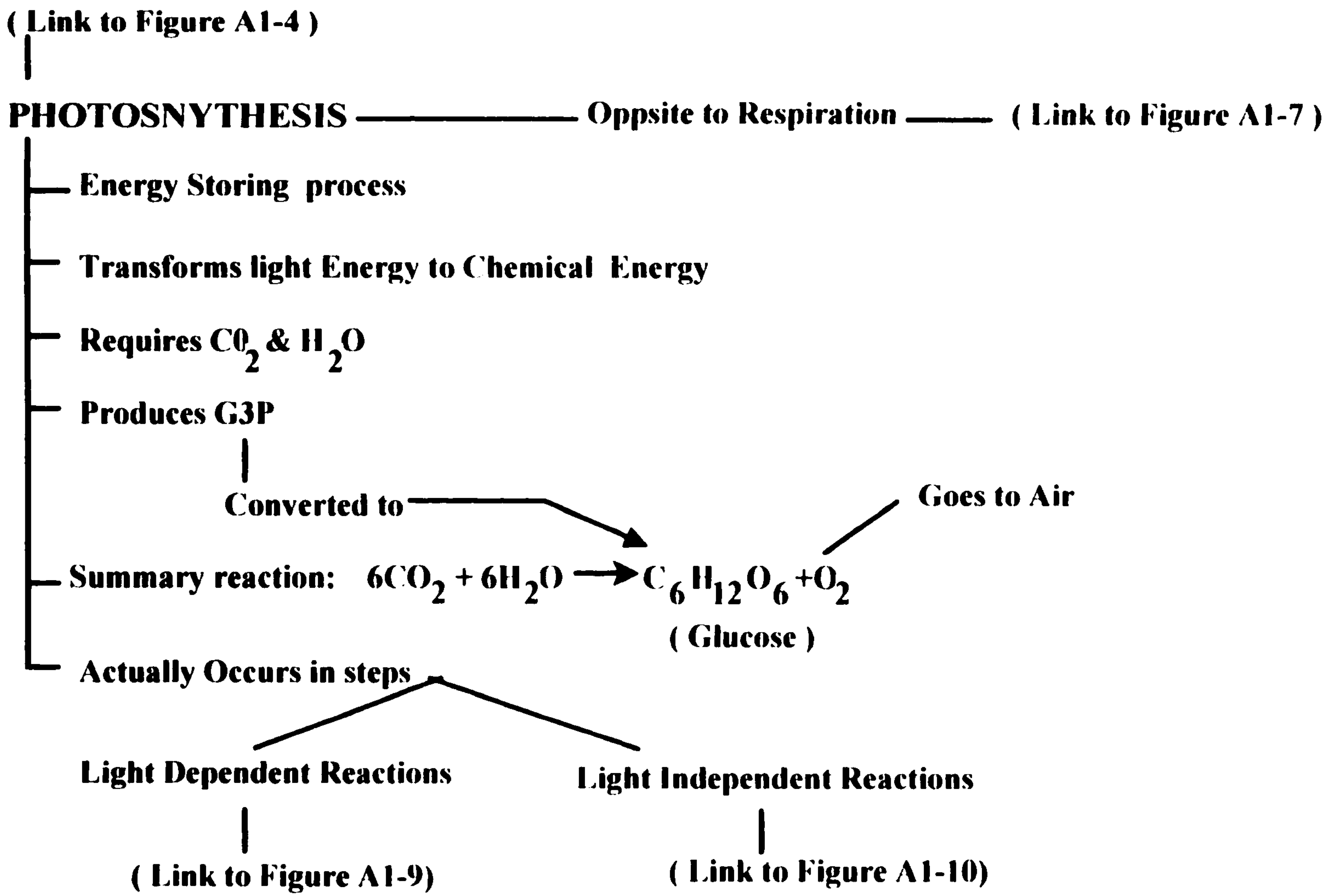


Figure A1-6: Knowledge Web for Photosynthesis: General Aspects

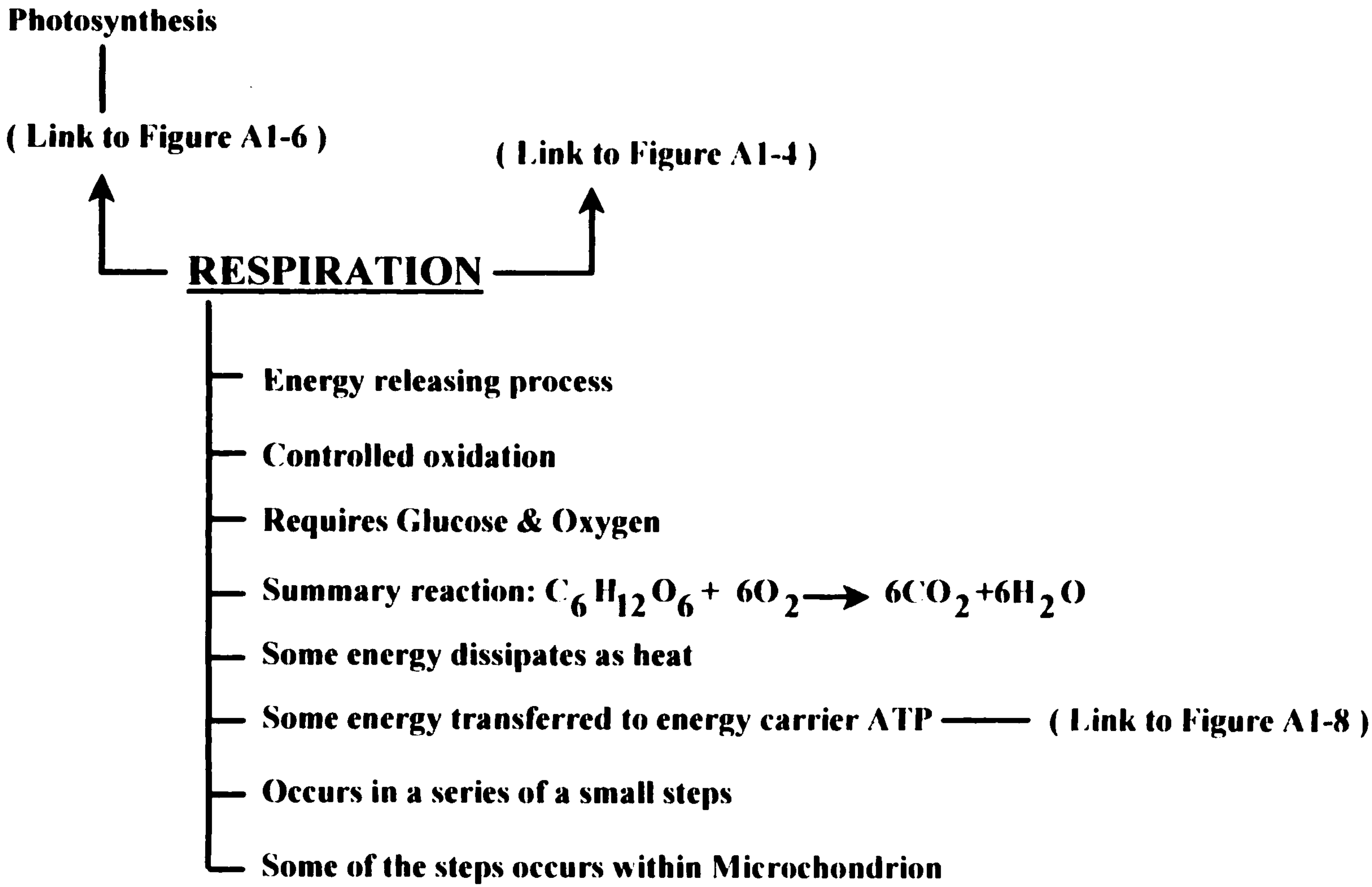
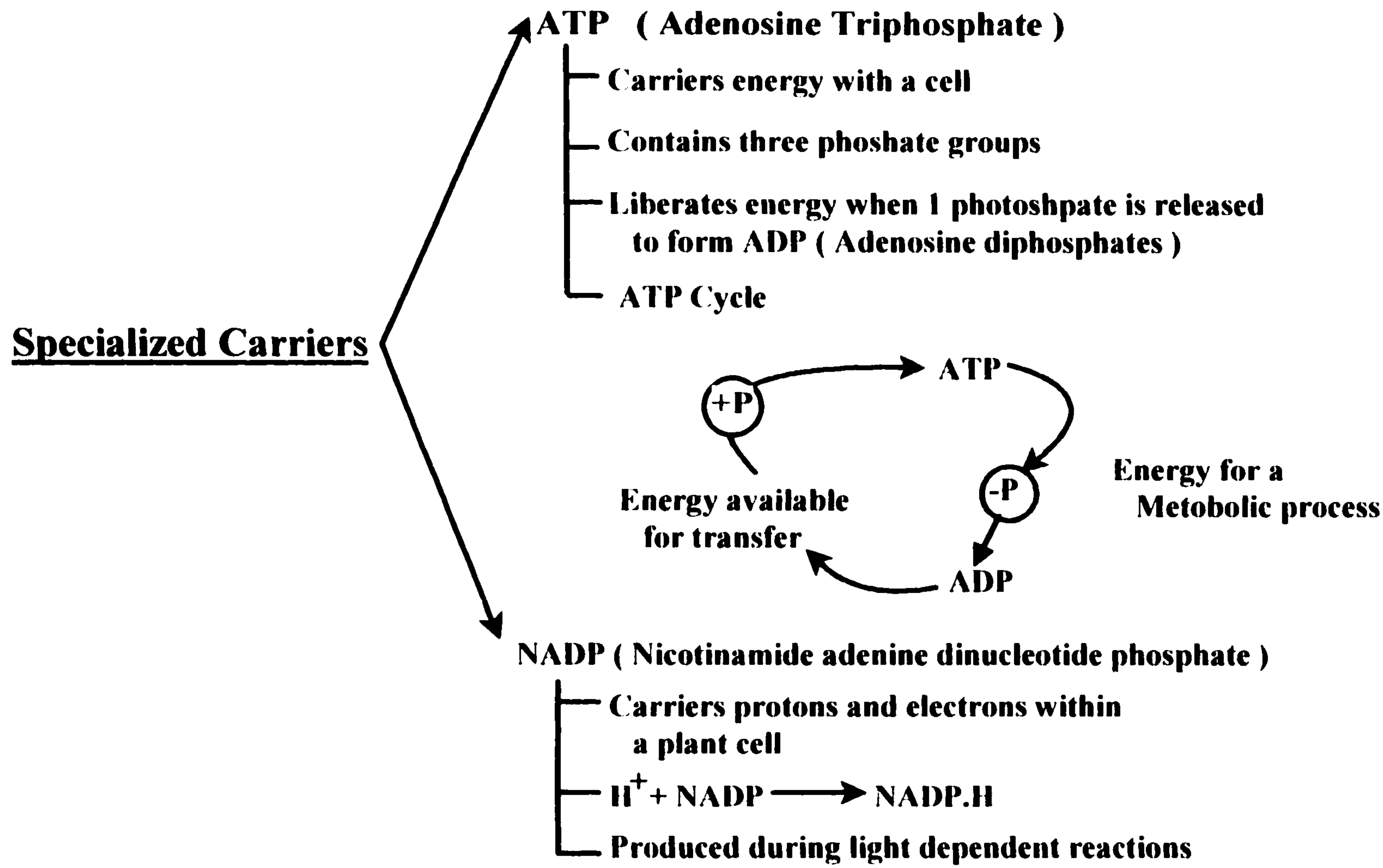


Figure A1-7: Knowledge Web for Photosynthesis: Respiration



FigureA1-8: Knowledge Web for Photosynthesis: Specialized Carriers

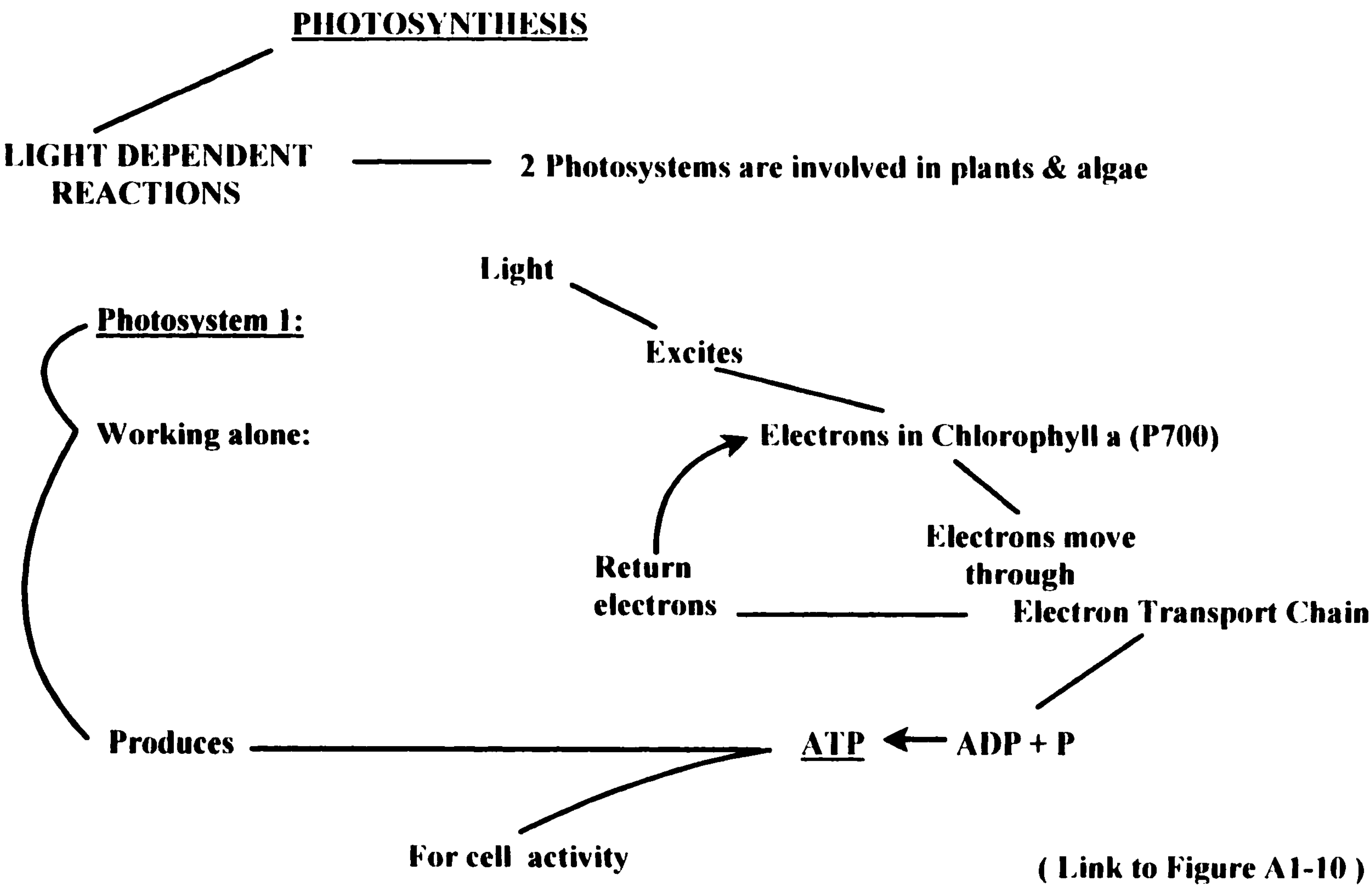


Figure A1-9: Knowledge for Photosynthesis: Light Dependent Reactions, Photosystem 1

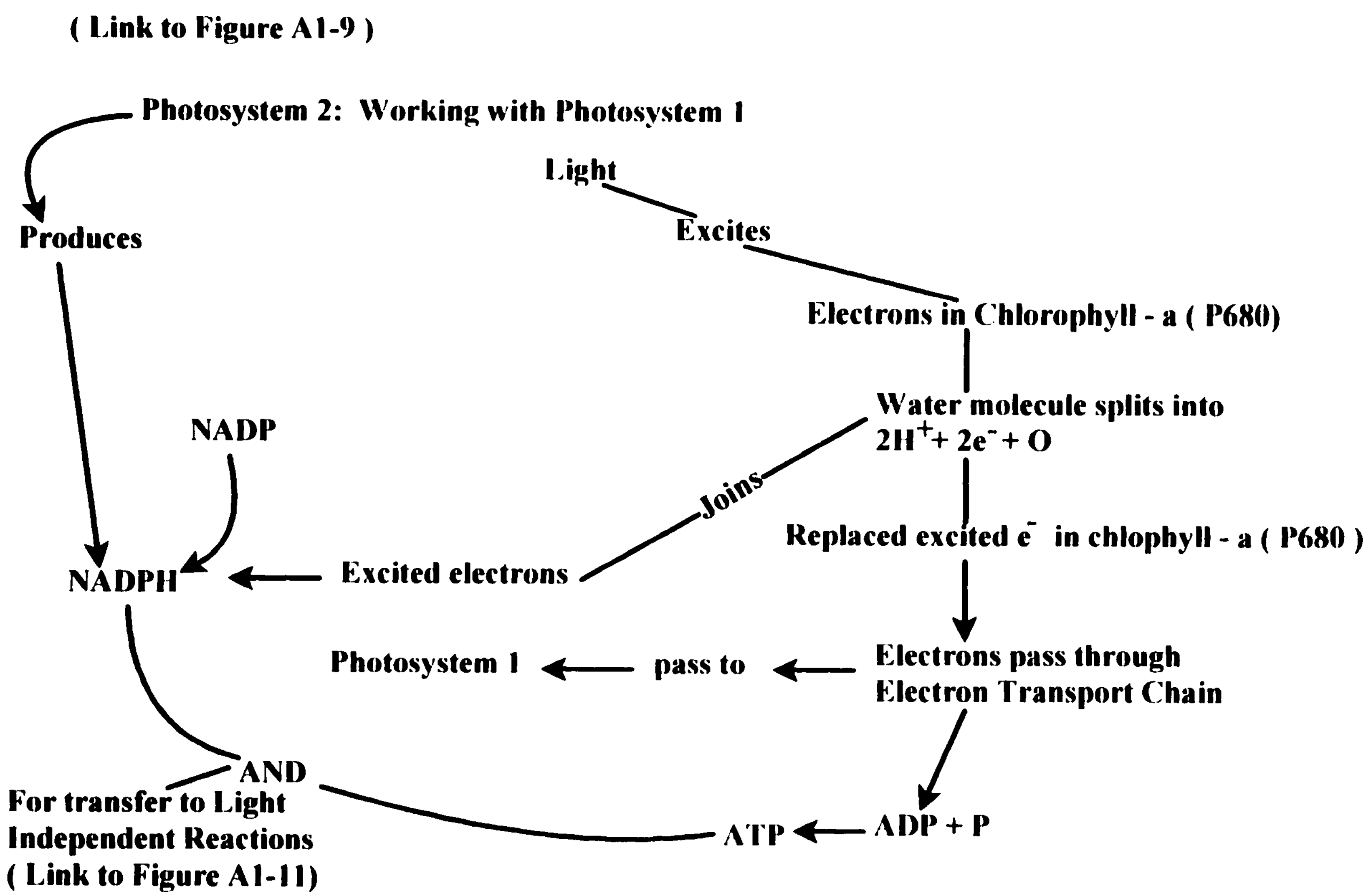


Figure A1-10: Knowledge Web for Photosynthesis: Light Dependent Reactions, Photosystem 2

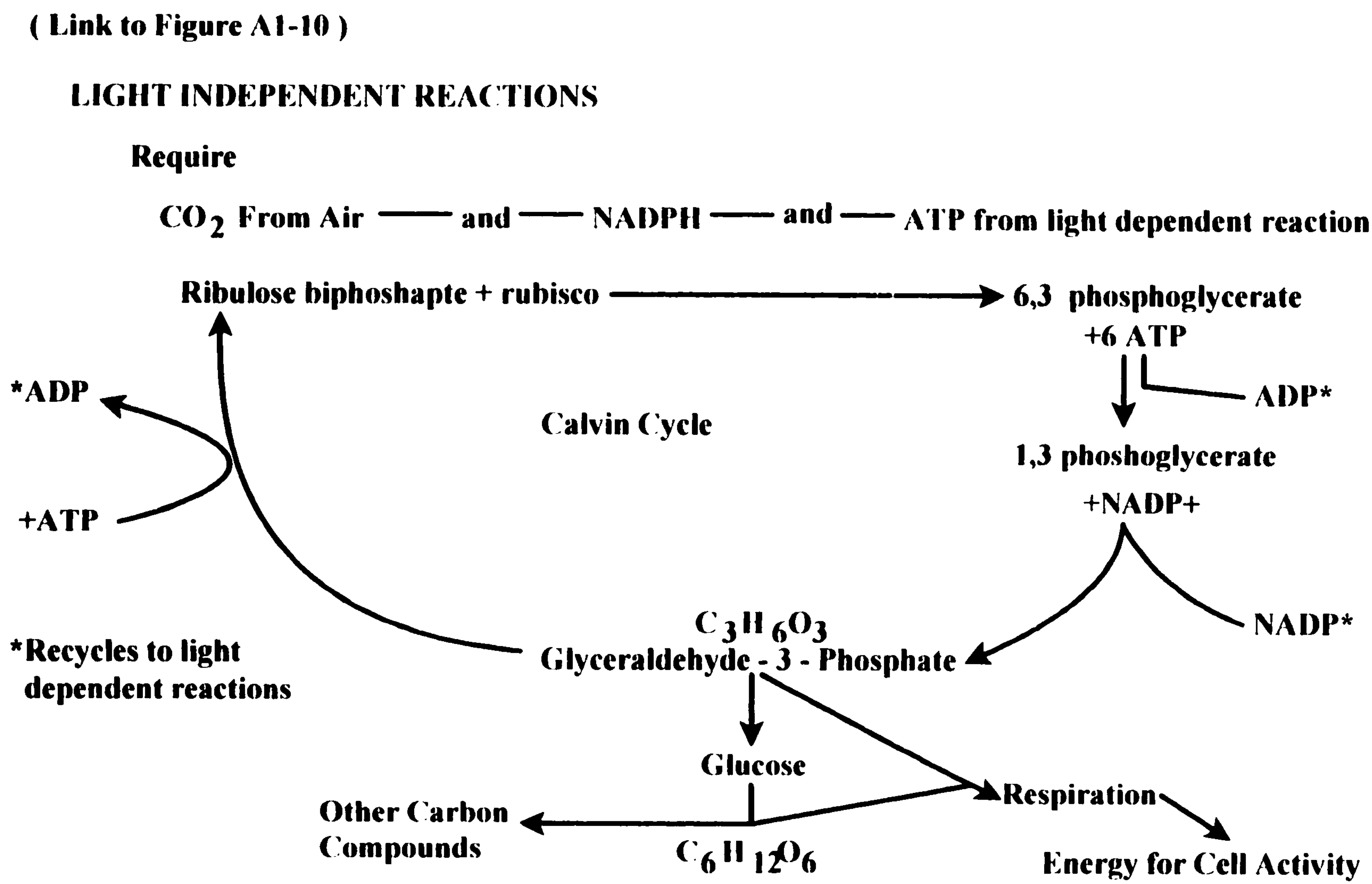


Figure A1-11: Knowledge Web for Photosynthesis: Light Independent Reaction Details

CHEMIOSMOSIS

- Occurs in Electron Transport Chains
- Actualy provides potential energy by establishing a proton concentration gradient across a membrane
- Depends on energy of moving electrons to pump H+ (protons) into the thylakoid

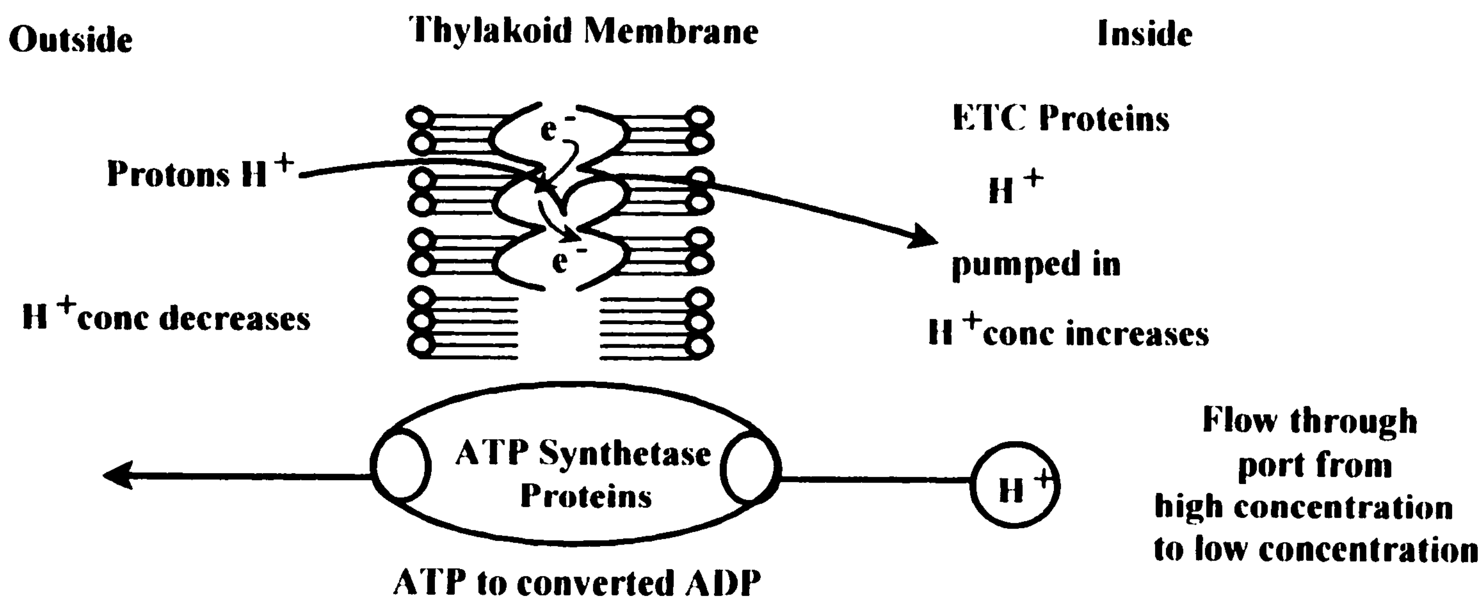


Figure A1-12: Knowledge Web for Photosynthesis: Chemiosmosis

REDUCTION - OXIDATION (REDOX)

- Photosynthesis may be considered as a series of Redox reactions
-
  - Reduction occurs when a substance gains electrons
  - Oxidation occurs when a substance loses electrons
- Light Oxidizes Chlorophyll - a
- Electrons are lost but pass from one electron transport chain protein to the next - each of these is reduced then oxidized

  Energy of these moving electrons is used to move Protons through membrane - (Link to Figure A1-12)

  Electrons that end up in NADPH* at photosystem 1 are used in fixation of CO_2 by reduction
- Water is oxidized and electrons liberated replace those initially lost from Chlorophyll - A oxidation

Figure A1-13: Knowledge Web for Photosynthesis: Reduction - Oxidation (REDOX)

APPENDIX 2

CAPTURING ENERGY FOR LIFE

A TEXT CHAPTER ABOUT PHOTOSYNTHESIS

CAPTURING ENERGY FOR LIFE

As you probably well know, any living thing requires a steady supply of energy to stay alive and perform its activities. In working on this lesson, you should learn about or review the basic concept of energy, where it comes from, and where it goes. Then you will be studying how the energy in sunlight is captured by plants and transformed into a form that the plant can use to carry on its basic activities. Fortunately, plants are so good at capturing energy and storing it in chemicals that they produce a surplus. Other living things can then consume plants to obtain the vital materials to maintain themselves.

Energy and Matter

One of the characteristics of living things is the requirement for a source of energy. Our energy comes from the food we consume and, if you trace back along your food chain, you find that light energy from the sun is the ultimate source of that energy. A quick and easy definition of energy is the ability to do work. Without going into detail, our bodies and their functional units, the cells, do a great deal of work. Some of this is obvious as you run down the street to catch a bus or carry your textbooks home. Other work is not so obvious. Just lifting the ribs to breathe is work. Chewing up your food or moving a pen over paper to write, are examples of work done by muscle contraction. As well materials must be pulled into or pushed out of the cells. There are a number of chemical transitions that require energy. Synthesizing the enzymes to break up the ingested proteins requires chemical energy.

Food chain - the flow of food from producers through various consumers; it shows who eats whom.

Energy - the ability to do work.

Work - what is done when things are moved or changed.

We do not, under ordinary conditions, produce energy or destroy it, only transform it into different states. There are two major states that energy takes. Kinetic energy involves action or movement. A rolling ball has kinetic energy. Heat, light, sound and electrical energy are forms of kinetic energy. The other state is potential energy. Here the energy is stored in some way. The storage might be a consequence of the position of an object. The water behind a dam has potential energy as does a rock resting on a ledge. Chemical energy is a special type of potential energy. Here the energy is stored in the bonds that hold atoms together to form molecules. A battery has energy stored in this form that can be transformed into light energy when the battery is used in a flashlight. When energy is transformed, some seems to get lost. Often this is in the form of heat, but sometimes it is in the form of light. The energy is not destroyed but scatters off or dissipates into space in forms that are not easily recovered or transformed back into usable energy. This unusable energy may be considered to be in a rather disorganized form or in a state of disorder. The amount of the disorder or disorganization in a system is called

Kinetic energy - the energy of motion or action.

Potential energy - stored energy.

Entropy - the amount of disorder or disorganization in a situation.

entropy, and as energy dissipates away from the planet we have an increase in the amount of entropy.

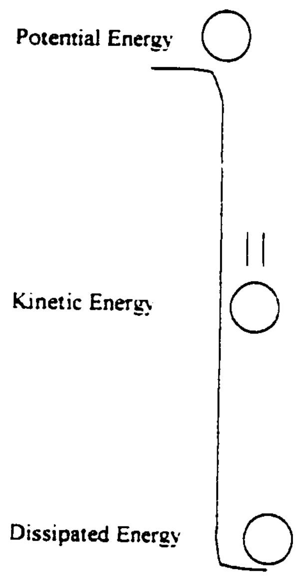


Figure 1: Energy Transformation

Because energy cannot be created or destroyed, there must be a balance between what is put into a system and what comes out of it. The gasoline that is put into a car has a certain quantity of potential energy. As it is used in the engine, some of that energy is used to do the work of moving the car from place to place. This is an example of kinetic energy. Some of the energy is used to overcome inertia, the tendency for an object to stay put, and some is used to overcome friction, or the resistance of the engine parts and the roadway. Most of the energy in the gasoline is actually dissipated into the atmosphere in the form of heat, another example of how entropy is increasing.

Likewise, under ordinary conditions, matter cannot be created or destroyed, only rearranged. Matter is composed of tiny particles called molecules and these in turn are composed of smaller particles called atoms. Atoms have a central structure made up of tiny pieces known as protons and neutrons. Surrounding this is a cloud of even smaller particles called electrons. When matter is changed, there is a rearrangement of the atoms to form new molecules. At the same time, the electrons are rearranged and energy may be stored or released in the bonds that hold the atoms together.

Molecule - the tiniest particle of a substance that has the chemical characteristics of the material.

Atom - a tiny particle of matter that cannot be divided by chemical means.

When gasoline is burned in the car, the matter is not destroyed, only changed into other substances. Carbon dioxide, carbon monoxide and water are some of the materials that come from the car's exhaust pipe. If one measured the amount of gasoline put into the car, collected all the waste products put out, and carefully measured them, there should be a balance between what went in, the inputs, and what came out, the outputs. There is an important difference, however between the inputs and outputs, and that is in their organization. The molecules of gasoline put into the car at a gas station are large molecules that contain a lot of energy in bonds between the atoms. When the bonds are broken down, the resulting products are simpler substances that contain fewer bonds and thus less energy. Some of the energy was harnessed by the engine and transmitted to the wheels to produce the motion of the car and a lot of it dissipated away as waste heat.

These relationships are also true of living things. For example, it is possible to study the consumption and activity patterns of a person over a certain time period. The person should be weighed at the beginning of the period to establish a measure of the amount of matter in the body. Then the food and water consumed is carefully measured. The oxygen consumed and the wastes generated are also measured. Records of the activities of the person and the ambient temperatures must also be kept. At the end of the period, the person should be weighed again. Estimates of the energy in the food consumed can be made from nutritional charts, and an estimate of the energy expended for both the vital and voluntary activities can also be made. Allowing for heat loss to the environment, there should be a balance between the energy input and the energy output. It should also be possible to balance the food, water and oxygen intakes with the waste output. However, if the person does very little exercise during the period, the requirement for energy will be lower. The extra material will be stored by the body for a time of shortage, and this will be reflected in a weight gain. If the person does more exercise than the food allows, stored material will be withdrawn, and this situation will lead to a weight loss. Whether you want to gain or lose weight, you can use these principles of conservation of matter and energy to attain your goal.

INPUTS
Food Water Oxygen
OUTPUTS
Work Heat Wastes
STORAGE
Surplus foods as fat

Figure 2: Energy and Matter Balance Sheet

Energy from the Sun

Life as we know it is dependent upon energy that radiates out from the giant star we call the Sun. This is fiery mass of nuclear reactions occurring almost 150 million kilometres away from us. Actually, in these nuclear reactions, matter is being destroyed in the sun and turned into energy that travels away in all directions from the fiery ball. Again most of this energy is being dissipated in forms of energy that are disorganized and is increasing the over all amount of entropy in the universe. As a planet moving around the sun, some of the energy falls on the earth. Because the earth's orbit is not exactly circular, the distance varies through the year. In addition, our planet's axis is tilted and as a consequence, there is an uneven distribution of the heat and light at different times in the year. This unequal distribution of energy is an important factor in determining the aspects of our environment that we call the climate. Much of the energy arriving from the sun is reflected or bounced off and dissipates back into outer space. If you ventured off the planet, you would see some of the light energy reflected as "earthshine".

Nuclear Reactions - split the nucleus of an atom, thus changing its chemical nature and release the energy that held it together.

There are some living things that have evolved the capacity to capture some of the light energy coming from the sun. They actually reduce the amount of entropy by transforming the relatively disorganized light energy into chemical energy through the process known as photosynthesis. Although there are several types of organisms and some variety in the ways that this occurs, life as we know it is greatly dependent on the photosynthesis that occurs in the plants and the algae. These organisms store the energy in sugars and other energy rich chemicals that they can use to provide energy for their own life functions. Then, a host of the other living things, particularly animals and fungi, consume these materials to get the energy they need to maintain themselves. The next few pages are focused on describing how plants carry on photosynthesis.

Photosynthesis - the process by which some organisms can transform light energy into forms that can be used for their activities.

Plants and Photosynthesis - an Overview

Plants like other living things are built up from smaller units called cells. Within each cell, there are several parts called organelles. Some of these are common to most living things, but plants share with algae an organelle called a chloroplast. These are found in the green parts of the plant and are particularly numerous in the leaves. The chloroplast contains a special green pigment called chlorophyll that acts as a solar collector that can trap light energy. Actually, the light energy excites or energizes electrons attached to the chlorophyll molecule. This energy is then carried off and moves through many other molecules. Along the way, the atoms in carbon dioxide and water are rearranged to form energy rich sugars. Oxygen is left over and flows out of the plant and into the atmosphere.

One step involves splitting water molecules. Water is composed of relatively simple molecules composed of hydrogen and oxygen. We write the chemical formula for water as H_2O, because there are two atoms of hydrogen attached to an atom of oxygen. Some of the light energy captured by the chlorophyll is used to break down water molecules. This liberates one free oxygen molecule for every two water molecules. The hydrogen atoms and their electrons resulting from this breakdown are transferred to a special carrier molecule called NADP for short. Other electrons energized by the light energy are passed through a variety of steps to produce molecules of the energy carrier called ATP.

Carbon dioxide (CO_2) is composed of a carbon atom bonded to two oxygen atoms. This gas is a component of the atmosphere and tends to diffuse into the plant. Using energy carried by ATP, and the electrons and hydrogen carried by the NADP, the chloroplast also rearranges carbon, hydrogen and oxygen atoms to build a high energy molecule with three carbon atoms. This substance is called glyceraldehyde 3-phosphate or G3P, for short. Two molecules of G3P join together to produce a highly stable but high energy substance called glucose.

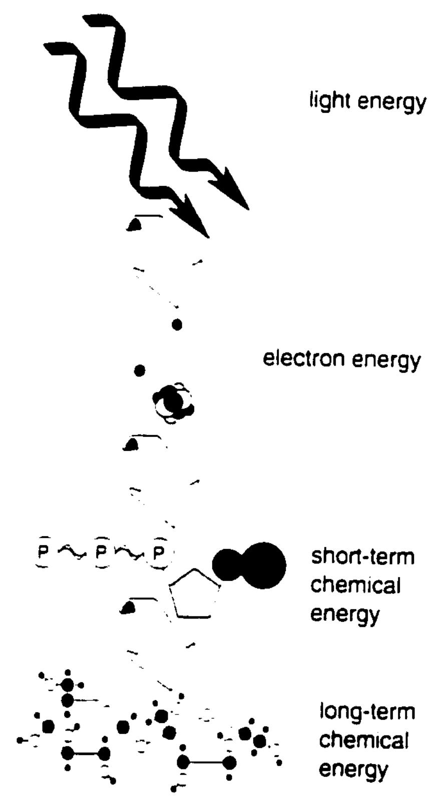


Figure 3: Transformations of Energy during Photosynthesis

Leaving out the many steps in the process, we can summarize all the chemistry of photosynthesis in simple word equations. (See next page.) This shows the material inputs to photosynthesis as carbon dioxide and water, and the material outputs as glucose and oxygen. It also shows the energy input as light and the energy output is in energy rich chemical bonds in the glucose molecule. Glucose molecules can be further transformed into other types of sugar or chained together to form molecules of the sugar sucrose that we commonly use to sweeten our cereal or coffee and tea. In many plants glucose molecules may be chained together into starch for long term storage. This is seen in the potato.

Unlocking the Energy in Glucose

Before starting the detailed discussion of photosynthesis, you might find it useful to know a little about how the energy in the glucose molecule is extracted to provide energy for the organism's activities. To do this organisms have a way of breaking down the glucose molecule to liberate the energy. We call this process respiration in living things and it is a controlled oxidation that slowly liberates the energy. In the first step, the glucose molecule is broken in half to form glyceraldehyde 3-phosphate (G3P). This is the same substance that is produced by the chloroplast. In highly active organisms like plants and animals, the G3P enters a specialized organelle called the mitochondrion, where it is oxidized under the control of enzymes by oxygen. The consequence is that the glucose molecule is broken apart in very small steps and the energy is transferred to the carrier ATP. The ATP can then enter into the host of other biochemical reactions that require an input of energy. Some of the energy that is liberated in this process is dissipated in the form of heat.

Again, by leaving out the steps, we can summarize the chemistry of respiration in the simple word equation shown just below that for photosynthesis. Look at the two equations. Notice the similarities and differences. Since animals do not carry on photosynthesis, we are dependent on this process to maintain our lives. It is important to realize that the proper functioning of the plant also requires this respiration to unlock the energy that is stored in sugars during photosynthesis. The detailed study of respiration requires more time and is not covered in this lesson.

Summary Word Equations

Photosynthesis:

Carbon dioxide + Water + Light Energy -----> Glucose + Oxygen

Respiration

Glucose + Oxygen -----> Carbon dioxide + Water + ATP

Specialized Carriers

You have been introduced to some special substances that carry energy and hydrogen. It may be useful to have a little more information about these.

ATP is an acronym that stands for Adenosine triphosphate. This is a complex molecule that has a tail of three phosphate groups. A phosphate group is made up of an atom of the element phosphorous with three oxygen atoms attached to them. In the chemistry of life, there are reactions that require energy to be added. When ATP transfers energy into a chemical reaction, one of the phosphate groups breaks off leaving Adenosine diphosphate (ADP), which consequently contains less energy. The reactions necessary for muscle contractions provide an example of reactions requiring energy. In the contracting units of the muscle cells, a lot of ATP is transformed to ADP. There are also reactions that liberate or release energy. Examples of these are the steps of respiration, the oxidation of glucose. Here ADP molecules receive phosphate groups, thus collecting energy. Many of these reactions occur in the mitochondria of the muscle cells, and there is a shuttling of ATP molecules to the contractile units and ADP molecules to the mitochondria. This is why we call ATP an energy carrier and can think of it as carrying along small packages of energy that is ready to use.

ATP - stands for Adenosine triphosphate.

ADP - stands for Adenosine diphosphate.

NADP - stands for nicotinamide adenine dinucleotide phosphate.

NADPH - stands for NADP when it is carrying a proton and electrons.

An analogy some people make is to relate the ATP to money. It is convenient to make small purchases with cash, but inconvenient or unsafe to carry around or store large amounts of ready cash. Instead, we store our money in banks and withdraw small amounts of cash to do our day to day shopping. The energy in glucose is like money in the bank; it is stored and waiting. ATP is like cash in your pocket that is available to help you buy what you want or need. Therefore, sometimes people call ATP the energy currency that powers most of the actions of the living thing.

The other carrier mentioned above is NADP. Again this is an acronym for a longer set of words: nicotinamide adenine dinucleotide phosphate. This carrier picks up electrons and a hydrogen ion (H^+). After they are attached, it is written as NADPH. NADPH is produced in the area of the chloroplast where the chlorophyll is activated by the light energy shining on the plant. It moves to the area where carbon dioxide is being fixed to form glyceraldehyde 3-phosphate and provides hydrogen for this reaction. It also loses electrons during this process and becomes NADP again. It then returns to the other area of the chloroplast and is ready to start again.

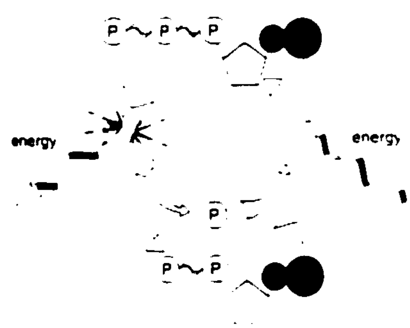


Figure 4: The ATP Cycle

The Chloroplast -- Site of Photosynthesis

This organelle is found in the cells of both plants and the algae. In plants, it is generally found in the leaves of the plant, although cells in the stems of small plants that are green also contain these structures. It is a relatively large organelle and can easily be seen with a light microscope. In a typical plant, water and mineral matter is absorbed by the roots and carried up to the leaves and made available to the cells and their parts, the organelles. Air flows in and out of the leaf through tiny holes called stomata. The air flowing in is generally rich in carbon dioxide and the air flowing out during the day is rich in oxygen. The chloroplast is separated from the rest of the cell's contents by a double membrane and then divided internally by other membranes. There are stacks of flattened membranous sacs. The stacks are called grana

Stomata - tiny holes in a leaf that allow air to enter and leave.

Granum - (plural: grana) one stack of thylakoids.

Thylakoid - a flat disc shaped structure surrounded by a membrane, the site of photosynthesis inside the chloroplast.

and each granum consists of several individual structures called thylakoids. The chlorophyll pigment is found inside the thylakoids and they therefore function in the steps of photosynthesis that initially capture the light energy. Outside of the thylakoids there is viscous fluid called the stroma. The other reactions involved in converting carbon dioxide to sugar occur within this fluid.

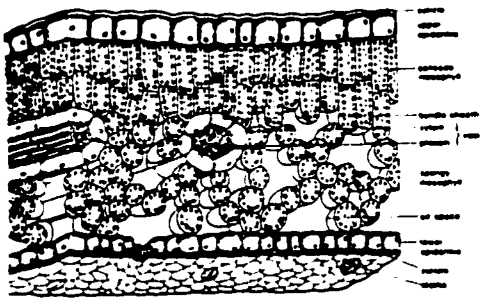


Figure 5: Cross Section of a typical Plant Leaf

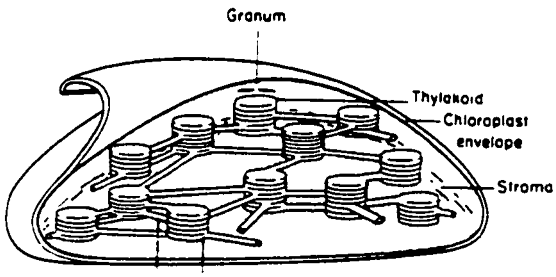


Figure 6: Detailed View of typical Chloroplast

The Nature of Light

Light, as mentioned before, is a type of energy. Only a very small amount of the light produced by the sun arrives at the earth, as most of it radiates out into space. Only about one per cent of the amount that does arrive is captured by photosynthesis. Light is sometimes explained by thinking of it as being in the form of waves, and, at other times, as if it were made up of particles called photons. When the visible white sunlight is passed through a prism, we see a series of colours like the rainbow, red orange yellow, green, blue, and violet. This is explained by the wave theory of light -- the prism separates the light based on its wave length and the variations in the wave length are related to the colour. When sunlight falls on the leaves of plants, we see them as green because the red, orange, yellow, blue and violet wave lengths are absorbed by the chlorophyll pigments in the leaves, while most of the green light is either reflected or transmitted through the leaves. In the Autumn, the leaves turn colours as the chlorophyll pigments deteriorate from the cold, and we see the evidence of some of the other light trapping pigments present in the leaves.

The waves of light contain energy, and it is easier to use the particle explanation of light to explain how light energy is captured by the plants and algae. Each of the particles, called photons is considered to have a fixed amount of energy. This amount of energy is inversely proportional to the wave length of the light, so that a photon of violet light has nearly twice the energy as a photon of red light. It is the light at the ends of the spectrum that provides the energy for photosynthesis. When light of these colours shines on the plant the photons are trapped by the pigments in the plant cell and the energy is transferred to electrons.

Photon - a particle of light with a fixed amount of energy. Red light photons contain about half as much energy as those of blue-violet light.

The important pigment in the plant for photosynthesis is chlorophyll a. There is another type of chlorophyll labelled as chlorophyll b that is an accessory pigment. Like the pigments with other colours, chlorophyll b is capable of capturing light energy and transferring it to chlorophyll a. There are also two types of chlorophyll a, one labelled as P680 and the other as P700. They absorb slightly different wave lengths of light. All these active pigments are in the thylakoids of the chloroplasts, although the amounts and their distribution may vary. There is also a variation in the clustering of the pigments that generate two different approaches to the capture of light energy, photosystem 1 and photosystem 2.

Chlorophyll - the green pigment active in photosynthesis. There are two categories Chlorophyll a and Chlorophyll b.

P680 & P700 - these refer to two variations of chlorophyll a based on the wave lengths of light that they absorb.

The Photosystems and the Light Dependent Reactions of Photosynthesis

Photosystem 1 is built around molecules of the P700 type of chlorophyll a embedded in the thylakoid membranes. In this photosystem, a photon strikes the chlorophyll a and excites electrons in the chlorophyll molecule causing two of them to leave. These are accepted by a carrier that moves them along an electron transport chain also in the membrane of the thylakoid. Along this chain a series of step like reactions redirects the energy of the electrons for differing purposes. When only photosystem 1 is present, such as in photosynthetic bacteria and blue-green algae, the energy of the electrons is transferred to convert one molecule of ADP to a molecule of the carrier ATP. At the end of this series of reactions, two electrons return to the chlorophyll a molecule, thus restoring it and making it ready to react to another photon. Because the electrons cycle around and return to the chlorophyll the process occurring when photosystem 1 is active by itself is called cyclic photophosphorylation or cyclic electron flow. The complex photosynthesis occurring in chloroplasts depends on an interaction of photosystem 1 with photosystem 2.

Photosystem - a complex of chlorophyll molecules active in photosynthesis.

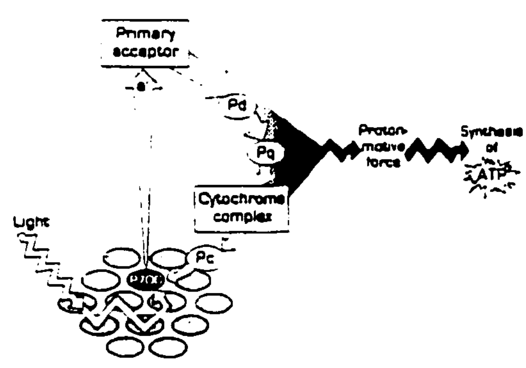


Figure 7: Photosystem 1

Photosystem 2 is built around the P680 variety of chlorophyll a. It is in photosystem 2 that water molecules are split. This liberates an atom of oxygen, two hydrogen ions (H^+) and two electrons. Each oxygen atom combines with another to form elemental oxygen (O_2) that will go into the atmosphere. The hydrogen ions, also called protons, add to the concentration of hydrogen ions and, consequently, the pH within the thylakoid becomes more acidic. The electrons that are left from the water molecules replace the electrons that were activated and pushed off from the chlorophyll a molecule by a photon of light. These electrons move through the electron transport chain in the thylakoid membrane. Their energy is used to move hydrogen ions through the membrane into the thylakoid and the electrons themselves are transferred to photosystem 1, where they replace the electrons bounced off of the P700 chlorophyll a by the arrival of another photon. The kinetic energy from these electrons is eventually transferred to produce a molecule of ATP by chemiosmosis.

Requirements for the light dependent reactions:

Chlorophyll in photosystems
Red and blue light
Water

Products of the light dependent reactions:

ATP
NADPH
Molecular oxygen

The electrons freed from chlorophyll a in photosystem 1 also pass through an electron transport chain and their energy is used to make NADPH from NADP. The electrons from photosystem 1 do not cycle and is called noncyclic photophosphorylation.

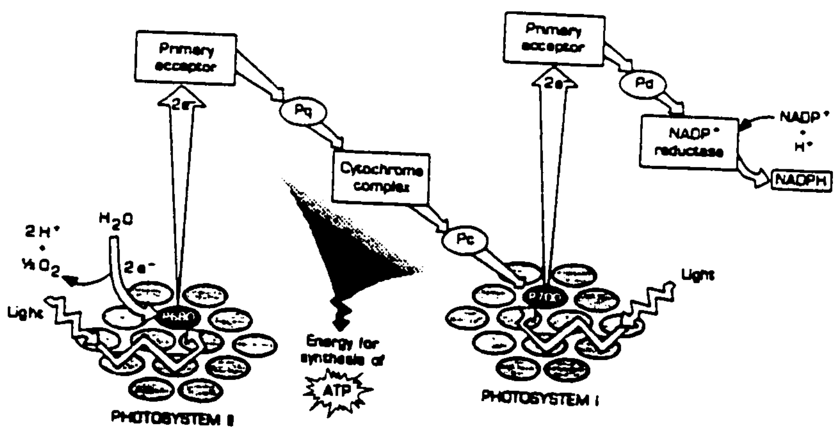


Figure 8: Photosystems 1 and 2

Nothing has been lost from the matter involved. The inputs to this part of the process are water and light. The water is broken into its component atoms and gives up two electrons. The oxygen atoms from two water molecules are joined to produce molecular oxygen that ends up in the atmosphere. The electrons replace those lost from the P680 chlorophyll a by the action of light. These in turn are passed through the electron transport chain and are transferred to molecules of P700 chlorophyll a to replace electrons pushed away by light energy. The electrons from the P700 chlorophyll a molecule are incorporated into molecules of NADP. The hydrogen ions produced may end up cycling from inside the thylakoid to the stroma, and becoming a part of the NADPH molecules. At this point, the laws of conservation of matter are obeyed. Energy is also conserved. The energy from photons has been transferred to energize electrons and is subsequently passed to the molecules of ATP. Some of the energy is dissipated as heat.

Because the operations of the photosystems are dependent on photons from light for their operations, they are known as the light dependent reactions. This is sometimes shortened to light reactions. The important result of these is the production of the NADPH and the ATP that will feed into the other set of reactions that do not require light, and are therefore known as the light independent reactions.

Electron Transport Chains and Chemiosmosis

An important part of the energy transfer process is located within the membranes of the thylakoids. There is a series of protein molecules that act as electron carriers embedded in the membrane. The series of protein molecules may also be referred to as an electron transport chain. As the energized electrons move along from one carrier to the next, they gradually lose energy which is used for varying purposes. In between photosystem 1 and photosystem 2, the energy is used to move hydrogen ions (H^+) across the membrane separating the thylakoid from the stroma. This establishes an osmotic gradient as the concentration of H^+ is greater inside the thylakoid than in the outer stroma. In this way, the energy from the electrons has been stored by the position of the H^+, and is a form of potential energy.

In other regions of the thylakoid membrane, there are large protein complexes that form ports through which the H^+ can diffuse back into the stroma. The difference in the concentration of the H^+ drives their diffusion from one area to another. The enzyme ATP synthase is found in this port and uses the energy of the moving hydrogen ions (H^+) to add phosphate groups to ADP molecules, thus making ATP molecules through a process known as chemiosmosis.

In the membrane near photosystem 1, there is another electron transport chain that operates to transfer the energy from the electrons lost by the P700 chlorophyll a. This energy is used to drive the formation of molecules of the carrier NADPH from $NADP^+$. This carrier moves electrons and hydrogen ions into the next phase of photosynthesis.

Electron Transport Chain - is a series of protein molecules embedded in the thylakoid membrane that transforms the energy of electrons to other forms for varied purposes.

Diffusion - movement of molecules from an area of high concentration to an area of lower concentration.

Osmosis - movement of solvent molecules through a membrane by diffusion.

Osmotic gradient - distinct areas of high and low concentration of a substance, that are separated by a membrane.

Enzyme - a biological catalyst that speeds up or slows down a chemical reaction in a living thing.

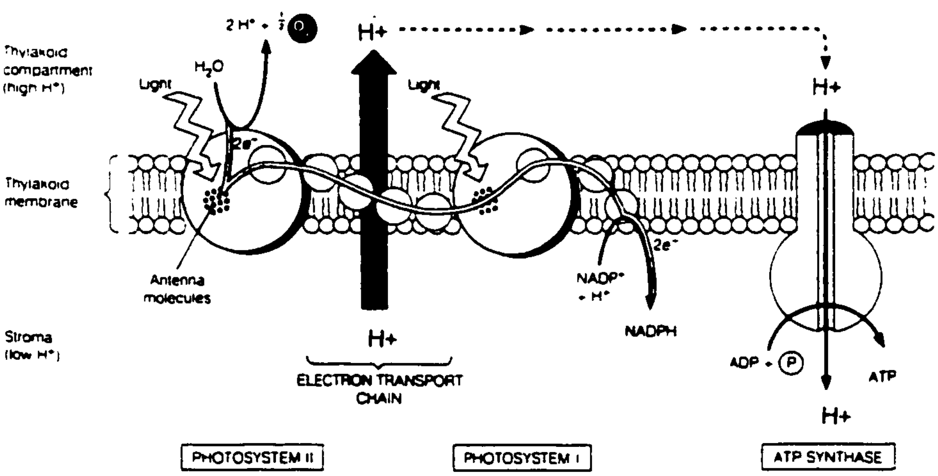


Figure 9: Chemiosmotic Production of ATP and NADPH

Light From Sun

Energizes

ELECTRONS IN CHLOROPHYLL a

energy used to

split

Water

H_2O

into

HYDROGEN → and → OXYGEN

joins to

NADP

forming

NADPH

released into the air

move

PROTONS (H^+)

through the thylakoid membrane creating a

Concentration Gradient

PROTONS

diffuse through ATP - synthetase complex (chemiosmosis)

ADP

becomes

ATP

Needed for Light Independent Reactions

Figure 10: Flow Chart for the Light Dependent Reactions

The Light Independent Reactions of Photosynthesis

An important ingredient for the light independent reactions is carbon dioxide. This gas enters the leaf from the atmosphere through the stomata. It then diffuses into the stroma of the chloroplasts where it undergoes a series of enzyme controlled reactions to build carbohydrate molecules. These reactions convert the carbon dioxide gas into stable carbon, hydrogen and oxygen compounds from which many other organic compounds can be built. The process of establishing the chains of carbon that form the carbohydrate molecules is called carbon fixation. This phase of photosynthesis is also named the Calvin Cycle after Melvin Calvin who did much of the initial research needed to discover it. The reactions are also sometimes called the dark reactions, since they do not require light to function. They are not, however, free from the light reactions as they require the ATP and the NADPH produced by them.

The reactions of the Calvin Cycle operate in a circle to produce their product and to also regenerate their starting material by the end of the cycle. This is similar to other biochemical processes. Each reaction results in a small change controlled by the presence of enzymes. Each of these changes results in the formation of an intermediate compound on the way to building the actual product. It is easy to describe the reactions as a series of steps and these may be found on the following pages. Only the important intermediate substances are described to simplify the process a little bit. Although water is not a reactant in the cycle, the reactions are taking place in a watery environment in the stroma of the chloroplast. Therefore, water is needed for the plant to carry out this part of the photosynthetic process.

Requirements for the light independent reactions:

Carbon dioxide
ATP
NADPH

Product of the light independent reactions:

glyceraldehyde 3-phosphate (G3P)

Steps in the Calvin Cycle:

Step 1: Three molecules of carbon dioxide enter the cycle and each molecule is attached to a five carbon sugar, ribulose biphosphate, that is already present. This reaction occurs through the action of the enzyme rubisco and results in a six carbon sugar.

Step 2: The six carbon sugar splits immediately into two three carbon molecules called 3-phosphoglycerate. For every three molecules of carbon dioxide that enter the Calvin Cycle, 6 molecules of 3-phosphoglycerate are formed.

Step 3: Each molecule of 3-phosphoglycerate receives a phosphate group from ATP to form six molecules of the intermediate substance 1,3-diphosphoglycerate. This step uses six molecules of ATP produced in the light dependent reactions, converting them back to ADP.

Step 4: The six molecules of 1,3-phosphoglycerate then gain high energy electrons and hydrogen from NADPH to form molecules of the substance glyceraldehyde 3-phosphate (G3P). This step uses six molecules of NADPH produced in the light dependent reactions, converting them back to NADP.

One of the molecules of glyceraldehyde 3-phosphate leaves the Calvin Cycle at this step and moves out of the chloroplast. Chemical reactions outside the chloroplast but inside of the cell can then use two of these molecules to form a molecule of glucose.

Step 5: Having produced one of the two molecules of the key substance for the plant cell to make glucose, the cycle continues by taking the other five molecules of glyceraldehyde 3-phosphate (G3P) and sending them through a series of chemical reactions to rearrange them into three molecules of ribulose biphosphate. This restores the substance from which the cycle started. These reactions also require energy and obtain it from three molecules of ATP that are derived from the light reactions.

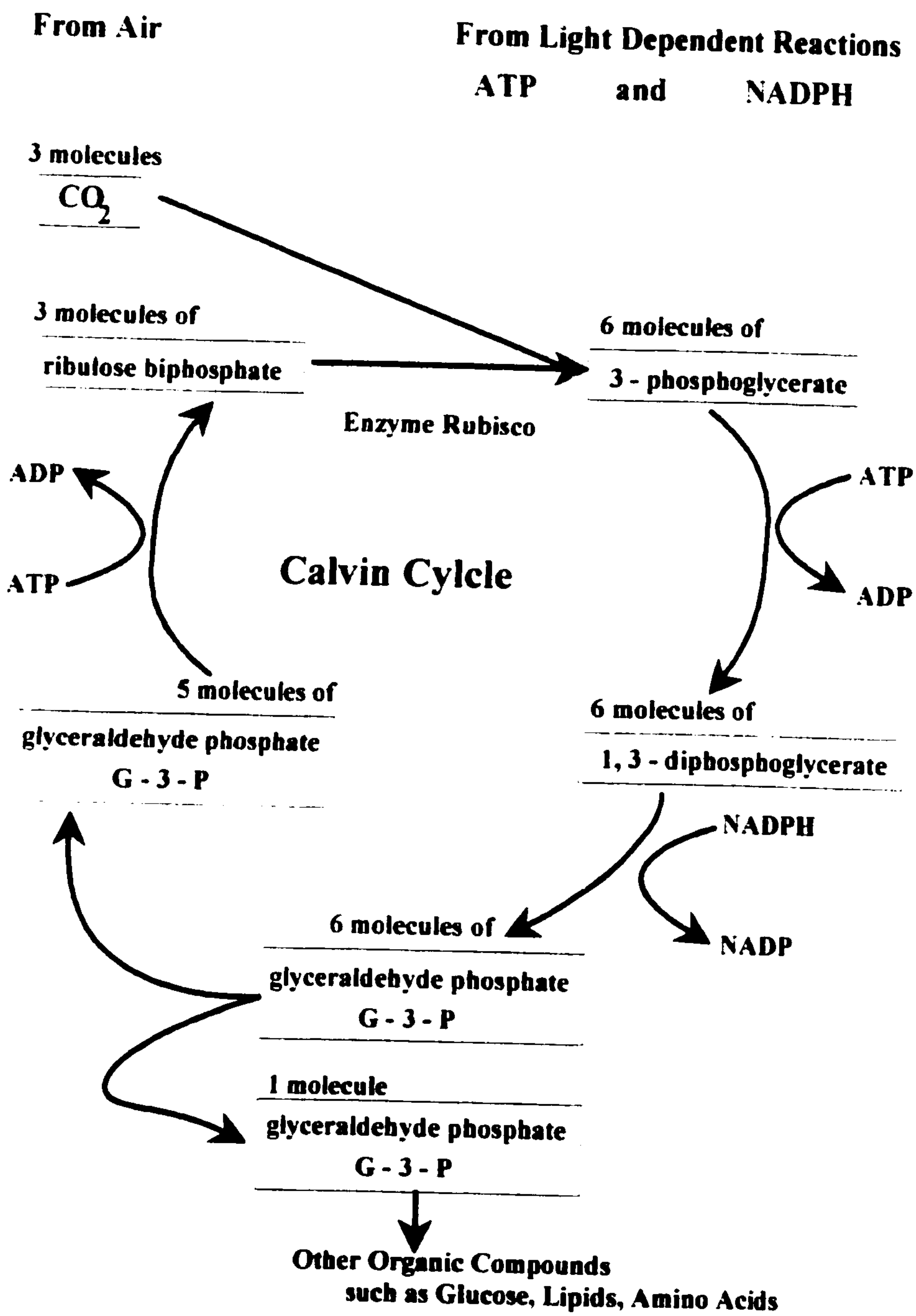


Figure 11: Flow Chart for the Light Independent Reactions

What Happens to glyceraldehyde 3-phosphate (G3P)?

After it is produced by the Calvin Cycle glyceraldehyde 3-phosphate can enter into other aspects of the plant's metabolism. Some of the G3P is used directly to supply energy for the producing cell's own activities. Much of it is converted into the six carbon sugar, glucose, and some of this may be subsequently converted to a similar six carbon sugar called fructose. In many plants, these two sugars are combined to form the substance sucrose, that is easily dissolved in water and moves through the plant to nourish areas where photosynthesis does not occur, such as the interior of the stem or the roots. The cells in these areas then may convert the sucrose back to glucose, then to G3P and to provide the energy for their activities. About half of the sugars produced are subsequently used for cellular respiration, the energy releasing process mentioned above.

Some of the G3P can enter into other chemical reactions to provide the basic carbon, hydrogen and oxygen skeletons that are needed by the plant to produce other materials such as amino acids and lipids. A large amount of the sugar produced is converted into cellulose to provide the cell walls that support the plant. The surplus sugar is converted to starch and stored in parts of the plant for future use. The starch that we draw on when we eat potatoes was produced from sugars made through photosynthesis and stored in swellings or tubers of the underground stems the potatoes.

Glyceraldehyde 3-phosphate (G-3-P) - the end of photosynthesis, the beginning of many other chemical cycles.

G-3-P can be used as an energy source for the photosynthesizing cell

G-3-P is used to produce other carbohydrates: glucose, fructose, sucrose, cellulose, and starch are a few examples.

G-3-P is used as a carbon framework to produce amino acids, and lipids.

Photosynthesis as a REDOX Process

Electron shuttling involves a chemical process called reduction-oxidation or REDOX for short. When electrons are lost from one substance, it is said to be oxidized and the when they are gained it is said to be reduced. Because an electron transfer always requires a donor and an acceptor the two processes always go together. As the electrons are transferred, energy is also moving. Photosynthesis is an energy requiring process that reduces carbon dioxide. Respiration is an energy releasing process that oxidizes glucose. In both processes, there is a series of reduction and oxidation reactions.

Photosynthesis starts with light causing the oxidation of chlorophyll a molecules in both photosystem 1 and 2. These molecules each lose two electrons. The electrons subsequently are transported along electron transport chains. In the case of photosystem 2, the electrons lost by the chlorophyll a P680 end up restoring electrons to the chlorophyll a P700 of photosystem 1, after the energy is used to move hydrogen ions. At photosystem 2, water molecules are also oxidized and lose two electrons that are used to restore Chlorophyll a P680. At the site of photosystem 1, the electrons lost are used to reduce the molecules of the carrier NADP and form the substance NADPH.

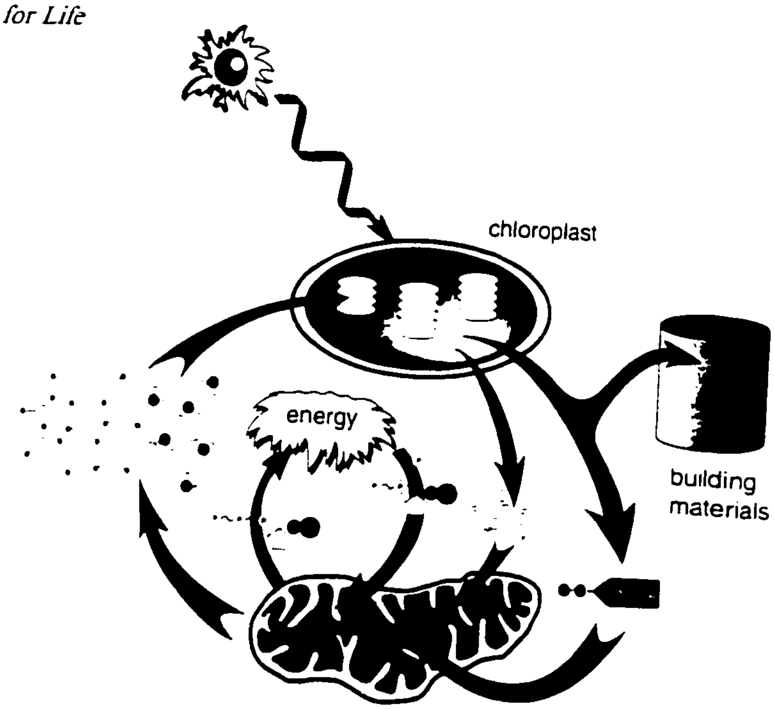
The electrons carried in the molecules of NADPH are subsequently used to reduce carbon dioxide molecules as they are assembled into the glyceraldehyde 3-phosphate (G3P). At this point the molecules of NADPH can be said to be oxidized as they lose electrons and become again molecules of NADP. One can trace the route of the electrons, and see that they are not lost or gained, but transferred in a series of redox reactions.

REDOX - short for reduction and oxidation, complementary electron shuttling.

Reduction - occurs when a substance gains electrons.

Oxidation - occurs when a substance loses electrons.

Summary



Energy pours onto the earth from the sun. A small amount of this energy is absorbed into the chloroplasts and becomes available to the photosystems for photosynthesis. The reactions that occur as a consequence of the light energy are called light dependent reactions.

Molecules of P680 chlorophyll a in photosystem 2 capture the light energy, causing electrons to become energized and leave.

Also in photosystem 2, molecules of water are split apart. The oxygen escapes into the atmosphere, and the hydrogen ions enter the interior of the thylakoid structure of the chloroplast. The electrons lost from the water replace the ones that escape from chlorophyll a.

The energy of the electrons moving away from the chlorophyll a pass through an electron transport chain and establish a chemiosmotic gradient of hydrogen ions. The energy is stored in ATP molecules and the electrons themselves are transferred to molecules of P700 chlorophyll a in photosystem 1.

At photosystem 1, light energy also causes two electrons to move away. These are subsequently replaced by those that originate in photosystem 2. The electrons moving from photosystem 1 also move through an electron transport chain and are picked up by the carrier NADP. This carrier also picks up hydrogen ions produced from the splitting of water.

The Calvin Cycle, also known as the light independent reactions, uses the energy stored in ATP, the electrons and the hydrogen stored in NADPH, and atmospheric carbon dioxide to generate six molecules of the three carbon sugar called glyceraldehyde 3-phosphate (G3P).

Five of these molecules are actually reprocessed to continue the cycle, while one molecule leaves the chloroplast.

The glyceraldehyde 3-phosphate (G3P) that moves out of the chloroplast can then be converted to other sugars, particularly glucose. This substance can also be used as a carbon skeleton for the formation of many other organic molecules.

The sugars produced supply the entire plant with the chemical energy required for its activities.

Thus, we can trace the flow of light energy from the sun through the chloroplasts of the green regions of a plant to produce glyceraldehyde 3-phosphate (G3P) from which glucose and other vital chemical substances can be synthesized. The extra glucose may be converted into other sugars or starch. When the materials produced by plants are consumed by other living things, they can utilize the chemicals for their own metabolism or transform the chemical energy into the energy forms needed to maintain themselves.

STUDY QUESTIONS

1. Write a simple definition of *energy*, and describe the forms that energy may take.

2. What is meant by the *law of conservation of energy*? What happens when energy is transformed from one type to another? How does the transformation relate to entropy?

3. Describe the structure of matter. What happens when matter changes? What is the relationship between matter and energy?

4. Explain what happens to a person who takes in more energy through food than is put out through exercise.

5. From where does the energy come to drive the activities of the living things here on earth?

6. What groups of living things are able to capture energy and transform it into forms that are useful to living things?

7. List the materials required or inputs for the process of photosynthesis. List the materials produced by the process of photosynthesis.

8. Write a word equation that summarizes photosynthesis by showing the inputs and the products.

9. Compare photosynthesis as an energy storing process and respiration as an energy releasing process that maintains life. Why are both of these processes essential to the continuation of life as we know it on this earth?

10. Where does the process of photosynthesis occur? Draw a sketch to show the basic structure of the cellular part that is responsible for photosynthesis.

11. Where do the light dependent reactions of photosynthesis occur. What must be taken in at this point? What is produced?

12. Describe the events occurring in the light dependent reactions.

13. Where do the light independent reactions of photosynthesis occur. What must be taken in at this point? What is produced?

14. Describe the events occurring during the operation of the light independent reactions. What are inputs and outputs of the Calvin Cycle? What is the role of the substance rubisco?

15. What roles are played by the substances ADP and ATP, and the substances NADP and NADPH, in linking the light dependent reactions with the light independent reactions?

16. What is the relationship between Chlorophyll a and Chlorophyll b? What is the relationship between P700 and P680 chlorophyll a? What roles do these substance play in the photosynthesis occurring in plants?

17. Describe flow of electrons during photosynthesis. How are Photosystems 1 and 2 related to electron flow?

18. Categorize the reactions occurring within the process of photosynthesis as oxidation or reduction (REDOX) reactions.

19. How is glyceraldehyde-3-phosphate (G-3-P), as the product of photosynthesis related to other materials such as glucose, fats, and proteins.

20. Considering the process of photosynthesis, and disregarding the addition of carbon dioxide through the human use of fuels, why is there a balance between the amounts of oxygen gas and carbon dioxide in the atmosphere?

APPENDIX 3

OBJECTIVES AND TEST QUESTIONS

FOR A LESSON ABOUT PHOTOSYNTHESIS

OBJECTIVES FOR A LESSON ON PHOTOSYNTHESIS

For this topic four levels of knowledge are required for college students:

General Knowledge Level

Every college student should be expected to understand photosynthesis at this level and we would expect the student to demonstrate this knowledge by:

Providing a simple definition of energy.

Explaining the concept of the conservation of energy by stating that energy is transformed from one form to another; differentiating between potential energy and kinetic energy; and listing chemical energy, heat, light, electricity and sound as forms of energy.

Providing a simple definition of matter.

Explaining the concept of conservation of matter by describing the basic structure of matter as composed of molecules; and how matter can be transformed through the rearrangement of atoms and molecular pieces.

Explaining the links between matter and energy by briefly describing that energy can be stored in the chemical bonds holding molecules together; and how that energy stored in molecules can be released and transformed into other forms of energy.

Naming the sun as the ultimate source of energy available to humans and briefly describing the process of photosynthesis as the way plants store the light energy coming from the sun in chemical bonds.

Naming plants as the major group of living things in which photosynthesis occurs.

Listing the materials required as reactants or inputs for the process of photosynthesis.

Listing the products of the process of photosynthesis.

Summarizing the process of photosynthesis by writing a word equation linking the inputs to the products.

Differentiating between photosynthesis as the energy storing process and respiration as the energy releasing process that maintains life.

First Intermediate Level

At this level the student still lacks the chemical and physical background to fully understand the process, but through a deeper study of general biology, can add to the above content by:

Locating the process of photosynthesis in the chloroplast found in plant cells.

Naming the algae as the other group of organisms capable of carrying on photosynthesis.

Differentiating between the light dependent and light independent reactions.

Describing that light energy activates the chlorophyll and provides the energy to split the water molecules, liberating oxygen and hydrogen as products.

Describing this liberated oxygen as the source of oxygen in the air.

Describing that the liberated hydrogen and carbon dioxide become chemically bound to form carbohydrate molecules destined to become sugars.

Second Intermediate Level

At this level the student begins to integrate knowledge of chemistry and physics to more fully understand the process, and can add to the above content by:

Describing the structure of the chloroplast and locating the sites of the light dependent and light independent reactions within the chloroplast.

Describing the function of the light as excitement of electrons in molecules of chlorophyll.

Naming the specific products of the light dependent reactions that provide the inputs to the light independent reactions summarized in the Calvin cycle.

Advanced Level

At this level the student integrates knowledge of chemistry and physics to more fully understand the process, and can add to the above content by:

Naming Chlorophyll a and Chlorophyll b as two forms of this substance and describing the role of each in the process of photosynthesis.

Naming P700 and P680 as two different types of chlorophyll a and describing the role of each.

Describing two potential routes for electron flow during the light reactions: cyclic and noncyclic flow.

Naming Photosystems 1 and 2 and describing the relationship of the products of each to the outcomes of the light dependent reactions.

Describing the role of the substances ADP and ATP in the transfer of energy.

Describing the role of the substances NADP and NADPH in the transfer of electrons.

Describing the processes occurring along the electron transport chain, the products produced and their role in each of the photosystems.

Describing the events occurring in the Calvin Cycle, the fixation of carbon dioxide, the role of the enzyme rubisco, the uses of ATP and NADPH, the product as a three carbon precursor to the substance glucose. At this level, there is no need to provide the names of every intermediate substance or the enzymes involved.

Describing the oxidation and reduction reactions (REDOX) occurring within the process of photosynthesis.

There are even more detailed knowledge requirements for students studying botany, biochemistry or biotechnolgy at the university level.

SAMPLE TEST QUESTIONS FOR A LESSON ABOUT PHOTOSYNTHESIS

1. Energy is defined as:

   A. something given off by light.
   B. something found only in living things.
   C. the ability to do work.
   D. another name for electricity.
   E. a push or a pull.

2. In an experimental situation, a college student was weighed on Monday morning. For the next five days, his diet was carefully controlled, his intake and outputs were carefully measured and he was weighed again on Friday afternoon. During the period, he had gained 2 kilograms. Which of the following statements best explains this weight gain?

   A. He has decreased the amount of potential energy in his body.
   B. He has increased the amount of matter stored within the body.
   C. He created matter out of the energy supplied to him.
   D. He has lost water and added fat.
   E. He has lost protein and added fat.

3. Most organisms depend directly or indirectly on energy from:

   A. radioactive decay on the earth.
   B. the primal heat of the earth.
   C. the decay of organic matter.
   D. inorganic reactions.
   E. the sun.

4. Entropy:

   A. is a measure of the disorder of a system.
   B. decreases in spontaneous reactions.
   C. is unrelated to the free energy.
   D. increases at equilibrium.
   E. decreases as complex chemicals are broken down.

Use the items in the list below to answer questions 5 and 6:

A. A skier at the top of a mountain
B. Water going over a falls
C. Water held behind a dam
D. A bike chained to a tree
E. A biker coasting down a hill
F. The batteries in flashlight
G. Smoke blowing through the air
H. A train stopped in a station
I. A parked truck full of sand
J. Blood flowing through veins
K. The gasoline in a truck's gas tank

5. Choose **three** items from the group above that serve as examples of kinetic energy.

6. Choose **three** items from the group above that serve as examples of potential energy.

Use the items in the list below to answer questions 7, 8, and 9:

A. In some chemical reactions energy is stored in the bonds between atoms.
B. The number of atoms remains the same before and after chemical reactions have occurred.
C. Molecules are made up of atoms.
D. There are three states of matter, solids, liquids and gases.
E. Matter can be changed from one state to another, but cannot be destroyed.
F. Chemical reactions involve rearranging the atoms of molecules.
G. Molecules are built and rebuilt from the atoms involved in chemical reactions.
H. Matter is made up of tiny particles called molecules.
I. In some chemical reactions energy is released in the form of heat and light.
J. The energy released from chemical reactions may be used to do work.

7. Choose **three** items from the group that may be used to describe the nature of matter.

8. Choose **three** items from the group that may be used to describe what happens to **matter** in a chemical reaction.

9. Choose **three** items from the group that may be used to describe what happens to **energy** in a chemical reaction.

10. What is happening at the sun?

    A. Nuclear reactions break up atoms releasing large quantities of energy.
    B. Atoms are rearranged to form new molecules.
    C. Light from other stars is captured and stored in chemical bonds.
    D. Energy is synthesized by assembling atoms into molecules.
    E. Light and heat are converted to potential energy.

11. Which combination of statements best describes how energy is captured by living things?

    1. Light provides the energy for photosynthesis.
    2. Light activates electrons in chlorophyll a molecules.
    3. The energy of activated electrons is used to move protons.
    4. The potential energy of a proton concentration gradient is transformed to chemical energy in ATP molecules.
    5. The energy of activated electrons is stored in ATP molecules.
    6. The chemical energy is transferred from ATP to G-3-P molecules.
    7. G-3-P molecules are assembled to form glucose molecules.
    8. Energy from light is transformed into chemical energy stored in glucose molecules.

    A. 1 only
    B. 1 and 8
    C. 1, 2, and 8
    D. 1, 2, 5 and 8
    E. 1, 2, 5, 6, 7, and 8
    F. 1, 2, 3, 4, 5, 6, 7, and 8
    G. 8 only

12. Which type of organisms carry on the process of photosynthesis?

    A. Animals
    B. Bacteria
    C. Fungi
    D. Plants
    E. Protozoans

13. Leaves of plants appear green because their_____ green light.

    A. chlorophylls reflect or transmit
    B. carotenoids reflect
    C. chlorophylls absorb
    D. carotenoids absorb
    E. Both C and D.

Use the following statements to answer questions 14 and 15:

A. an energy releasing process.
B. an energy storing process.
C. a process converting light energy into chemical energy.
D. a way that only animals acquire energy.
E. an process that makes chemical energy available for life processes.
F. a process that occurs in plants and algae.
G. a process occurs in all living things.

14. Choose **three** statements from the group to describe the process of photosynthesis.

15. Choose **three** statements from the group to describe the process of respiration.

16. Which gas is taken in by plants even when there is NO light energy available?

    A. Carbon dioxide
    B. Oxygen

17. The reason for my answer in question 16 is:

    A. This gas is used in photosynthesis which occurs in plants all the time.
    B. This gas is used in photosynthesis when there is no light energy available.
    C. This gas is used in respiration which occurs in plants when light energy is available.
    D. This gas is used in respiration which occurs continuously in plants.

18. Respiration in plants takes place in:

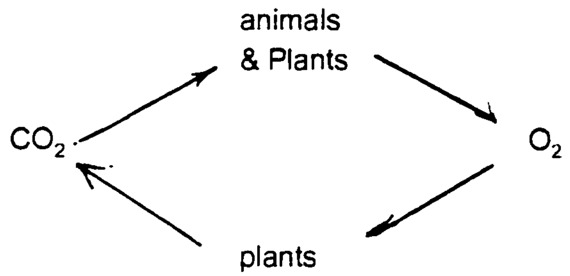
    A. the cells of the roots only.
    B. every plant cell.
    C. the cells of leaves only.
    D. none of the cells. It only occurs in animals.
    E. any cell with chloroplasts.

19. The reason for my answer in question 18 is:

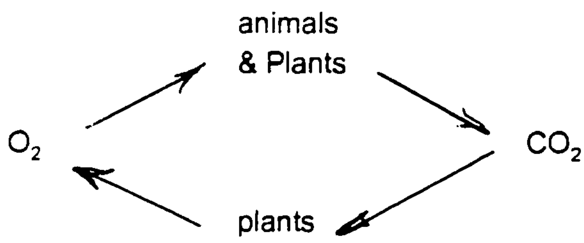
    A. Only roots need energy to absorb water.
    B. Only leaves need energy to produce sugars.
    C. Animals carry on respiration; plants carry on photosynthesis.
    D. Animals carry on photosynthesis; plants carry on respiration.
    E. All living cells need energy to live.

20. Which of the following diagrams correctly shows the cycling of carbon dioxide and oxygen in nature?

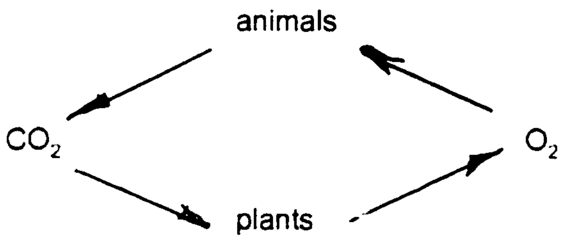
A.



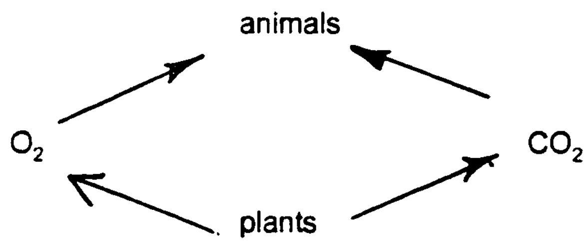
B.



C.



D.



21. The most important benefit of the process of photosynthesis is:

A. the removal of carbon dioxide from the air.
B. the transformation of light energy into chemical energy.
C. the creation of energy from inorganic substances.
D. the fixation of nitrogen from the air.

22. The reason for my answer in question 21 is:

A. Photosynthesis provides energy for plant growth.
B. During photosynthesis light energy is captured and stored in carbohydrate molecules.
C. Carbon dioxide is taken in by the leaf, and oxygen is put out.
D. Plants use photosynthesis to produce energy from matter.
E. Potential energy is being transformed into kinetic energy during photosynthesis.

23. Which cell structure converts solar energy to chemical energy?

A. ribosomes
B. mitochondria
C. leucoplast
D. chloroplast
E. lysosomes

24. The role of light in photosynthesis is to:

A. break down glucose molecules.
B. activate electrons in the chlorophyll molecules.
C. provide energy for splitting carbon dioxide molecules.
D. provide energy for building oxygen molecules.
E. activate carbon dioxide and hydrogen to react together.

25. Chlorophyll b and the carotenoids are important receptors of light energy because they:

A. can pass the energy to chlorophyll a.
B. have their own photosystems.
C. respond to wavelengths different from those that excite chlorophyll c.
D. Only A and C are correct.
E. All three answers (A, B, and C) are correct.

The following are summary equations for a few biological chemical reactions. Use these to answer questions 26 and 27.

A. Carbon dioxide + water + light energy --> Glucose + Oxygen

B. Carbon dioxide + water --> Carbonic Acid

C. Glucose + Oxygen --> Carbon dioxide + water + ATP

D. Glucose --> Alcohol + Carbon dioxide + ATP

26. Which of the reactions given above best summarizes the process called respiration?

27. Which of the reactions given above best summarizes the process called photosynthesis?

28. Grana, stroma, and thylakoids are parts or structures within:

    A. chlorophyll molecules.
    B. chloroplasts.
    C. any plant cell.
    D. vacuoles.
    E. cell nuclei.

29. The oxygen released in photosynthesis comes from:

    A. water.
    B. carbon dioxide.
    C. glyceraldehyde-3-phosphate (G-3-P).
    D. glucose.
    E. chlorophyll

30. Glyceraldehyde-3-phosphate (G-3-P) provides the basis for building molecules of:

    A. glucose.
    B. sucrose.
    C. cellulose.
    D. starch.
    E. all of the above.

The following are events that occur in the process of photosynthesis. Use these to answer questions 31, and 32.

1. ATP produced
2. ATP used up
3. Carbon dioxide and hydrogen joined or fixed
4. Electrons of chlorophyll excited
5. G-3-P (glyceraldehyde-3-phosphate) produced
6. Light falls on the chloroplast
7. NADPH produced
8. Oxygen gas produced
9. Splitting of water molecules
10. Use of transferred hydrogen ions
11. Use of transferred of electrons

31. Which selection of items represents the major events that occur in the light **dependent** reactions of photosynthesis?

    A. 2, 3, 5, 8
    B. 2, 3, 5
    C. 1, 4, 6, 7, 8, 9
    D. 2, 3, 5, 8, 9
    E. 10, 11

32. Which selection of items represents the events that occur in the light **independent** reactions of photosynthesis?

    A. 2, 3, 5, 8
    B. 2, 3, 5
    C. 1, 4, 6, 7, 8, 9
    D. 2, 3, 5, 8, 9
    E. 10, 11

33. Where do the light dependent reactions occur?

    A. thylakoids
    B. stroma
    C. grana
    D. lamellae
    E. cytoplasm

34. The "first step" in the light reactions of photosynthesis is the:

A. formation of ATP.
B. ionization of water.
C. excitement of an electron of chlorophyll a by a photon of light.
D. attachment of CO_2 to a 5-carbon sugar.
E. joining of two 3-carbon compounds to form glucose.

35. In the plants, the electrons that leave the chlorophyll of photosystem I are replaced by electrons from:

A. ATP
B. sunlight.
C. NADPH.
D. G-3-P.
E. photosystem II.

36. What are the important products of the light dependent reactions of photosynthesis that are necessary for the operation of the light independent reactions?

A. Water.
B. sugars.
C. G-3-P
D. ATP and NADPH.
E. Oxygen

37. What is the function of ATP in photosynthesis?

A. It carries phosphate groups around in cells.
B. It carries hydrogen ions from one place to another.
C. It carries water into the chloroplast.
D. It carries energy to drive the fixation of carbon dioxide.
E. It carries electrons needed in the fixation of carbon dioxide.

38. What is the function of NADP in photosynthesis?

A. It carries phosphate groups around in cells.
B. It carries protons (H+) from one place to another.
C. It carries electrons needed in the fixation of carbon dioxide.
D. It carries energy to drive the fixation of carbon dioxide.
E. Both B and C are correct.

39. The first step in the light independent reactions is the:

A. combining of ATP with ribulose biphosphate.
B. oxidation of G-3-P.
C. use of NADPH to add hydrogen ions to CO_2.
D. oxidation of glucose.
E. combining of CO_2 with ribulose biphosphate.

40. This first step in the light independent reactions depends on the presence of:

A. molecules of ATP.
B. molecules of NADPH.
C. the enzyme rubisco.
D. a surplus of oxygen.
E. G-3-P

41. The last step in the light independent reactions is the:

A. combining reaction of ATP.
B. 3-phosphoglyceric acid.
C. production of ribulose biphosphate.
D. glucose.
E. combining of CO_2 with water.

42. When there is an osmotic gradient, molecules or ions may move through a membrane:

A. from an area of higher concentration to an area of lower concentration.
B. from an area of lower concentration to an area of higher concentration.
C. in either direction.
D. only if it is an impermeable membrane.
E. None of these is correct.

43. What is the source of energy for establishing the osmotic gradient for protons at the thylakoid membrane?

A. Electrons energized by light falling on a photosystem.
B. Protons energized by light falling on a photosystem.
C. Energy released from glucose molecules during respiration.
D. Chemical energy locked up in ATP molecules.
E. Kinetic energy from the flow of protons.

44. The energy used to assemble molecules of ATP at the thylakoid membrane comes from the flow of:

A. protons (H+) into the thylakoid space.
B. protons (H+) out of the thylakoid space through a special port.
C. electrons from the stroma.
D. electrons through special ports into the thylakoid space.
E. electrons from the thylakoid space.

Use the following statements to answer question 45 and 46:

A. Electrons are drawn away from a molecule.
B. Protons are drawn away from a molecule.
C. Reducing agents donate electrons to other substances.
D. Oxidizing agents attract electrons.
E. Electrons are drawn toward a molecule.
F. Protons are drawn toward a molecule.

45. Choose **two** statements from the group that apply to oxidation?

46. Choose **two** statements from the group that apply to reduction?

47. Carbon fixation means that CO_2 is:

A. temporarily immobilized in fossil fuels.
B. stored in specialized areas of the leaf.
C. oxidized during the Calvin cycle.
D. incorporated into chains of carbon compounds.
E. reacted with water to form carbonic acid.

48. During respiration,___?___is oxidized. During photosynthesis,___?___is reduced.

A. carbon dioxide, carbon dioxide
B. carbon dioxide, glucose
C. glucose, carbon dioxide
D. oxygen, water
E. glucose, oxygen

Use the following statements to answer questions 49 and 50:

A. A concentration gradient for protons is established across the thylakoid membrane using energy from the light activated electrons.

B. As electrons pass along the electron transport chain each protein molecule is reduced and then oxidized.

C. The protons flow through a channel in the ATP synthetase complex.

D. Chemiosmosis is based on a flow of protons (H+).

E. NADP is reduced when it acquires electrons and hydrogen ions (protons).

F. In non-cyclic electron flow, two electrons come from each water molecule and two electrons are carried away by NADPH.

G. The thylakoid is a membrane surrounded space with chlorophyll molecules and other the complex molecules imbedded in it.

H. The kinetic energy of the protons is transformed into chemical energy by building ATP molecules.

I. In biological systems, the solvent is almost always water.

J. Electrons from NADPH are used to reduce carbon dioxide when G-3-P is formed.

K. Light oxidizes chlorophyll a in a photosystem.

L. Chemiosmosis occurs as the protons flow from an area of high concentration to an area of lower concentration.

M. In REDOX reactions there is a balance in the number of electrons moving from the reactants to the products.

49. Choose **four** statements from the items above to outline the oxidations and reductions that occur in photosynthesis.

50. Choose **four** statements from the items above to provide an explanation of chemiosmosis.

APPENDIX 4

SAMPLE SCREENS OF THE VIRTUAL TUTEE SIMULATION

The following pages contain a series of illustrations of the cards shown to the real student user who is participating in the conversation with the *virtual tutee*. These cards were printed out from the simulation software for Module I that introduces students to the basic concepts of matter and energy. The concepts are necessary for the understanding of photosynthesis. These illustrations follow the pattern of the flow charts shown in Figures 4-4 and 4-5. If the pages are turned in sequence, they simulate the progression of the computer program as seen by the user.

Figure A4-1 shows the card that appears as a title card and this is followed by the introductory note shown as Figure A4-2. There are then several cards that introduce the real student user to the *virtual tutee* who has been named Jack. The real student in this case was named Steve. These cards are shown as Figures A4-3 to Figure A4-7. Clicking on the box shown in Figure A4-7 causes the system to present the first Lead Question shown in Figure A4-8, from which the student asks for the Message Building Kit shown in Figure A4-9. For the purposes of the illustration, a set of chosen items has been entered on the interface, and, when the student clicks on the box "Read and Send Message", he will be moved to the card shown in Figure A4-10. Again for the purpose of illustration, the message being sent is regarded as an excellent one and the *virtual tutee* replies with the message shown in Figure A4-11. This item has the effect of confirming the basic concept of energy.

Figure A4-12 shows the second lead question about matter. In this case a poor answer has been entered by Steve, the real student. The result of this input is shown in Figures A4-15 as a simpler question about the nature of matter. The subsequent figures (Figure A4-16 to A4-26) show the progression through the sub questions of this part of the module aimed at building knowledge about matter. Figure A4-27 shows the final item in this set that confirms knowledge about matter.

Figure A4-28 begins the third Lead Question for the module. This sequence has been provided to illustrate the events following the entry of an odd sequence of items. The real student completes the answer to form an excellent message, and then the sequence ends with the card shown in Figure A4-35. At this point the *virtual tutee* responds by asking the real student to ask the questions. Figures A4-36 to A4-45 illustrate the events that occur through this phase of the module. The real student can enter comments and additions following each response from the *virtual tutee*. After four questions have been completed, the real student is given the options of choosing another topic or quitting the simulation. There is a final mesage from the *virtual tutee* thanking the real student for helping, and a message from the virtual professor commenting on the student's progress as shown in Figure A4-46.

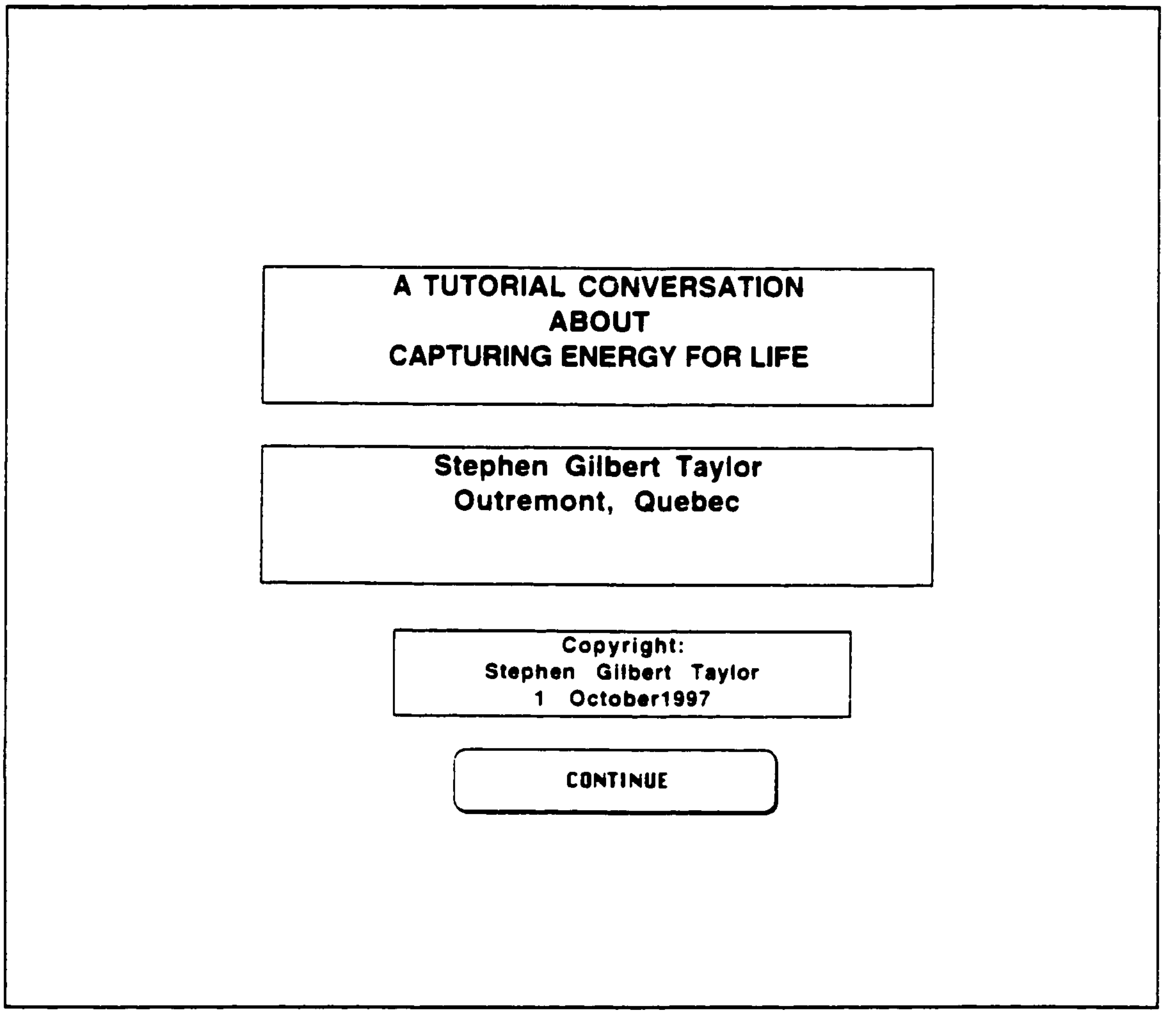


Figure A4-1: Title Card

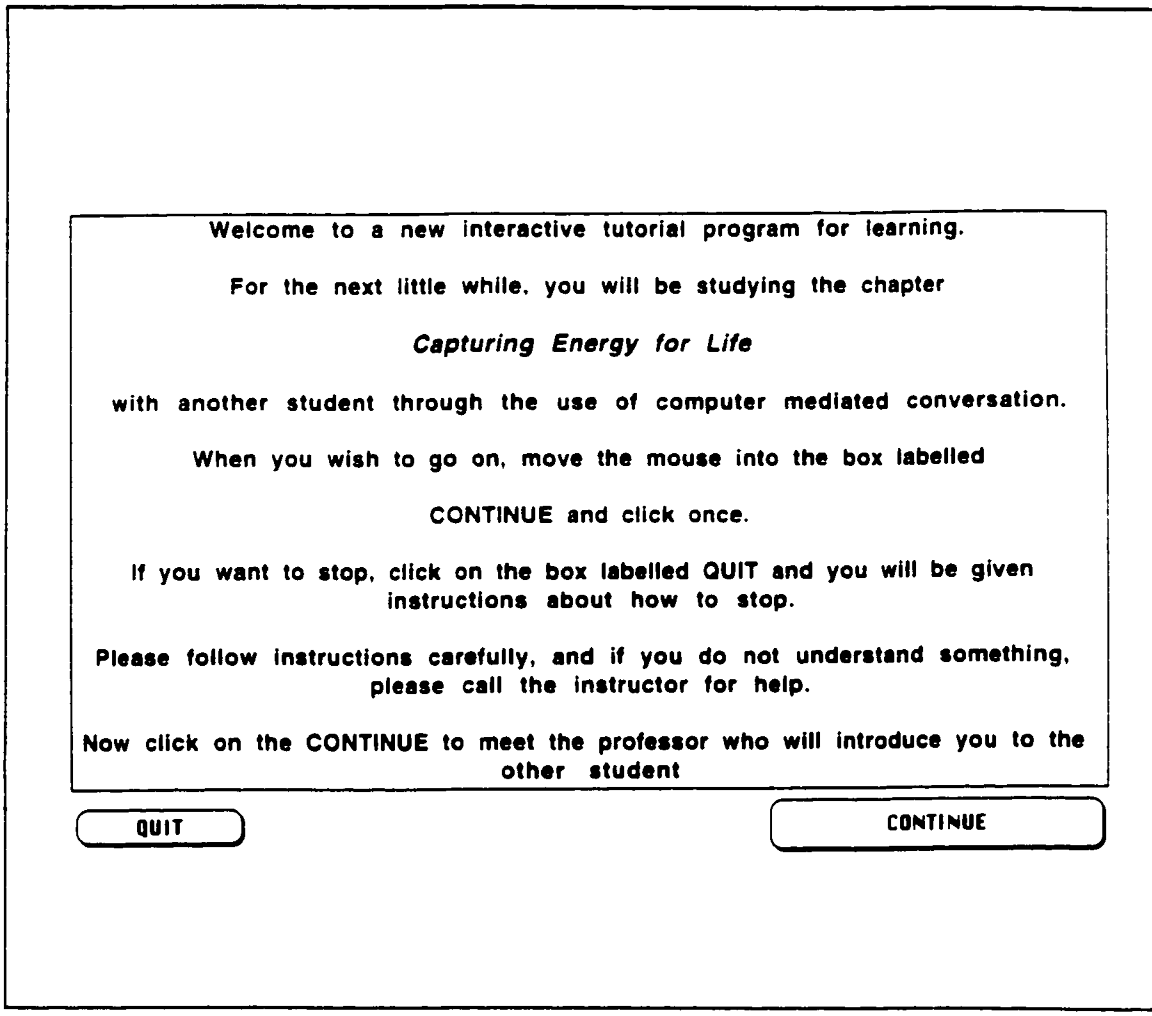


Figure A4-2: Introduction Card

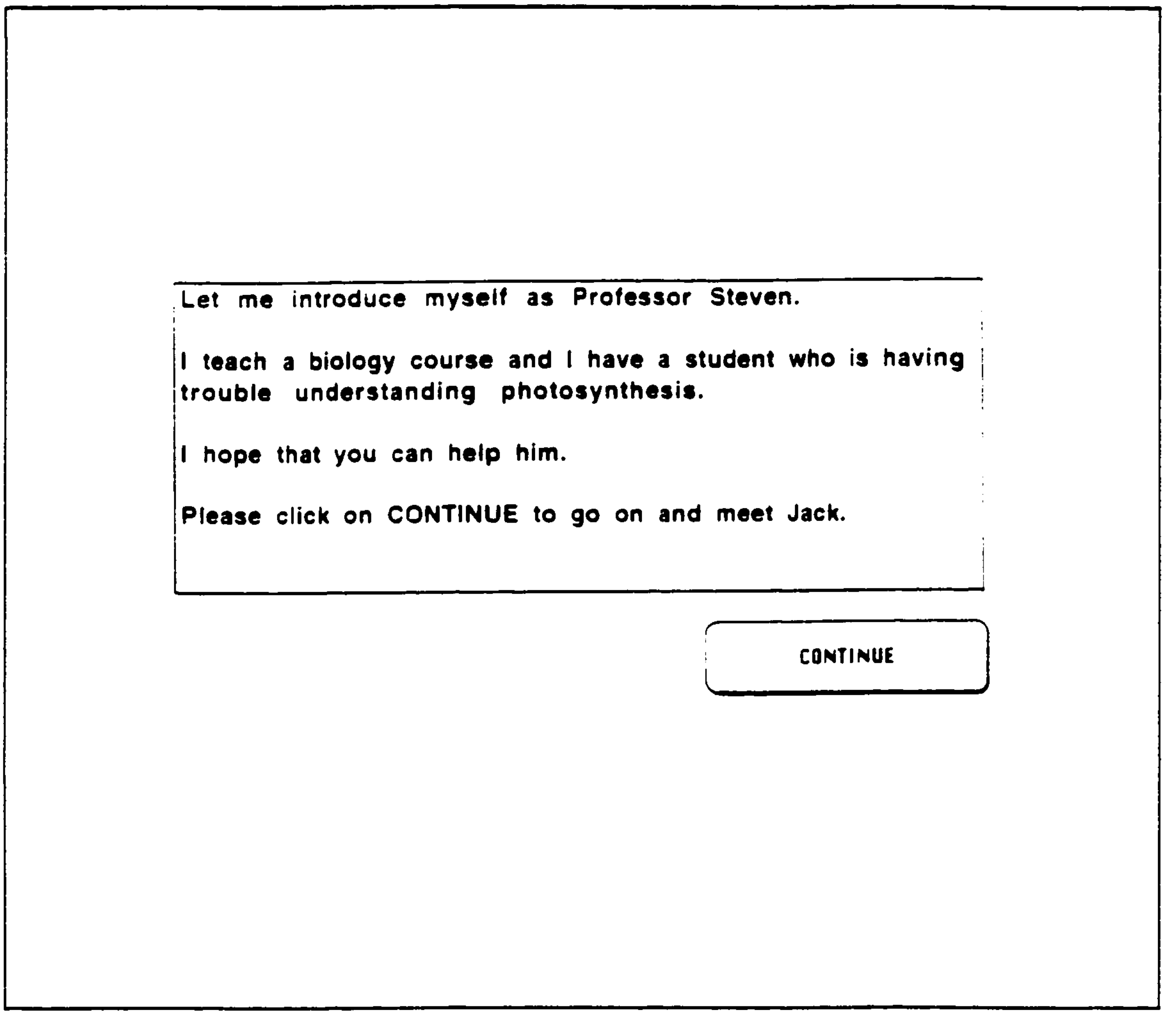


Figure A4-3: Meet Professor

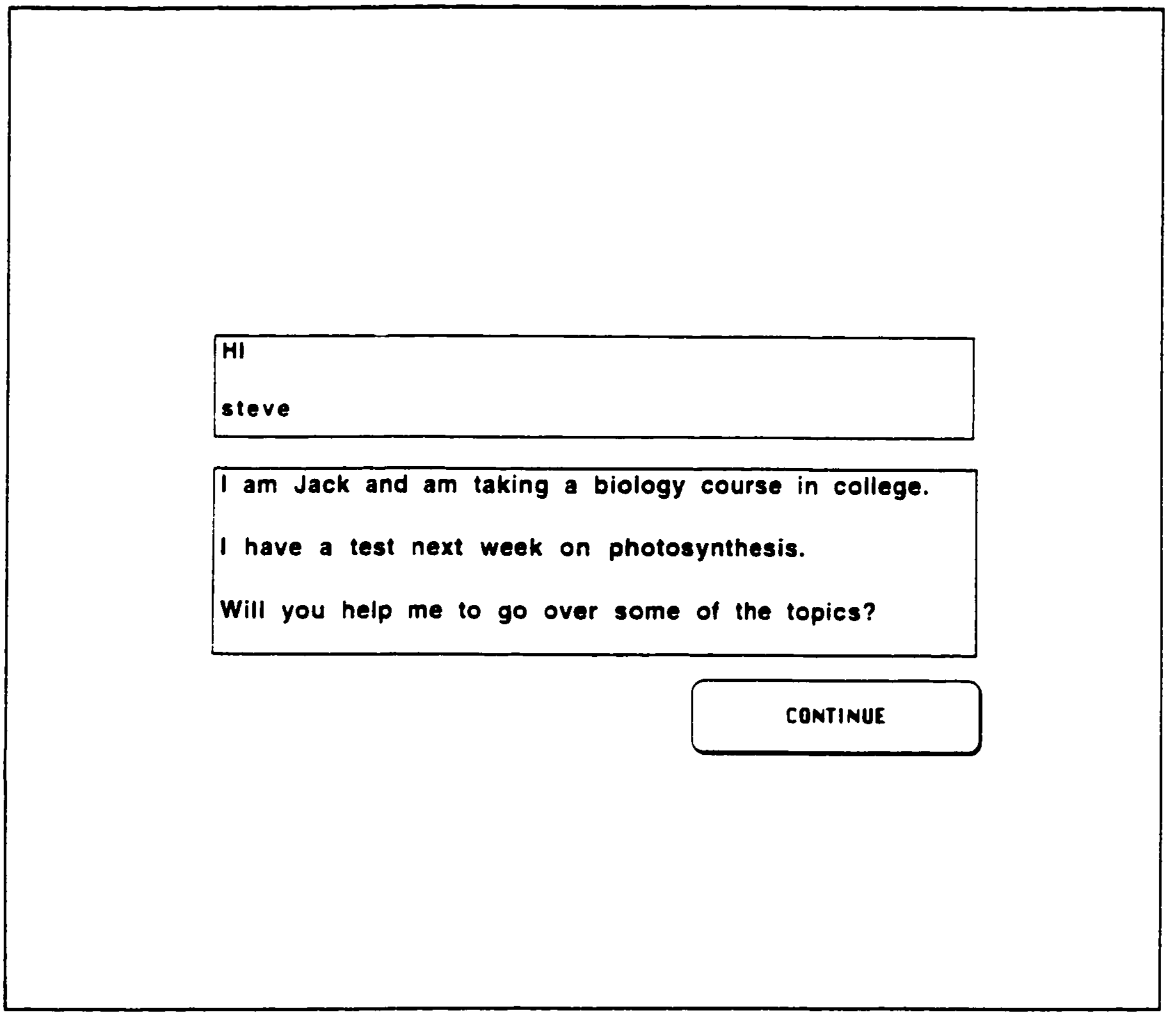


Figure A4-4: Meet Jack. the Virtual Tutee

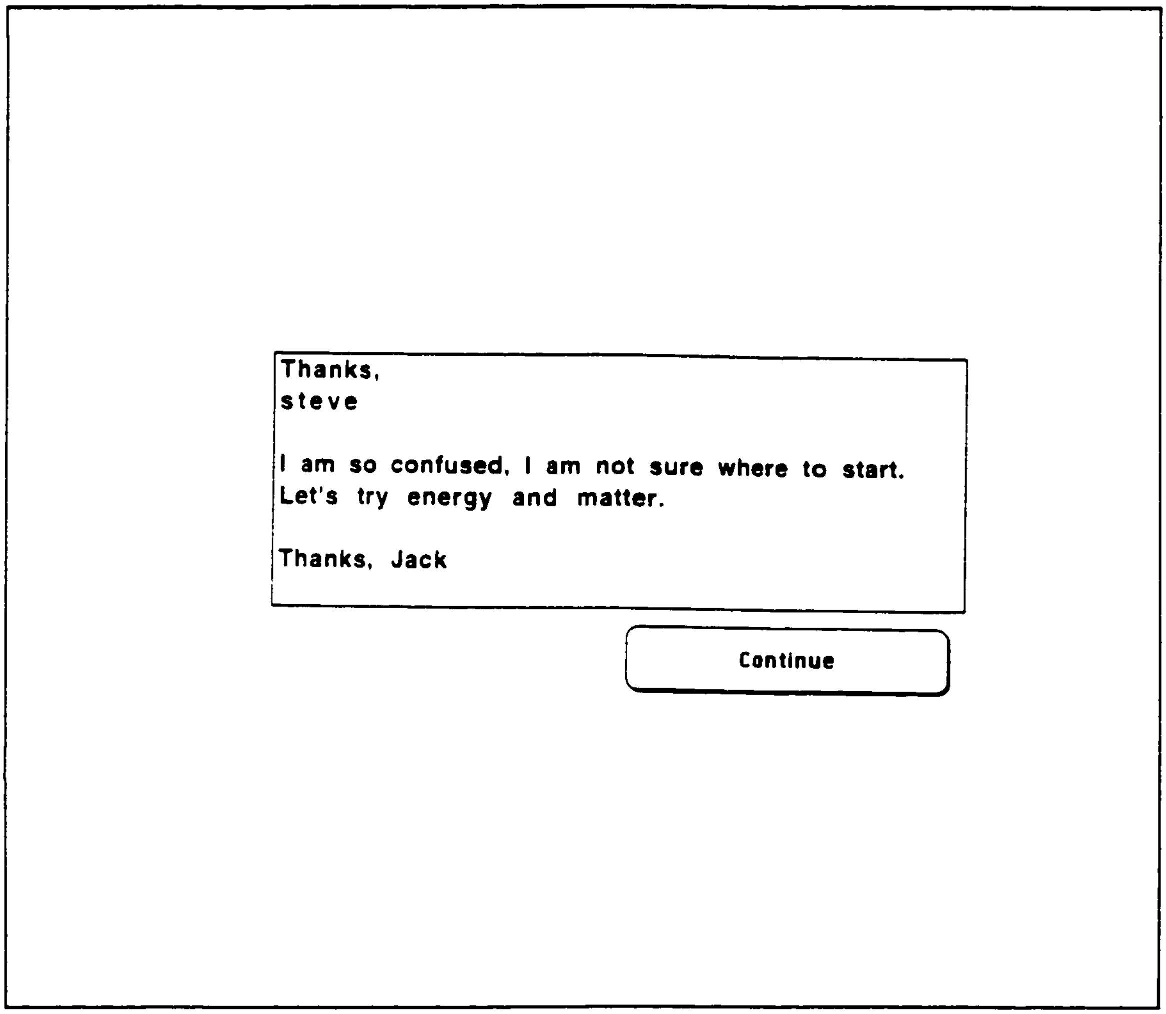


Figure A4-5: Beginning of Conversation

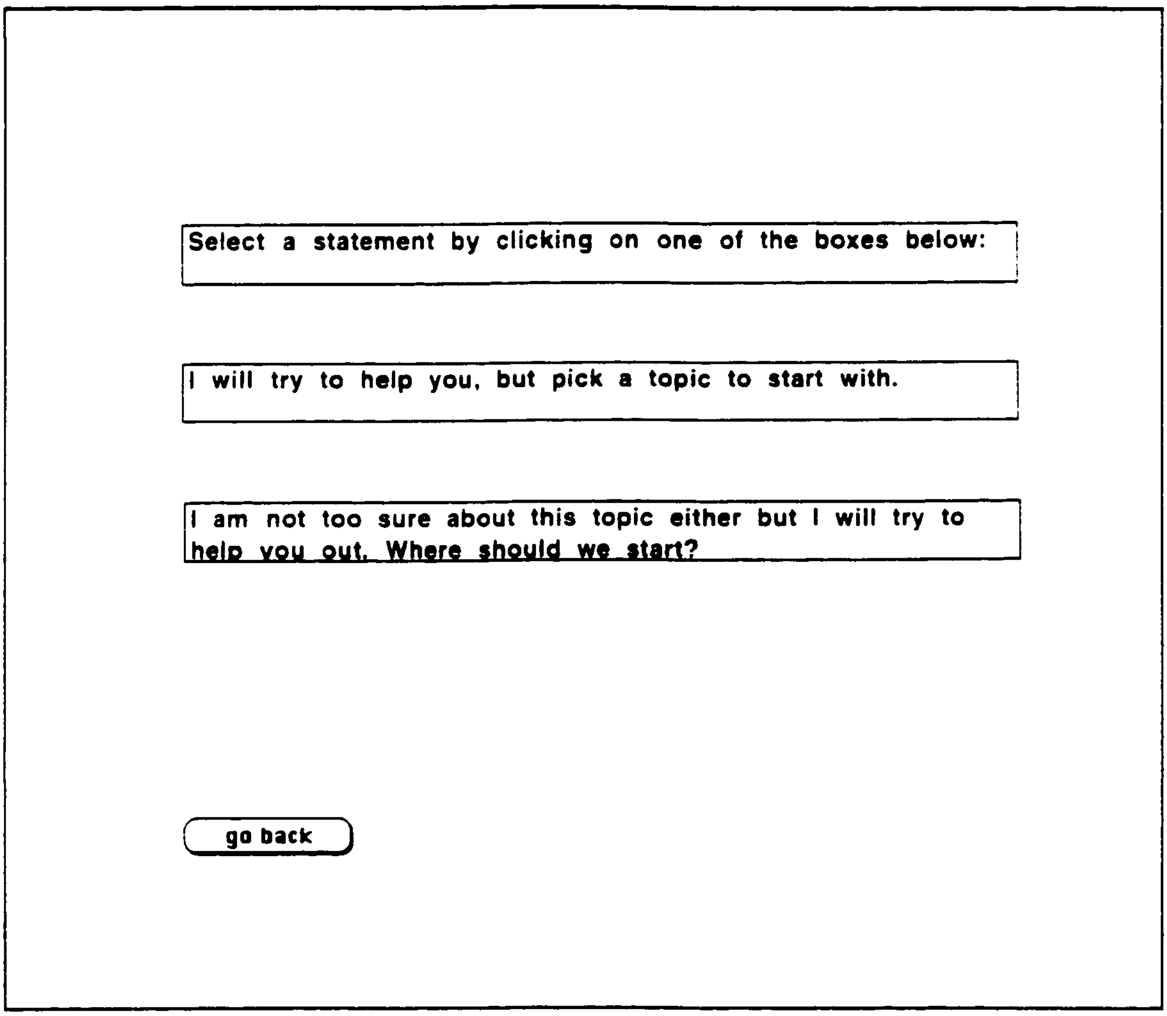


Figure A4-6: Response from Real Student

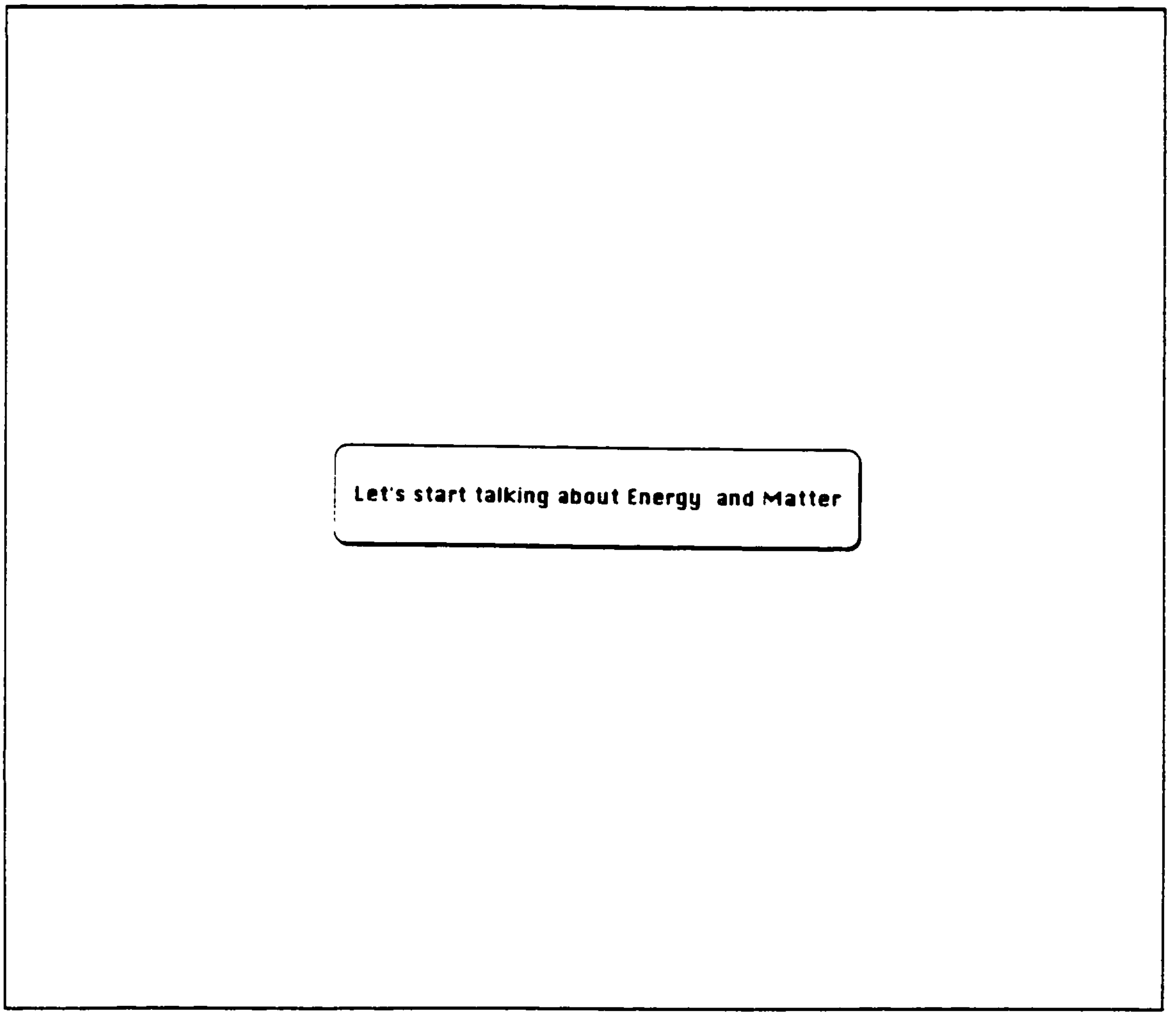


Figure A4-7: Starts Energy Module

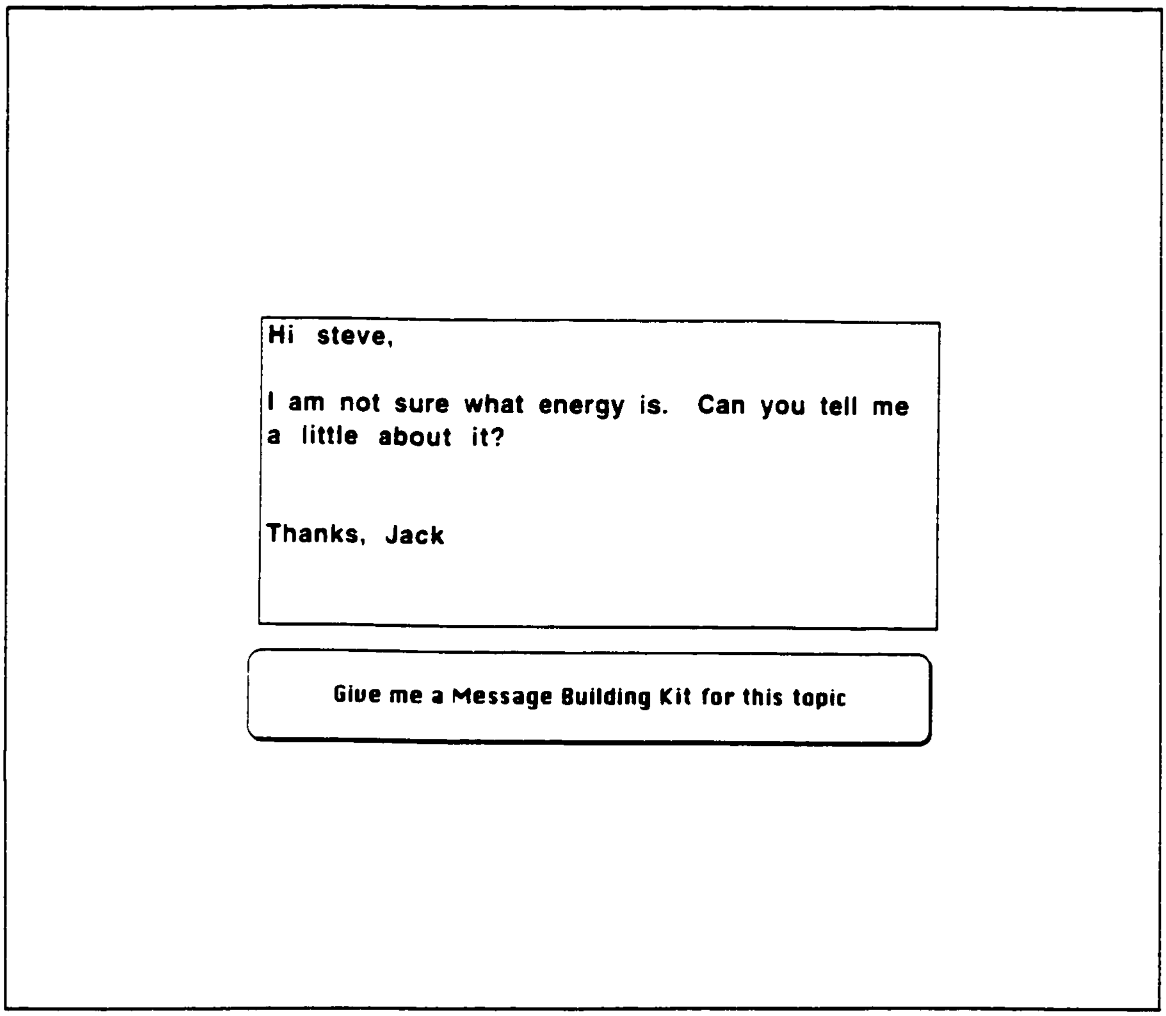


Figure A4-8: First Lead Question of the Energy Module

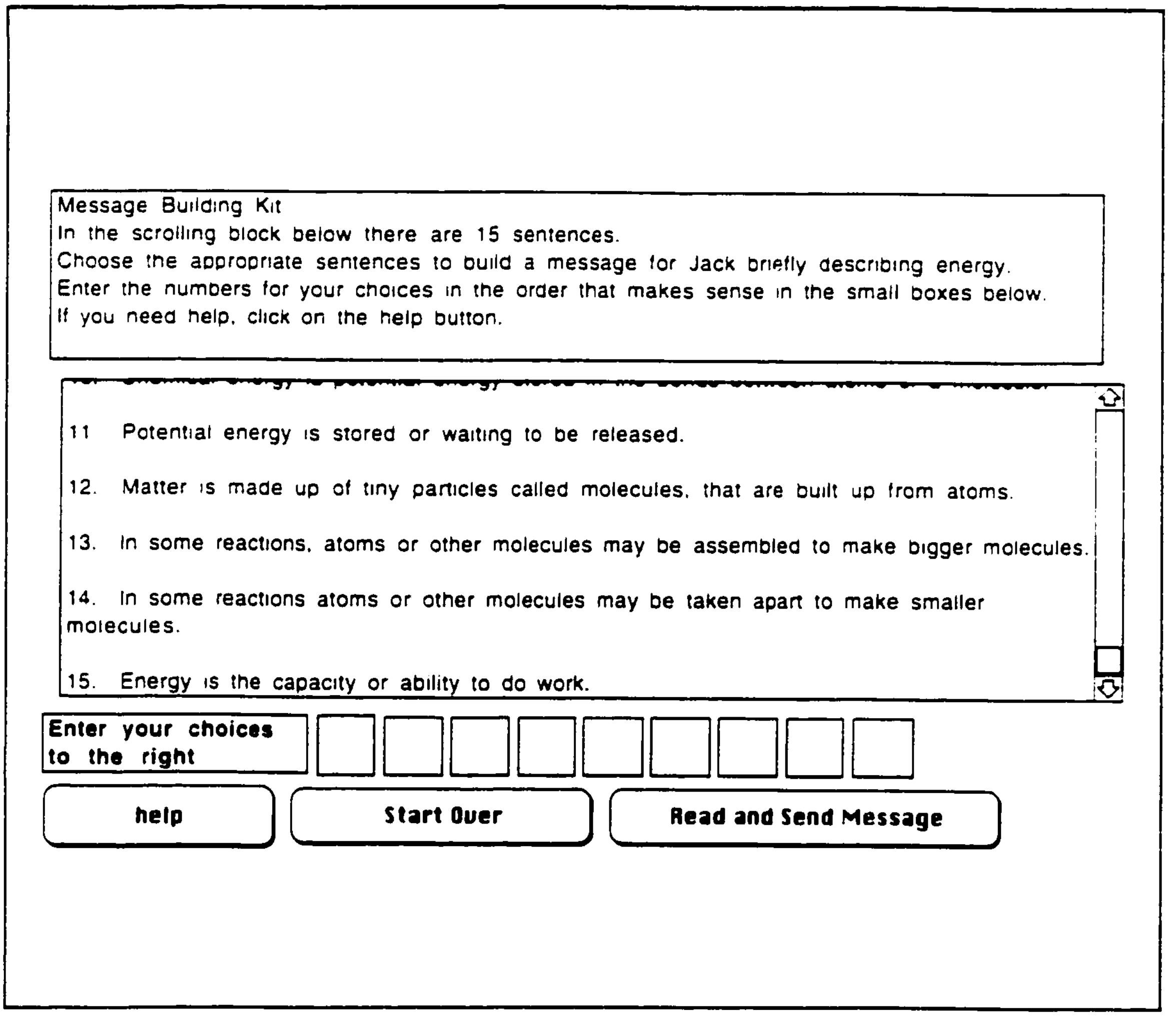


Figure A4-9: Message Building Kit for Lead Question 1

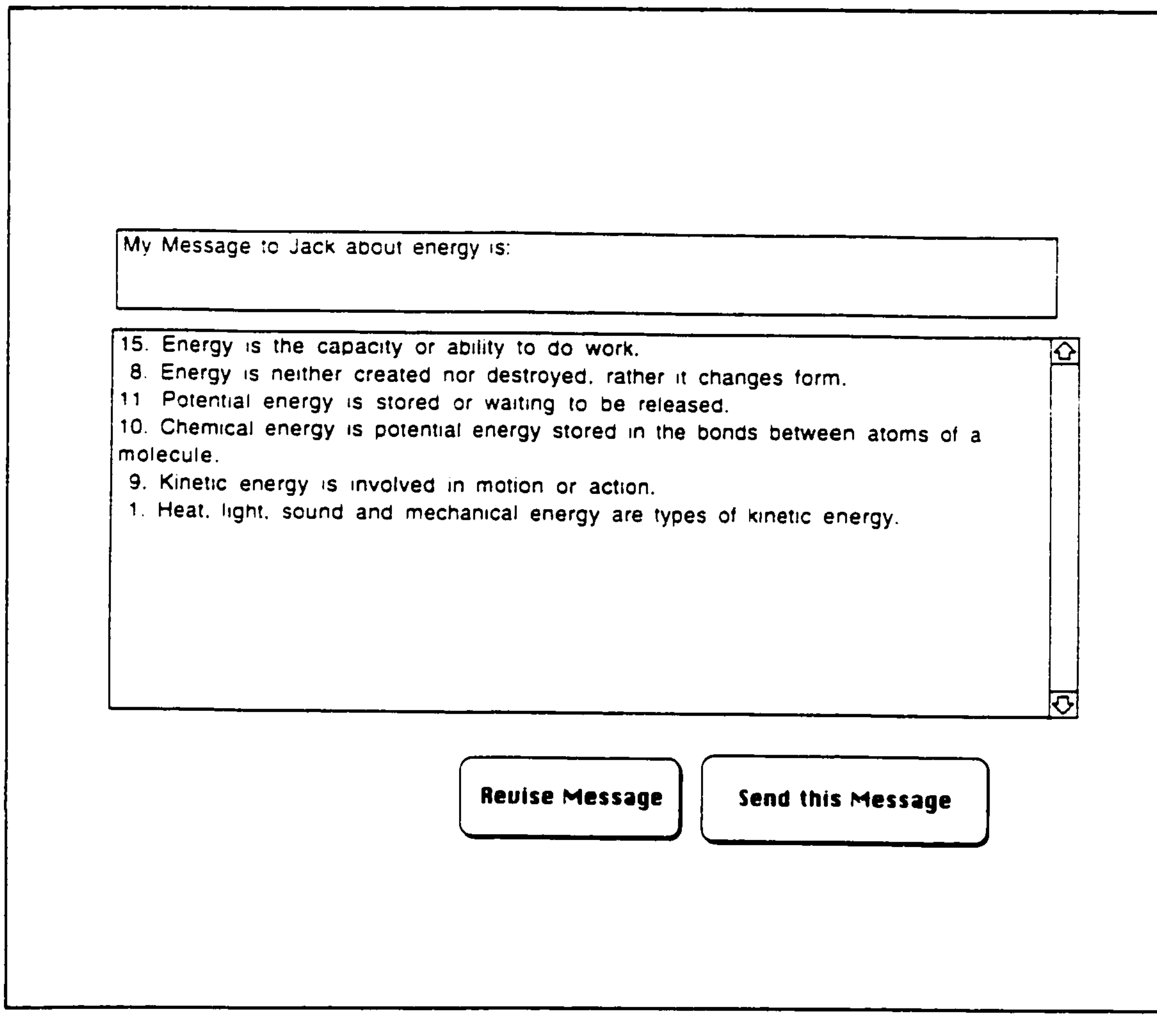


Figure A4-10: Real Student Can Read Message Constructed Before Sending
Excellent Model Items Have Been Selected

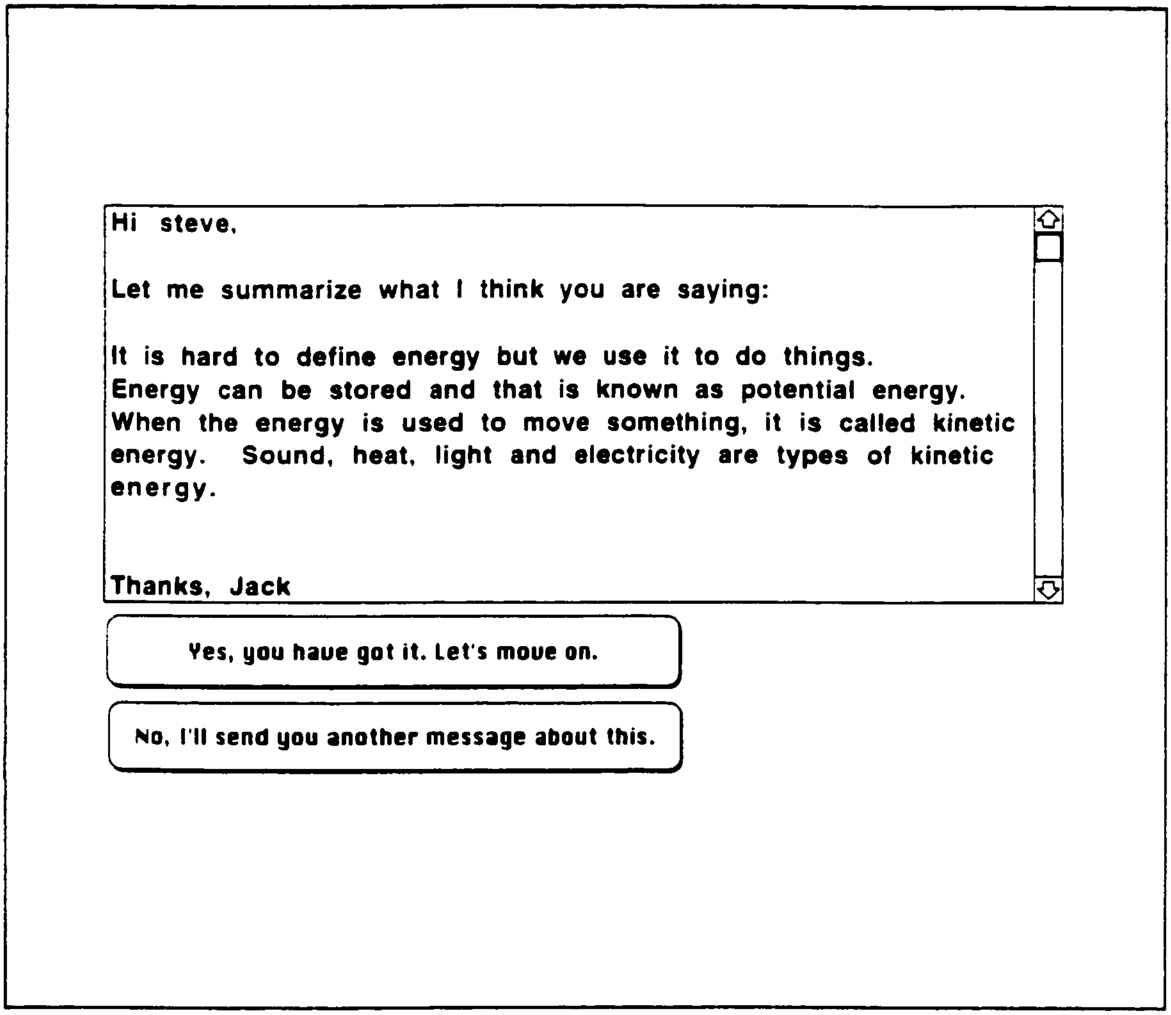


Figure A4-11: Response from Virtual Tutee to an Excellent Model Message for Lead Question 1

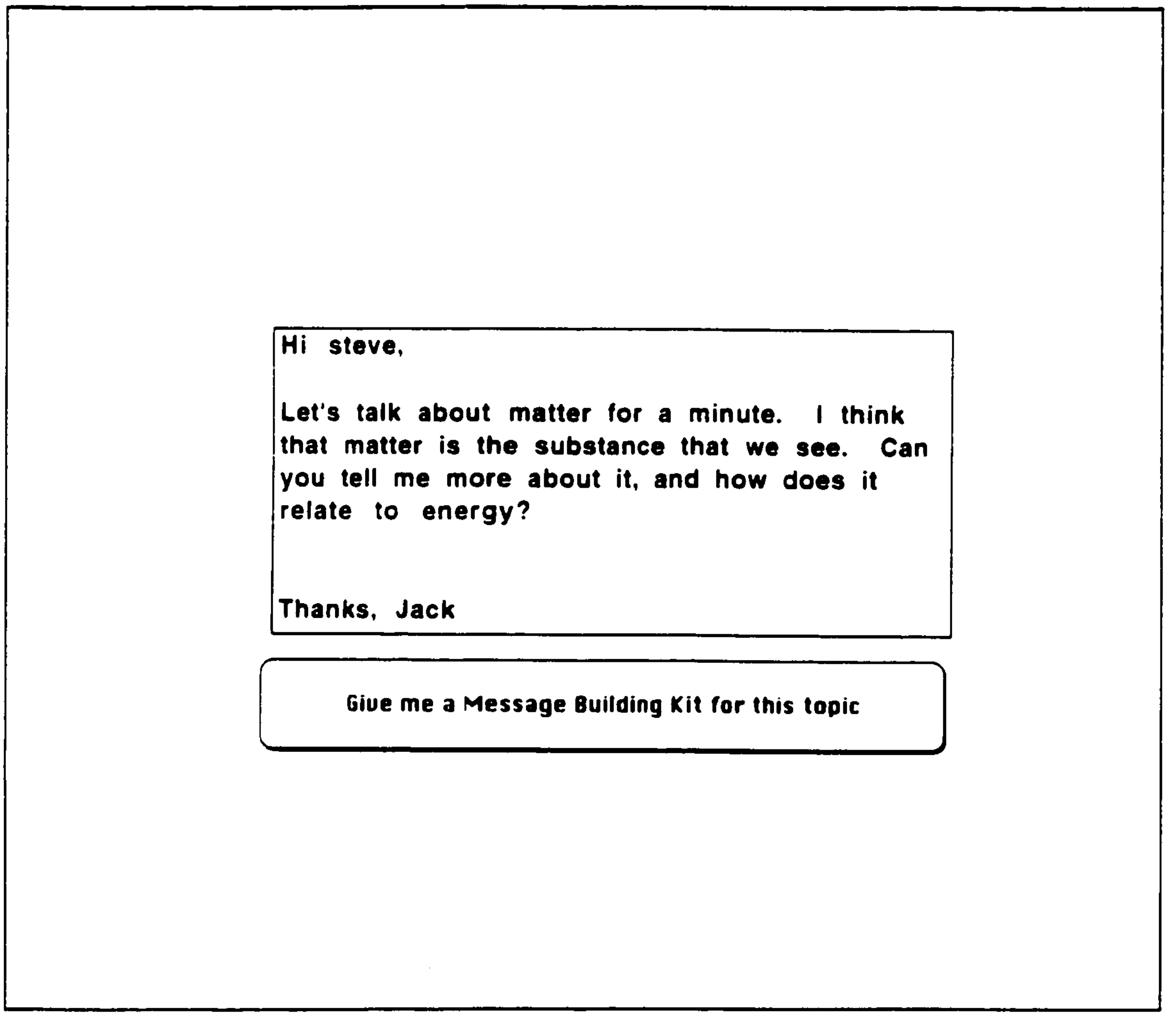


Figure A4-12: Lead Question 2 of the Energy Module

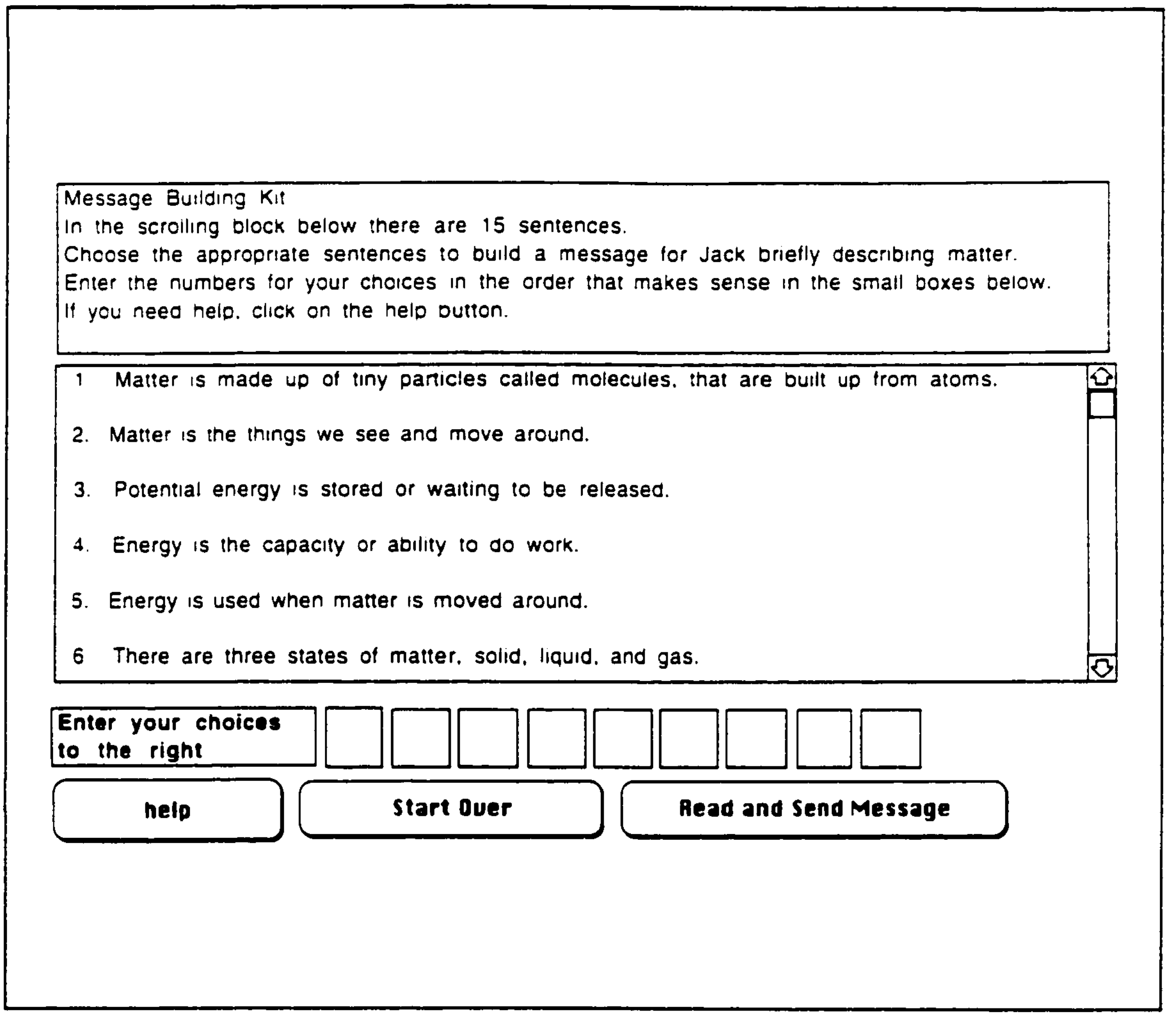


Figure A4-13: Message Building Kit for Lead Question 2

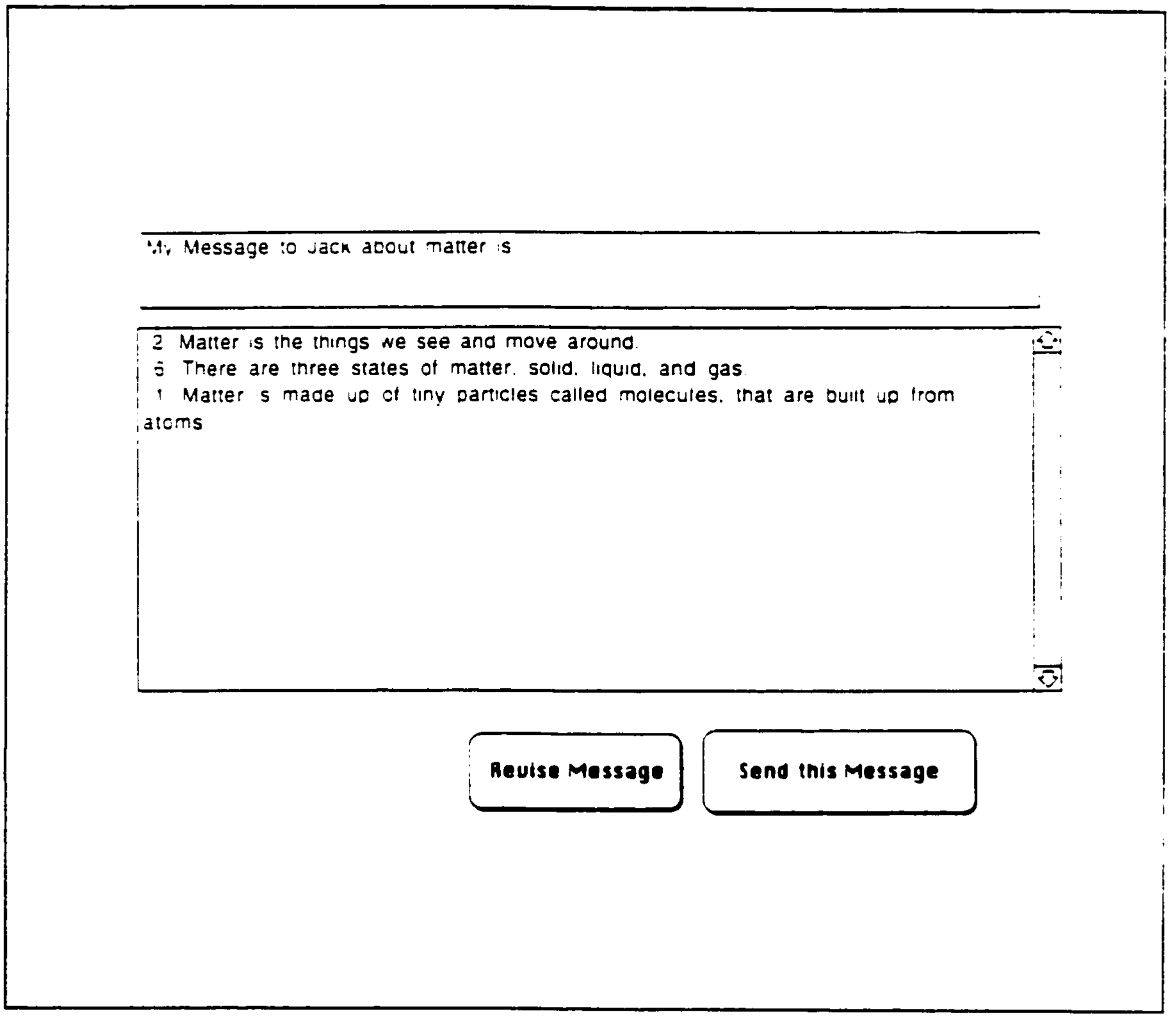


Figure A4-14: Real Student Can Read Message Constructed Before Sending
Poor Model Items Have Been Selected

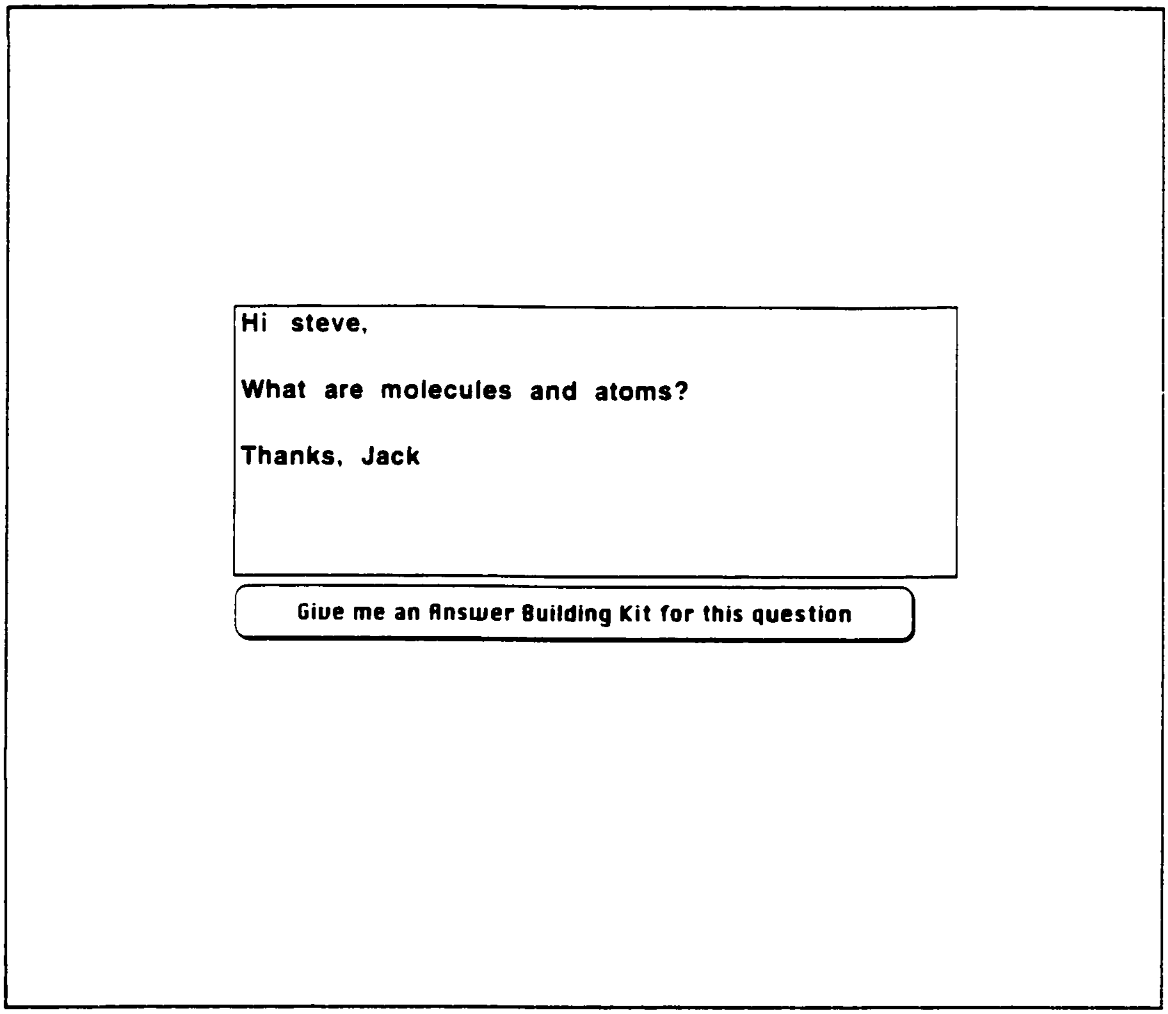


Figure A4-15: Response from the Virtual Tutee to a Poor Model Message for Lead Question 2 is Sub Question 4

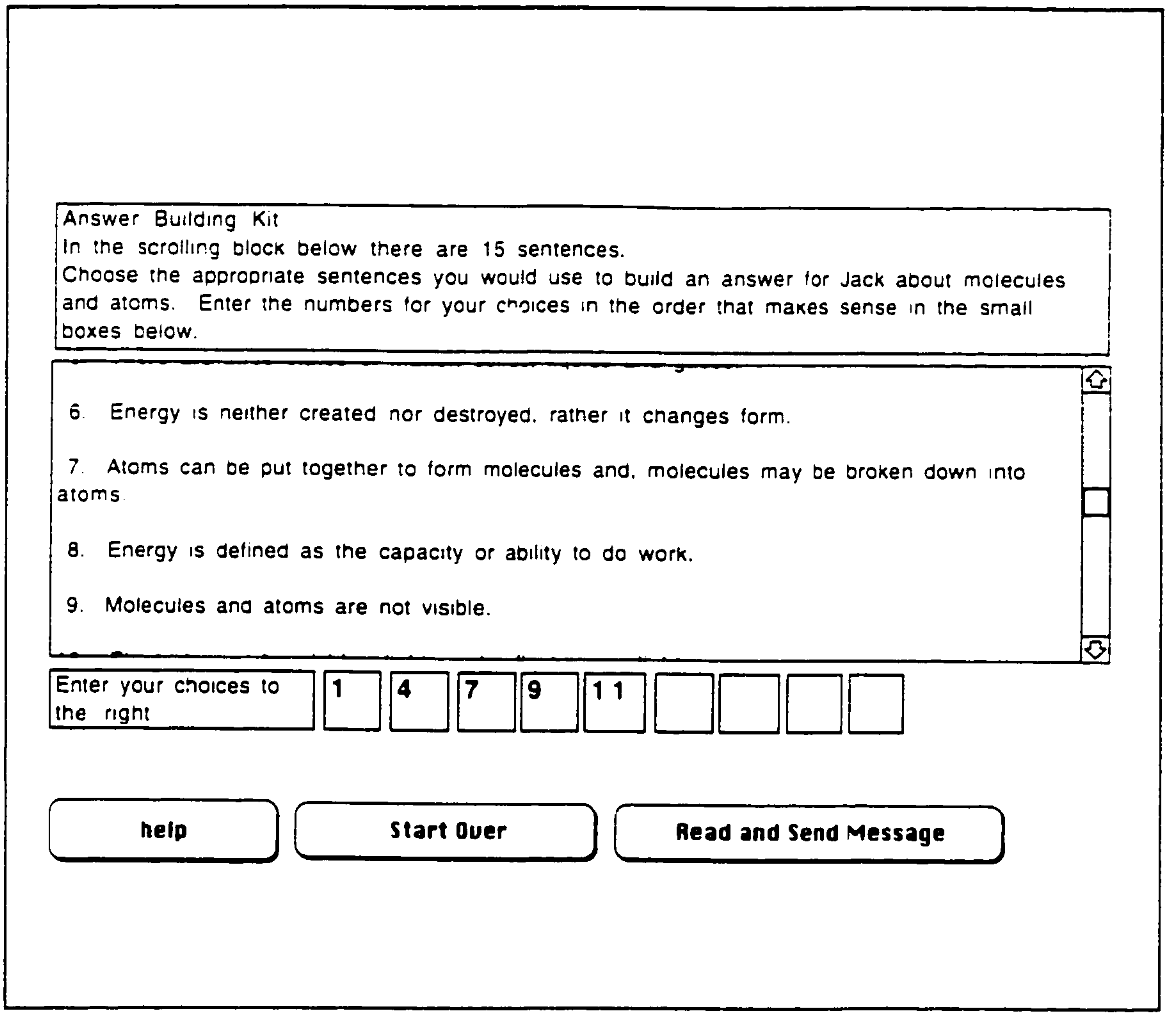


Figure A4-16: Message Building Kit for Sub Question 4
Good Model Items have been Selected

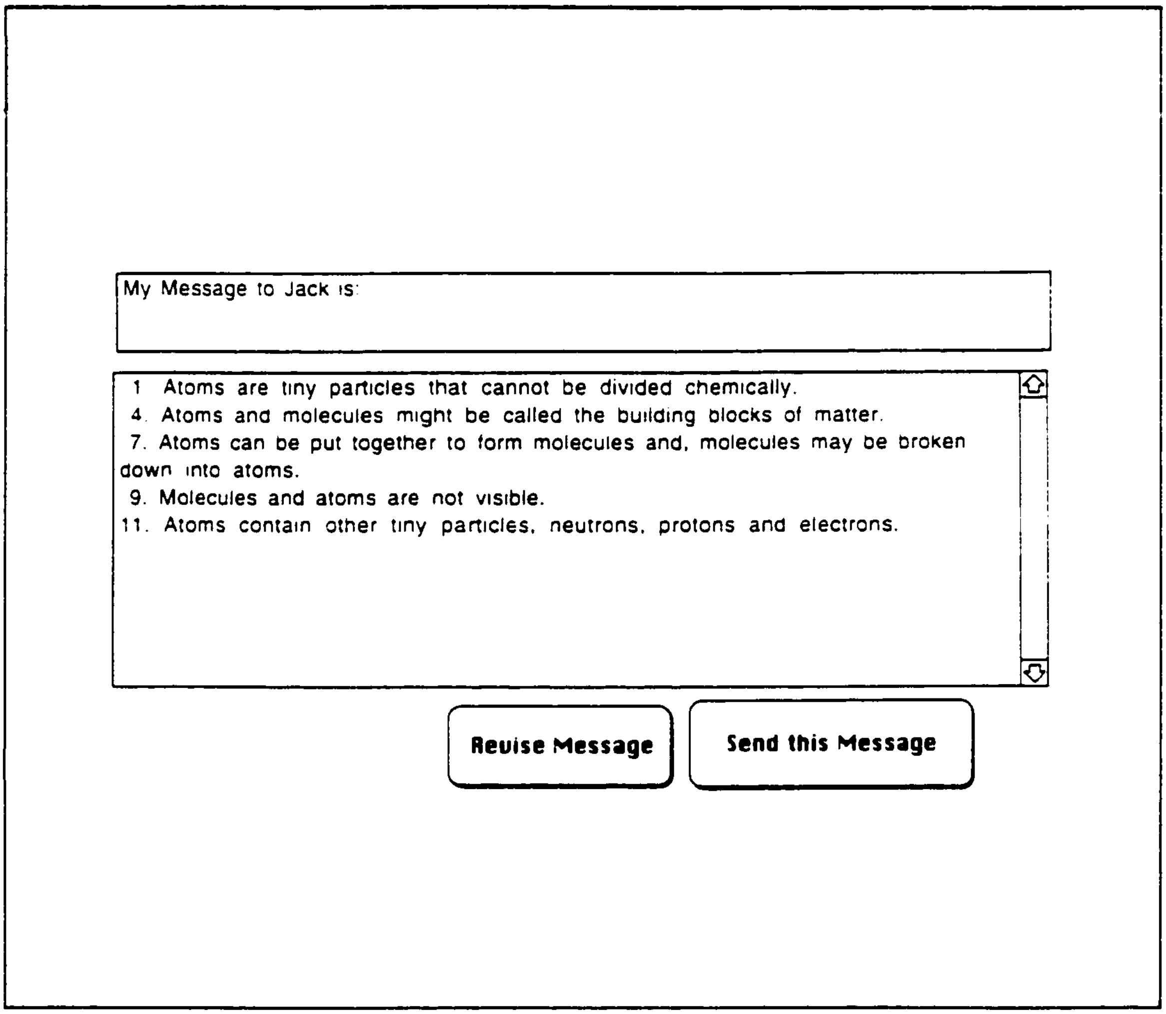


Figure A4-17: Real Student Can Read Message Constructed Before Sending
Good Model Items have been Selected

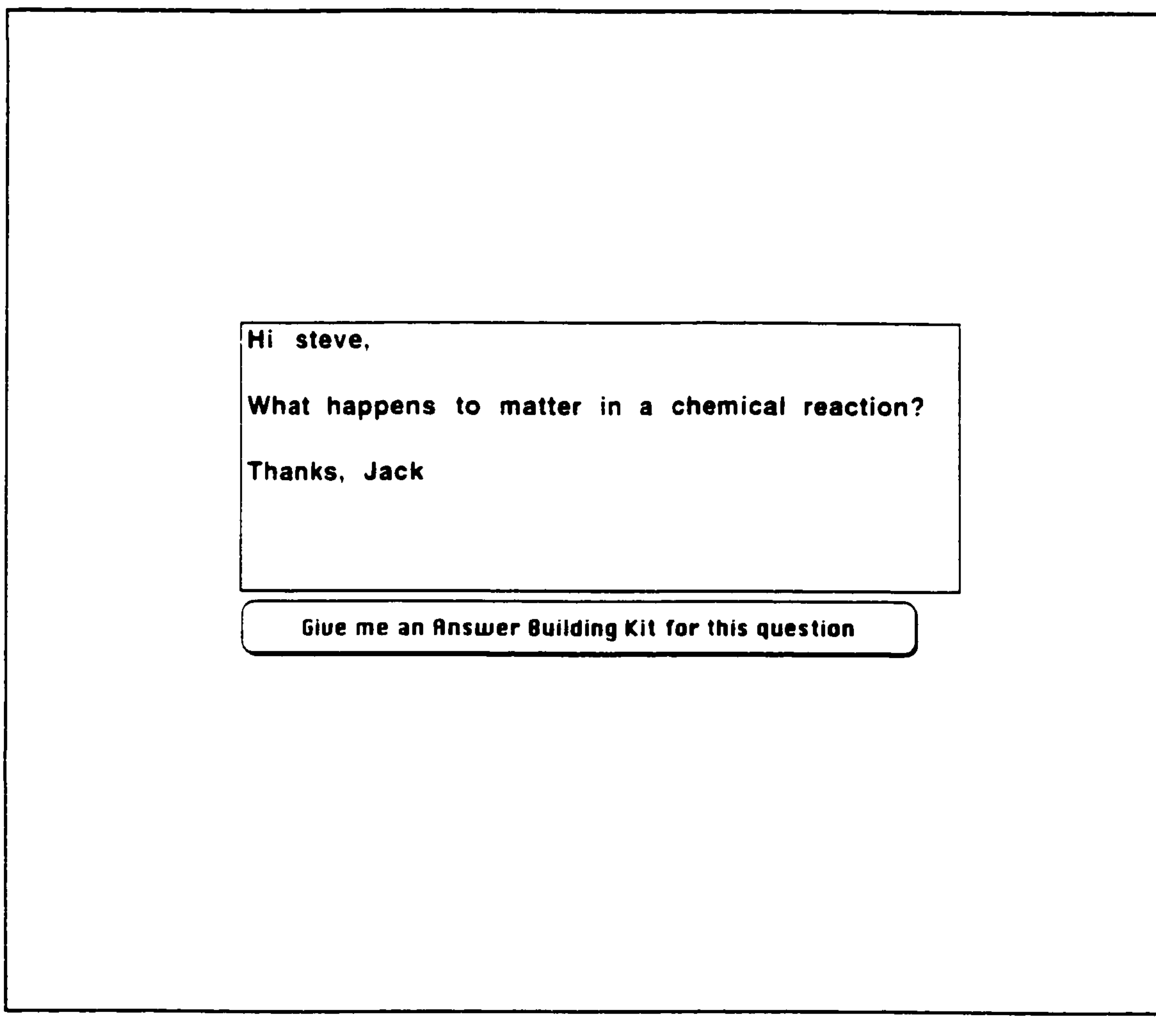


Figure A4-18: Response from Virtual Tutee to a Good Model Message for Sub Question 4 is Sub Question 3

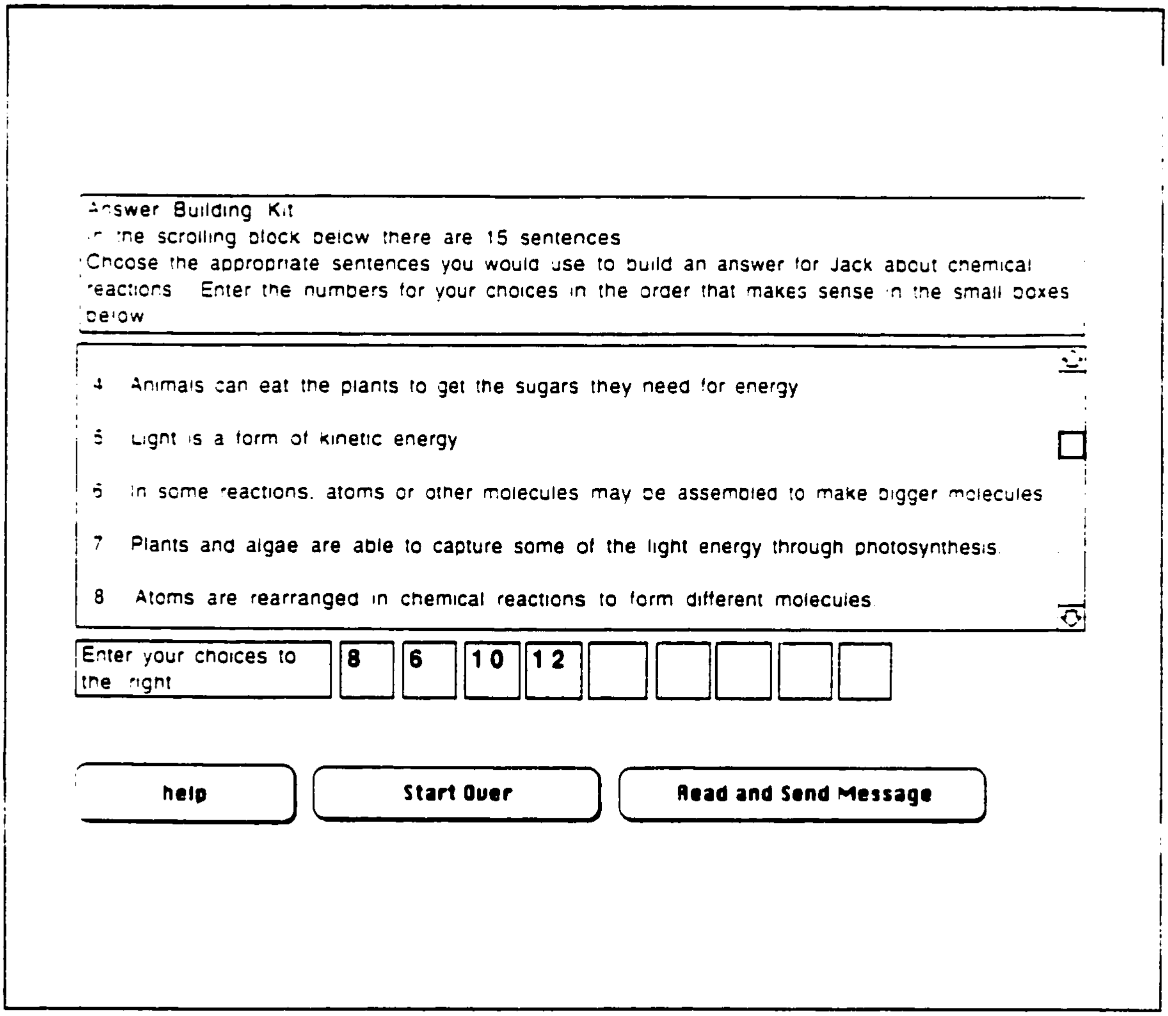


Figure A4-19: Message Building Kit for Sub Question 3
Good Model Items have been Selected

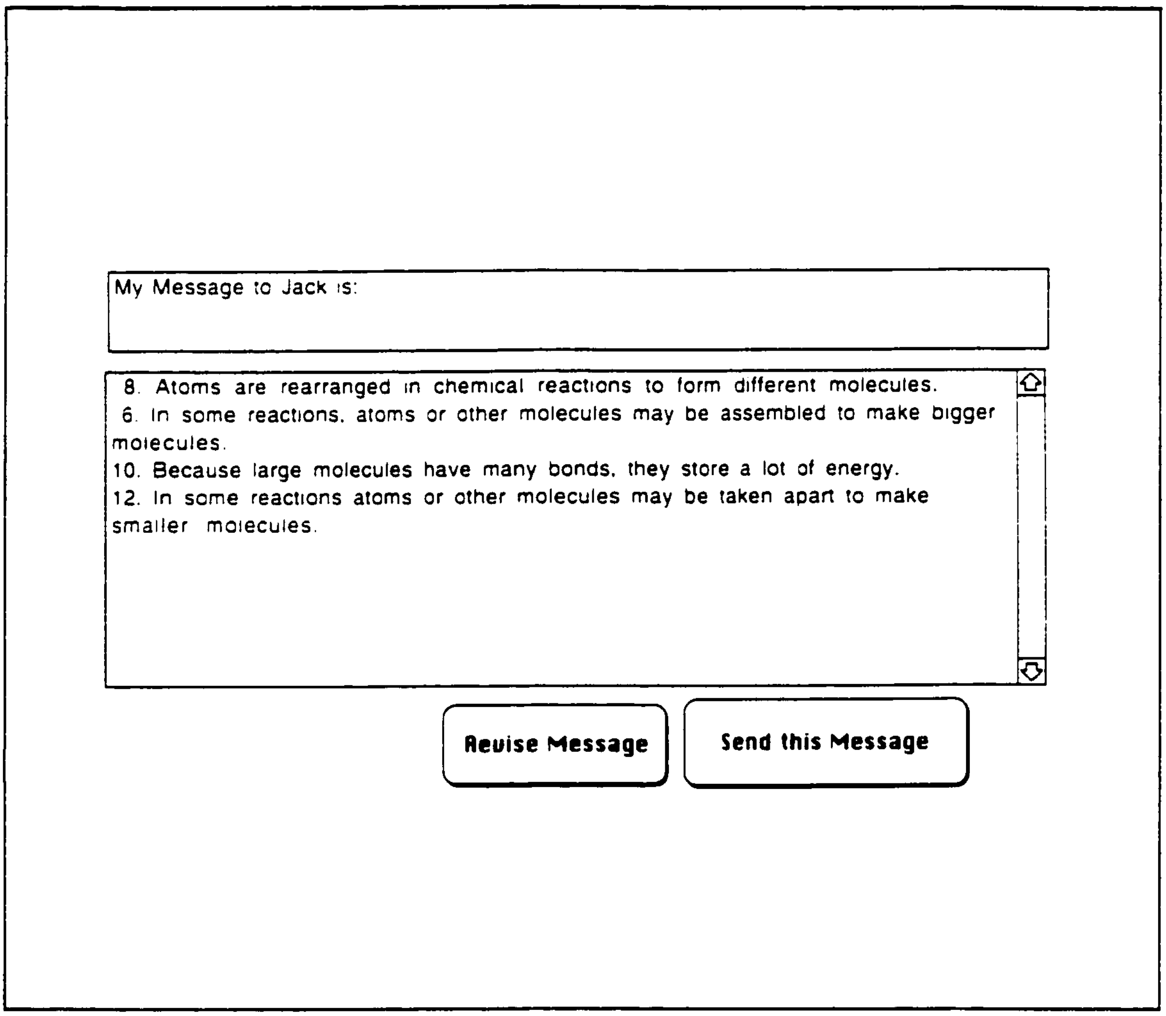


Figure A4-20: Real Student Can Read Message Constructed Before Sending Good Model Items have been Selected

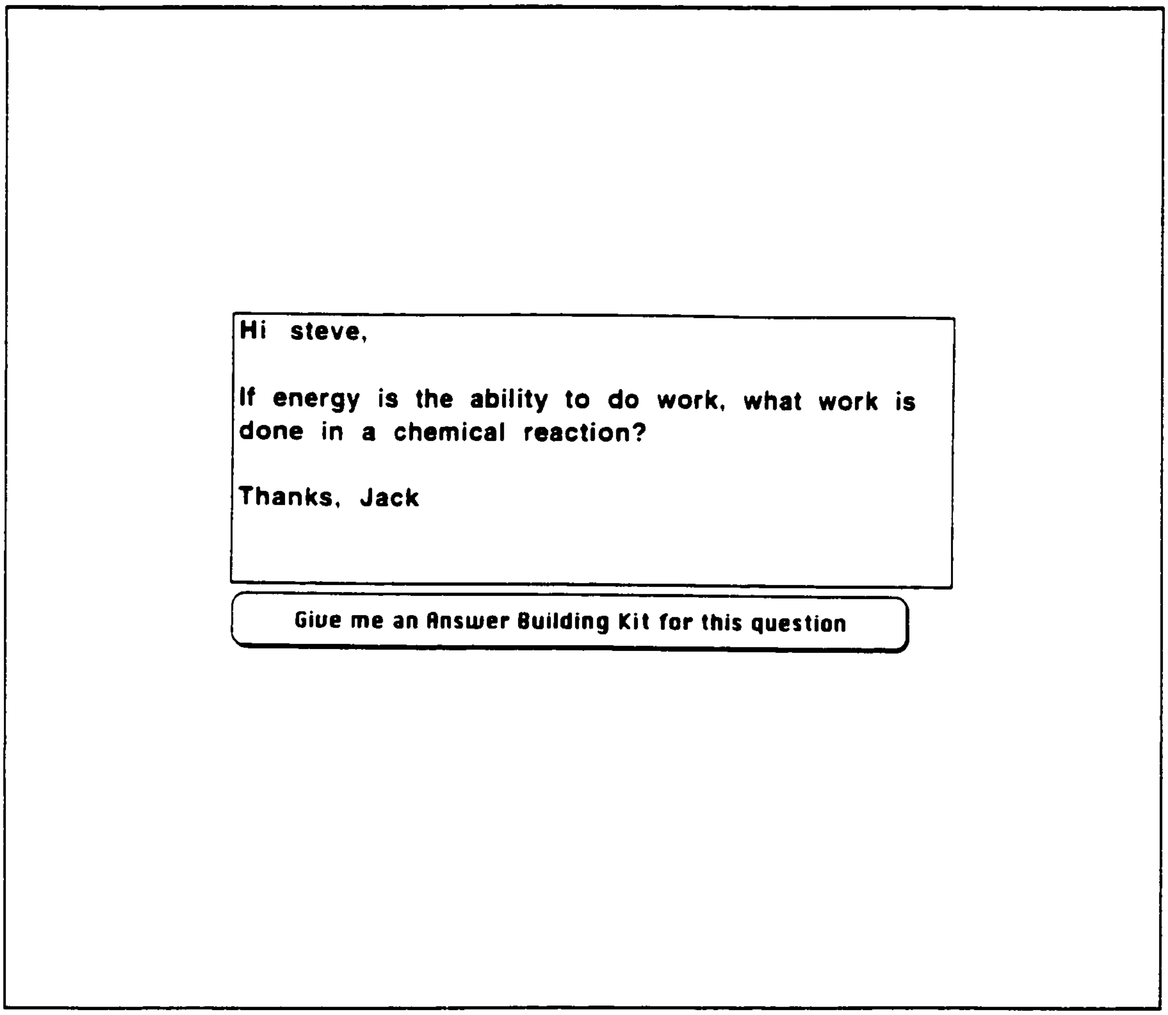


Figure A4-21: Response from Virtual Tutee to a Good Model Message for Sub Question 3 is Sub Question 2

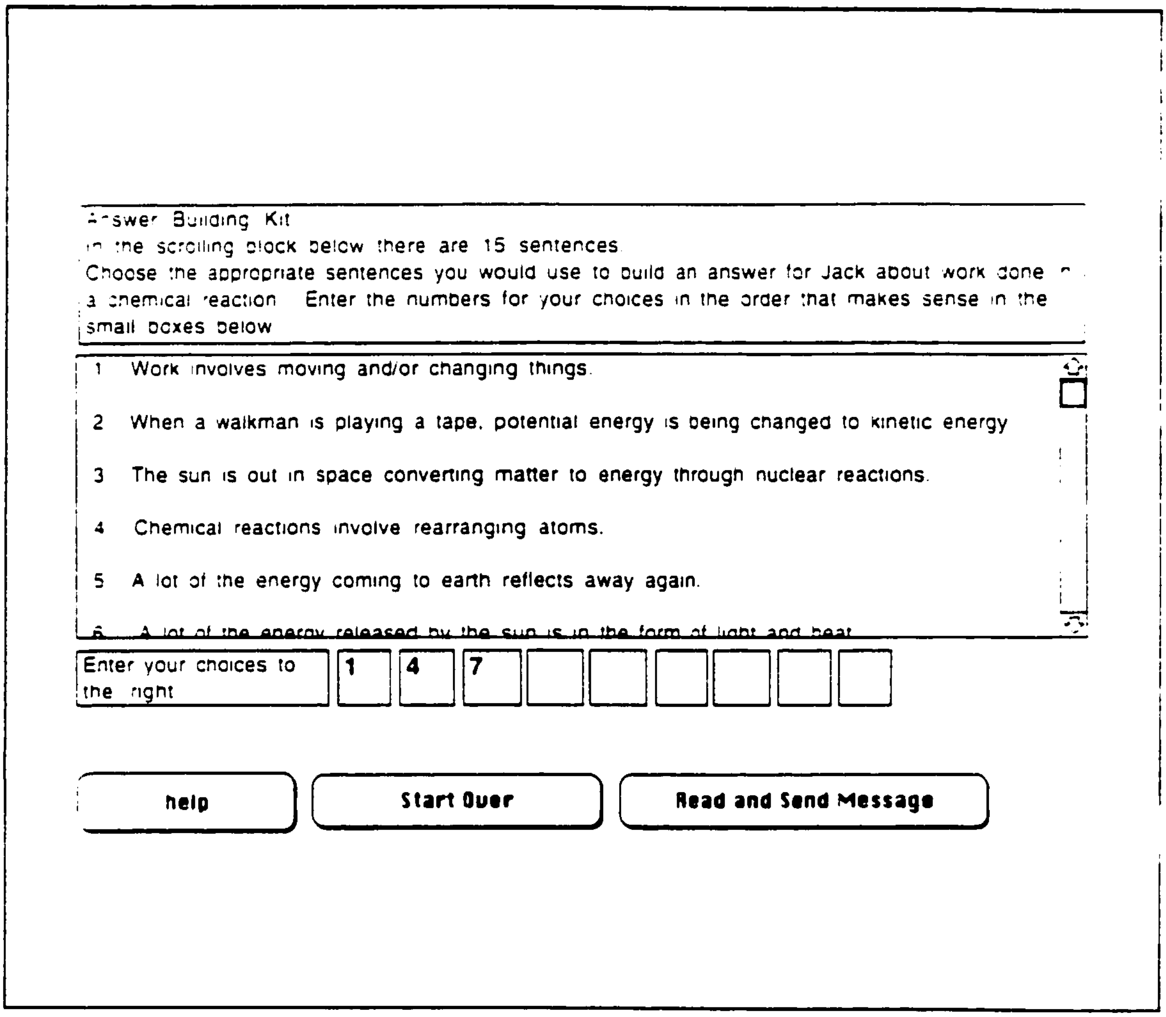


Figure A4-22: Message Building Kit for Sub Question 2
Items Selected Provide an Incomplete Message

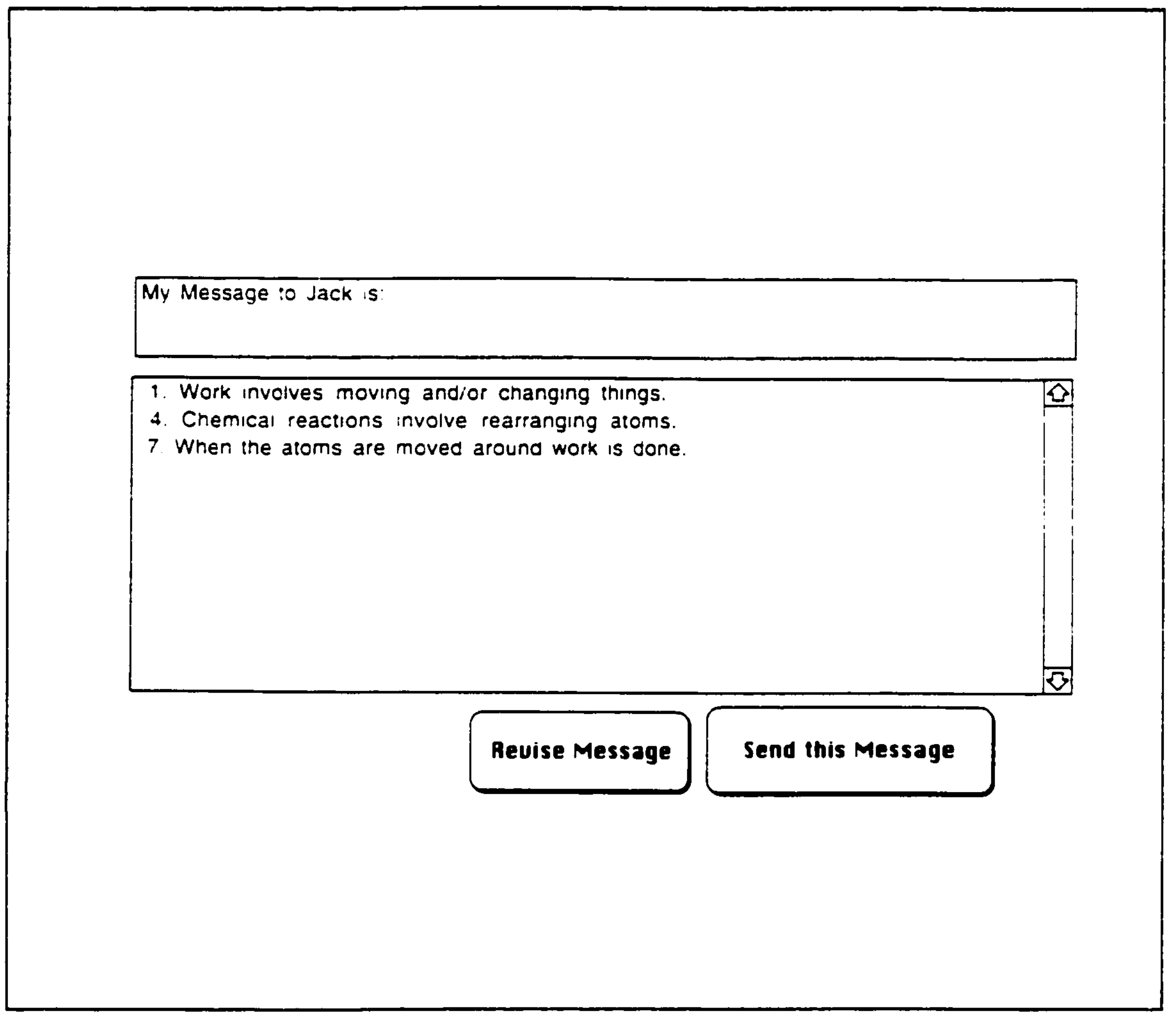


Figure A4-23: Real Student Can Read Message Constructed Before Sending
Incomplete Model Items have been Selected

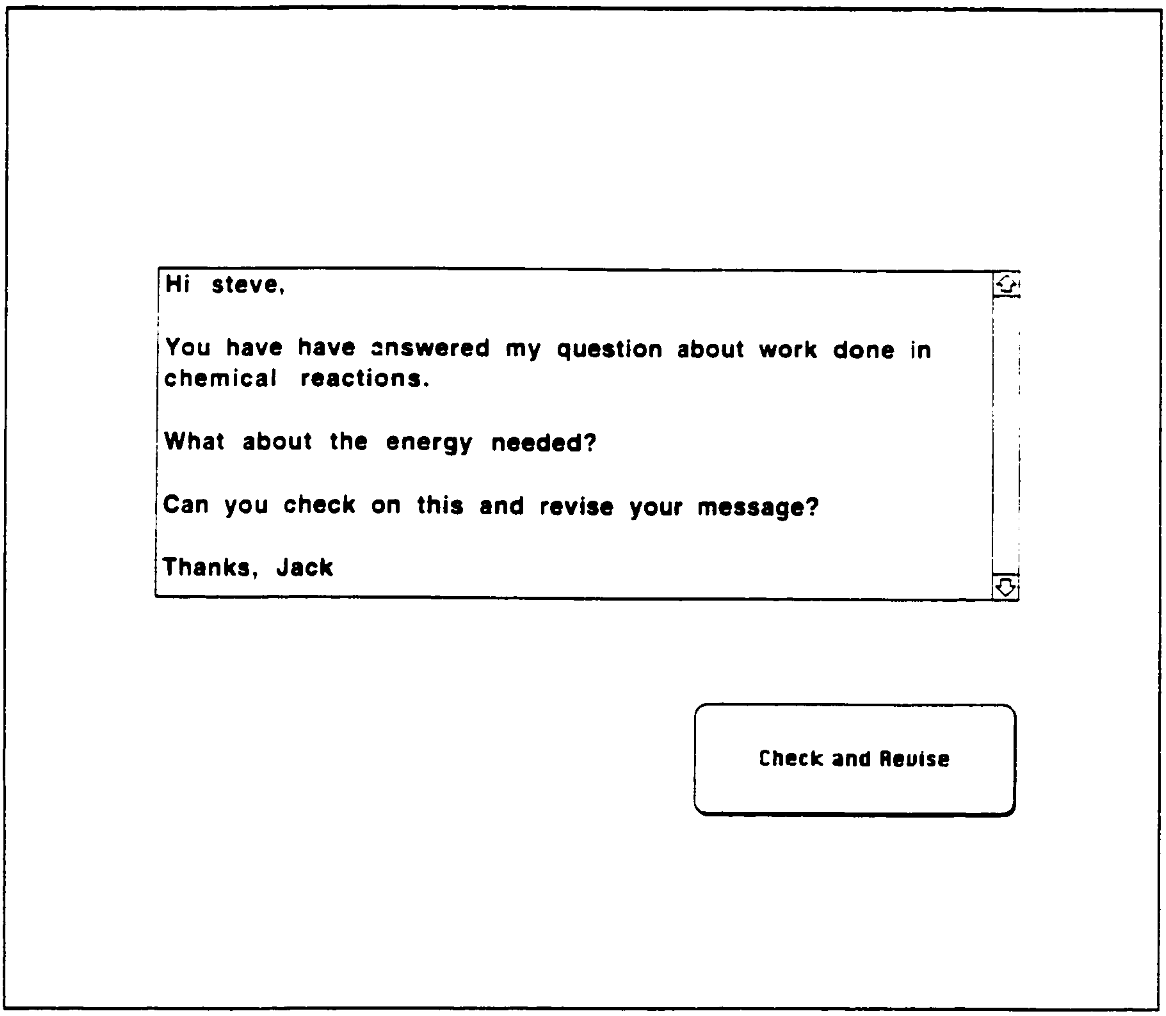


Figure A4-24: Response from Virtual Tutee to an Incomplete Message for Sub Question 2 is to Ask for More Information

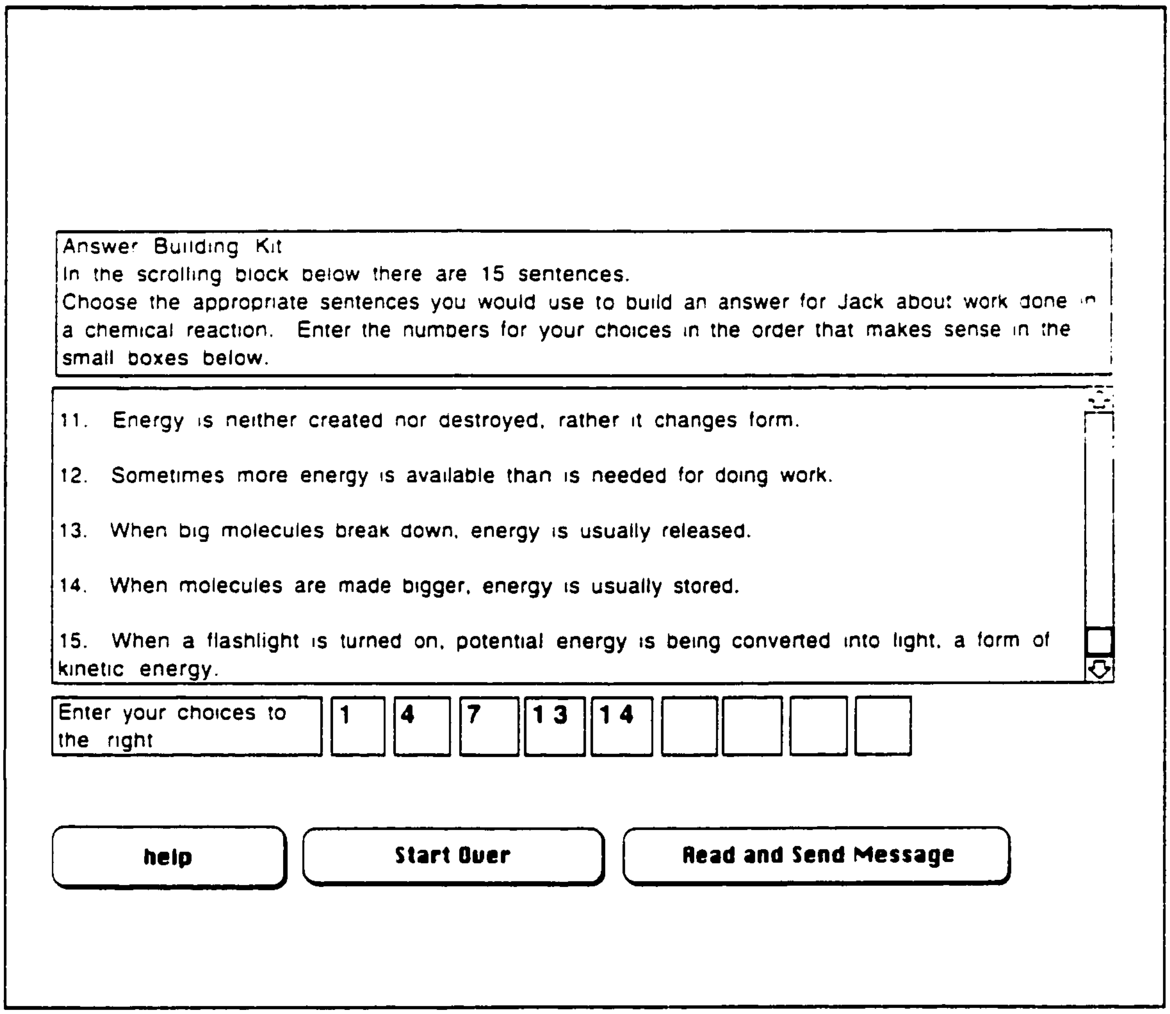


Figure A4-25: Message Building Kit for Sub Question 2
Items have been Selected to Complete the Message

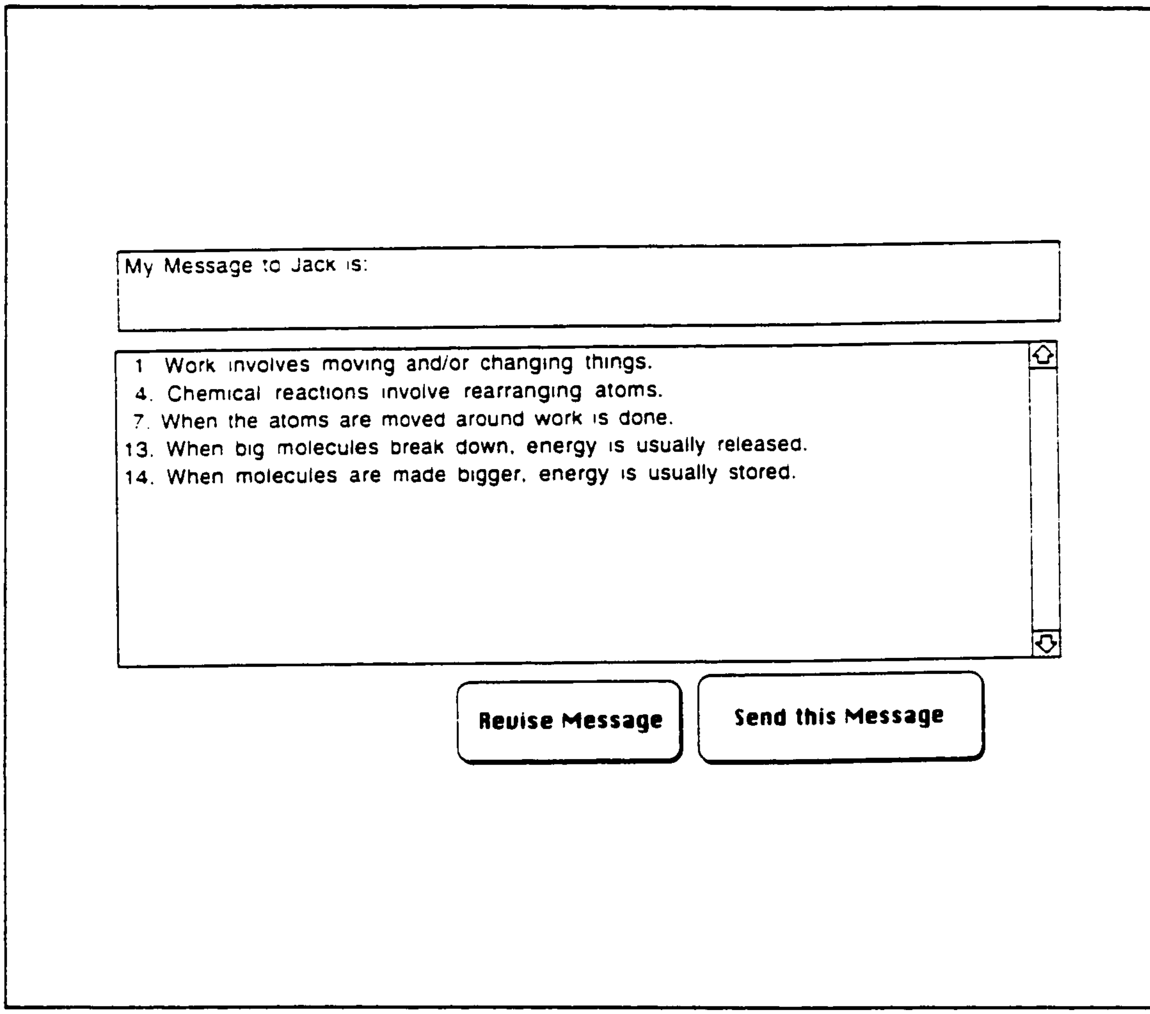


Figure A4-26: Real Student Can Read Message Constructed Before Sending

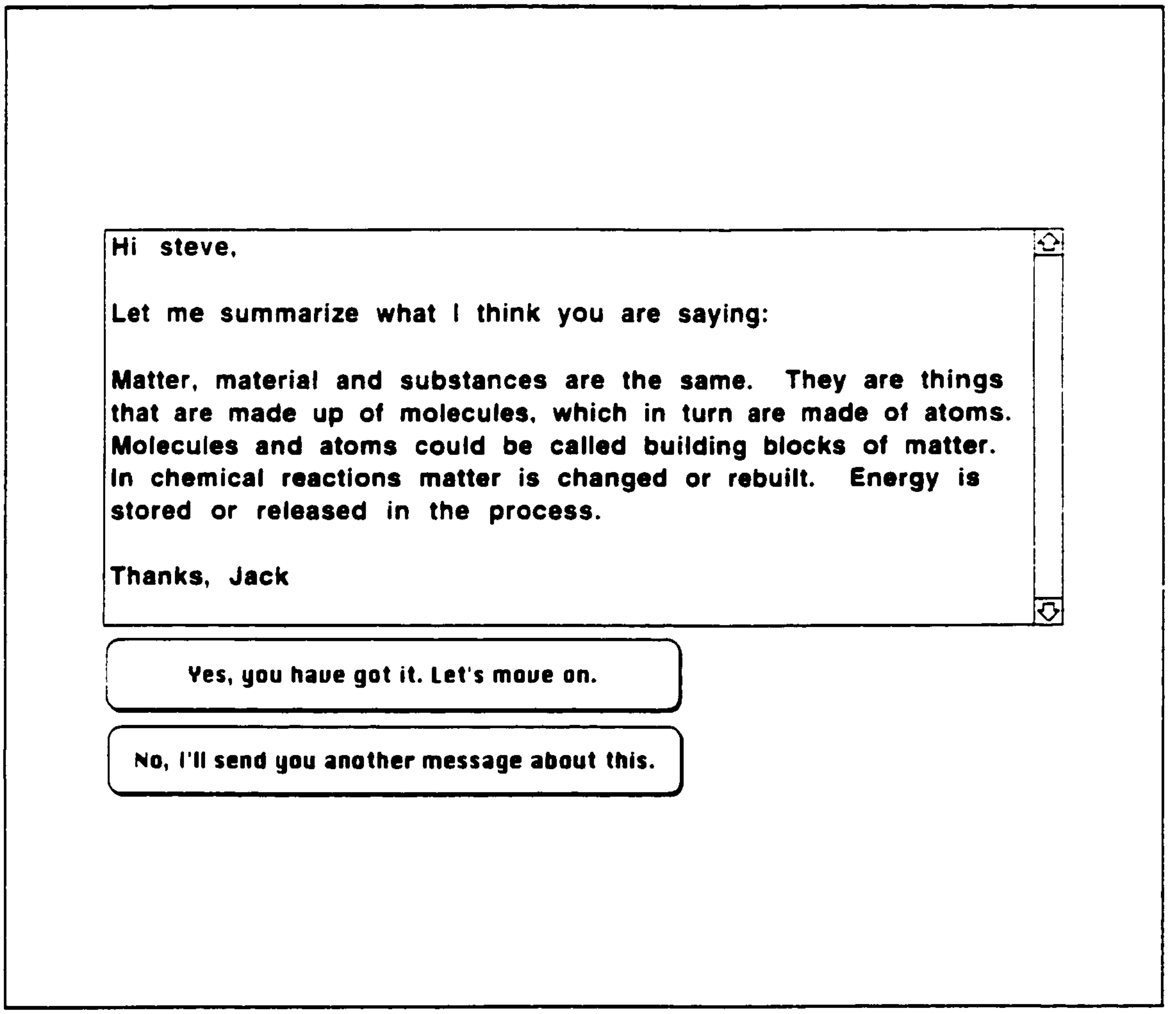


Figure A4-27: Response from Virtual Tutee to a Completed Message for Sub Question 2 is Sub Question 1

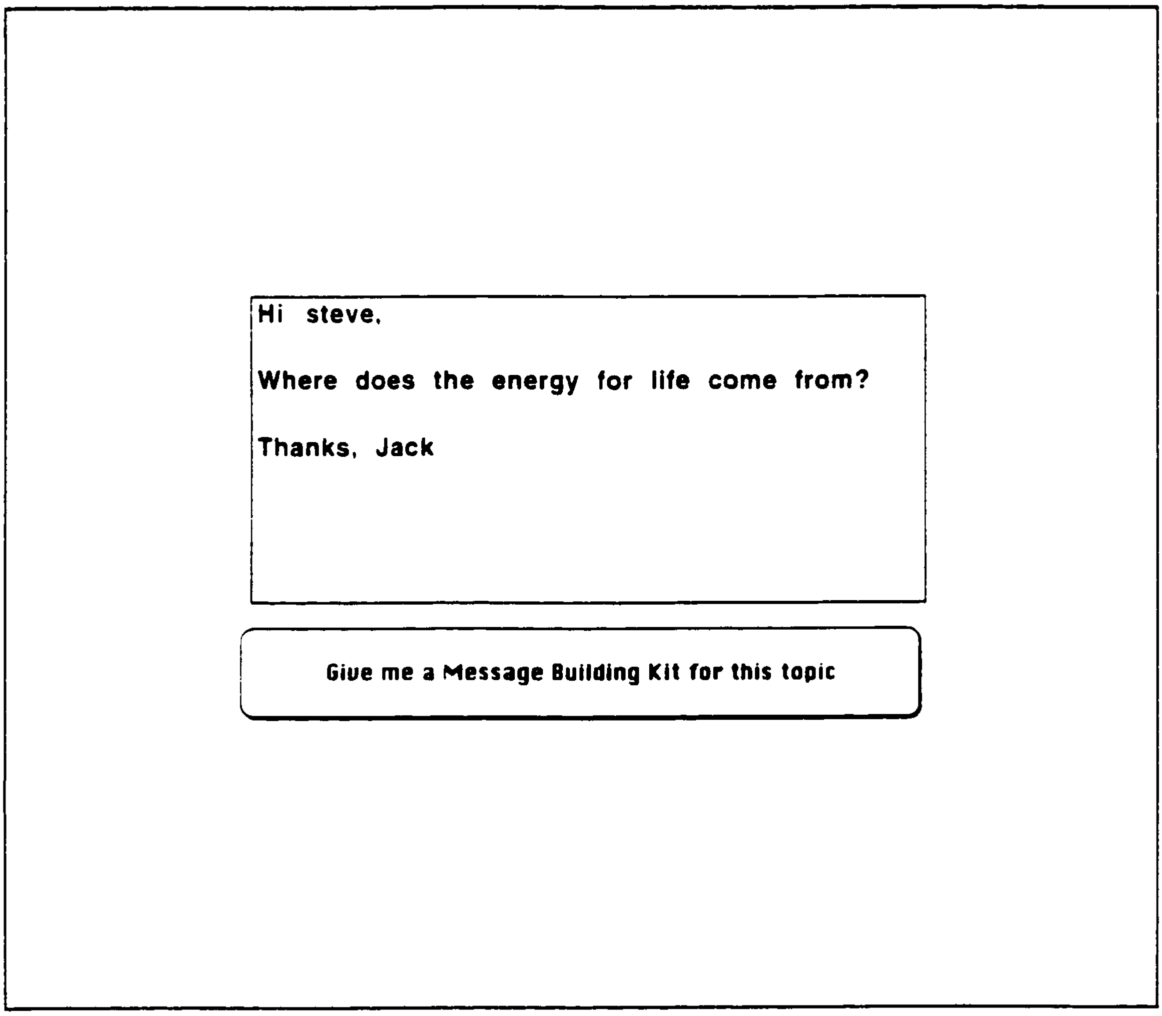


Figure A4-28: Lead Question 3 of the Energy Module

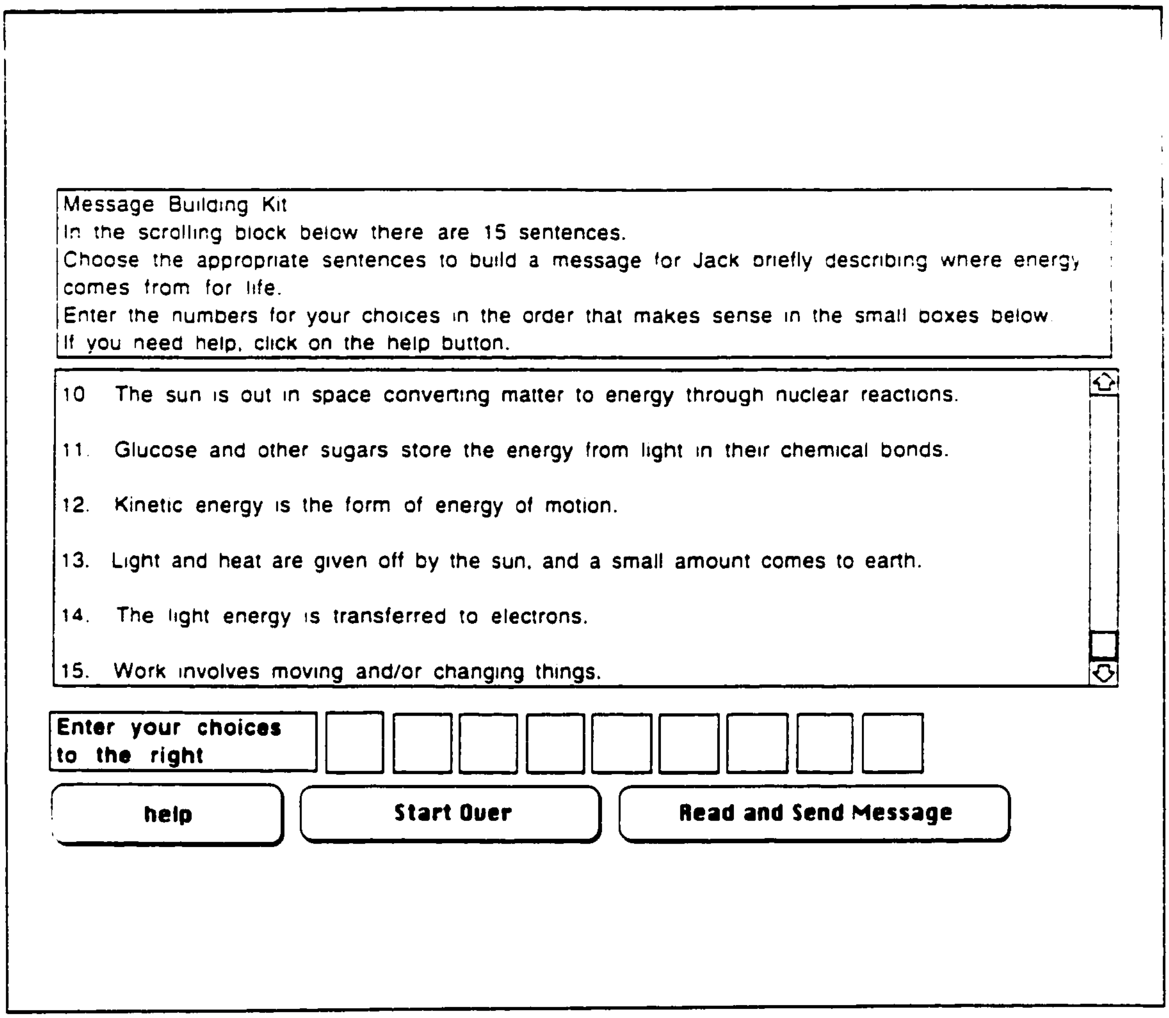


Figure A4-29: Message Building Kit for Lead Question 3

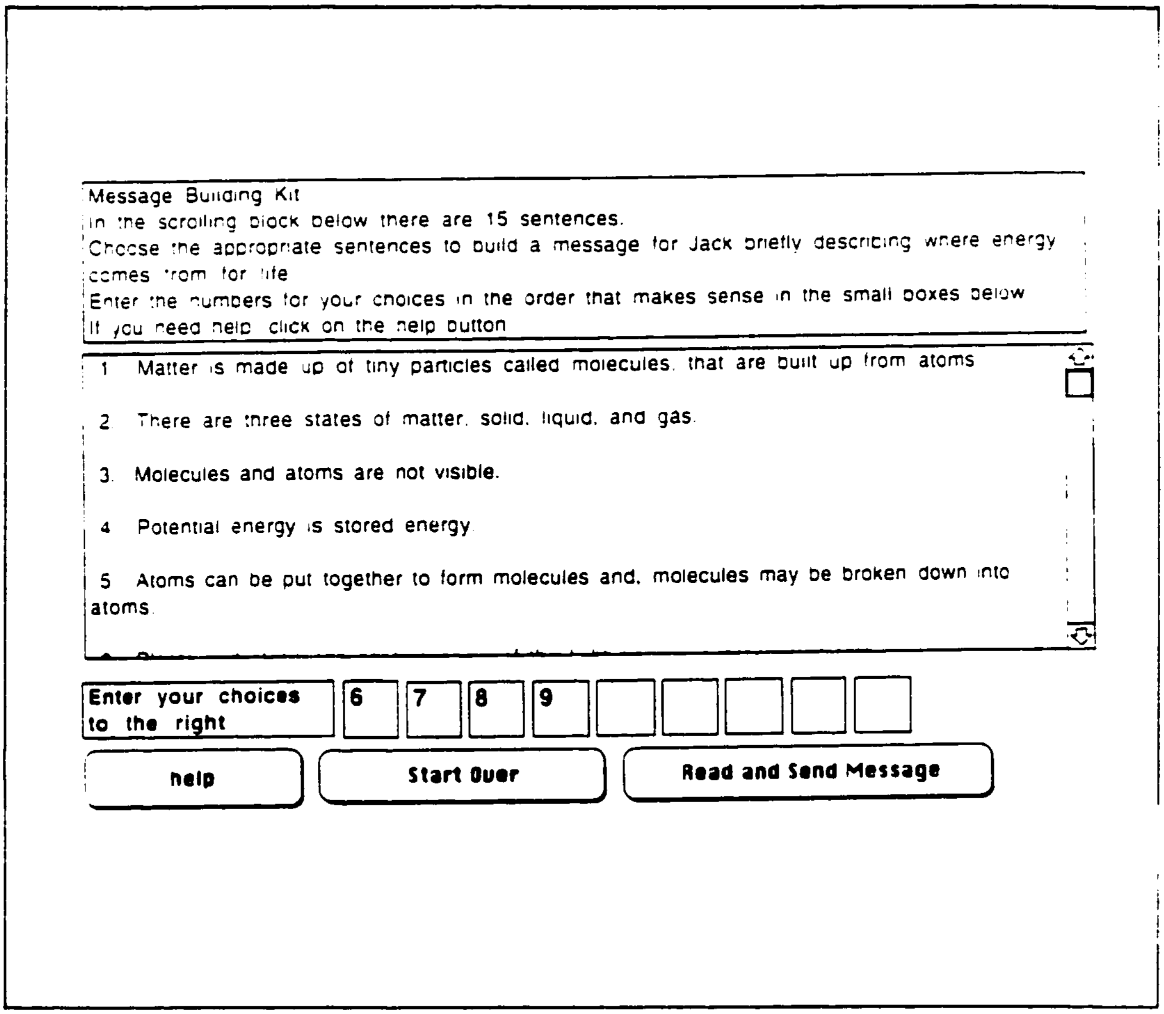


Figure A4-30: Message Building Kit for Lead Question 3
An Odd Selection of Model Items has been Selected

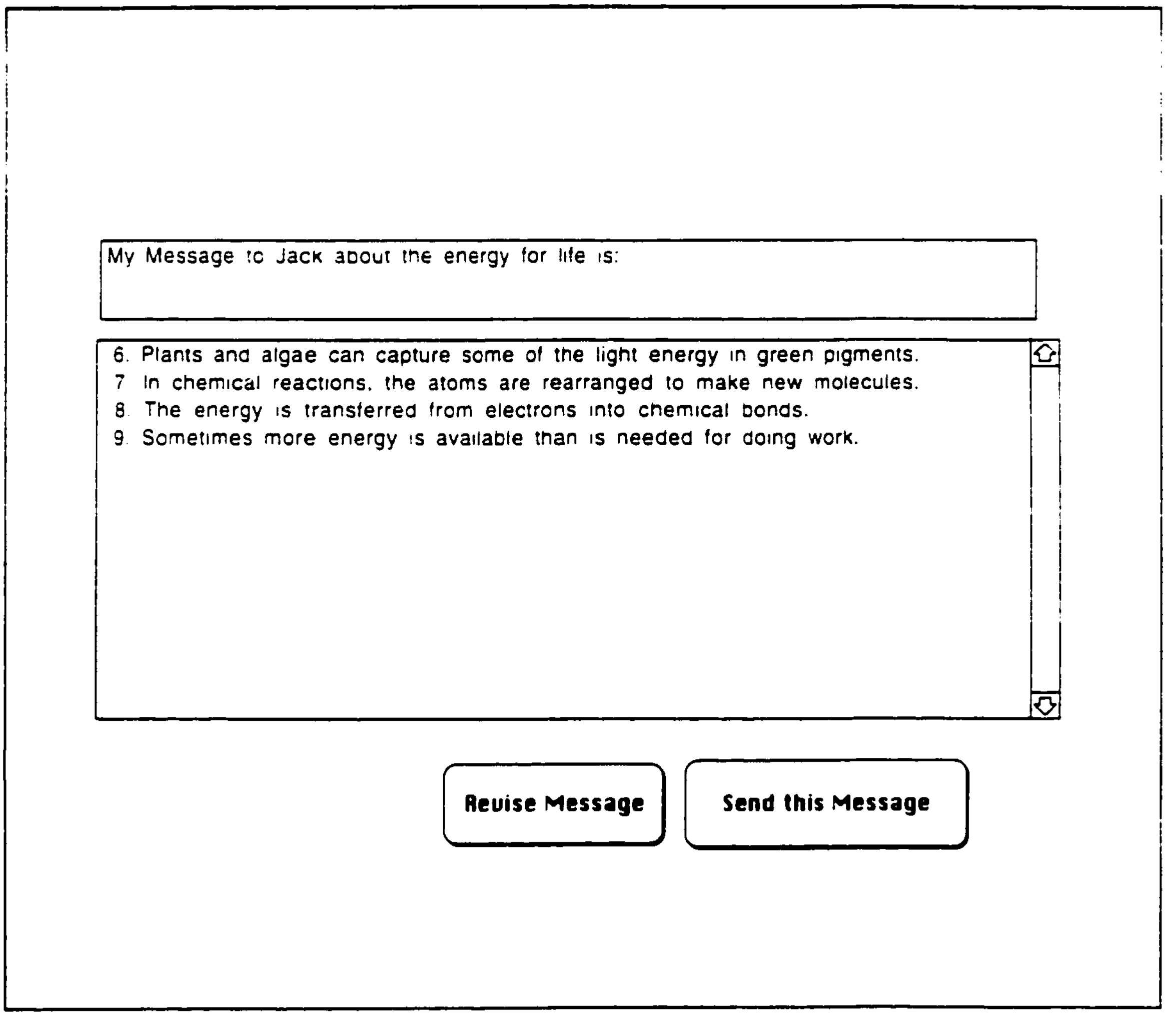


Figure A4-31: Real Student Can Read Message Constructed Before Sending

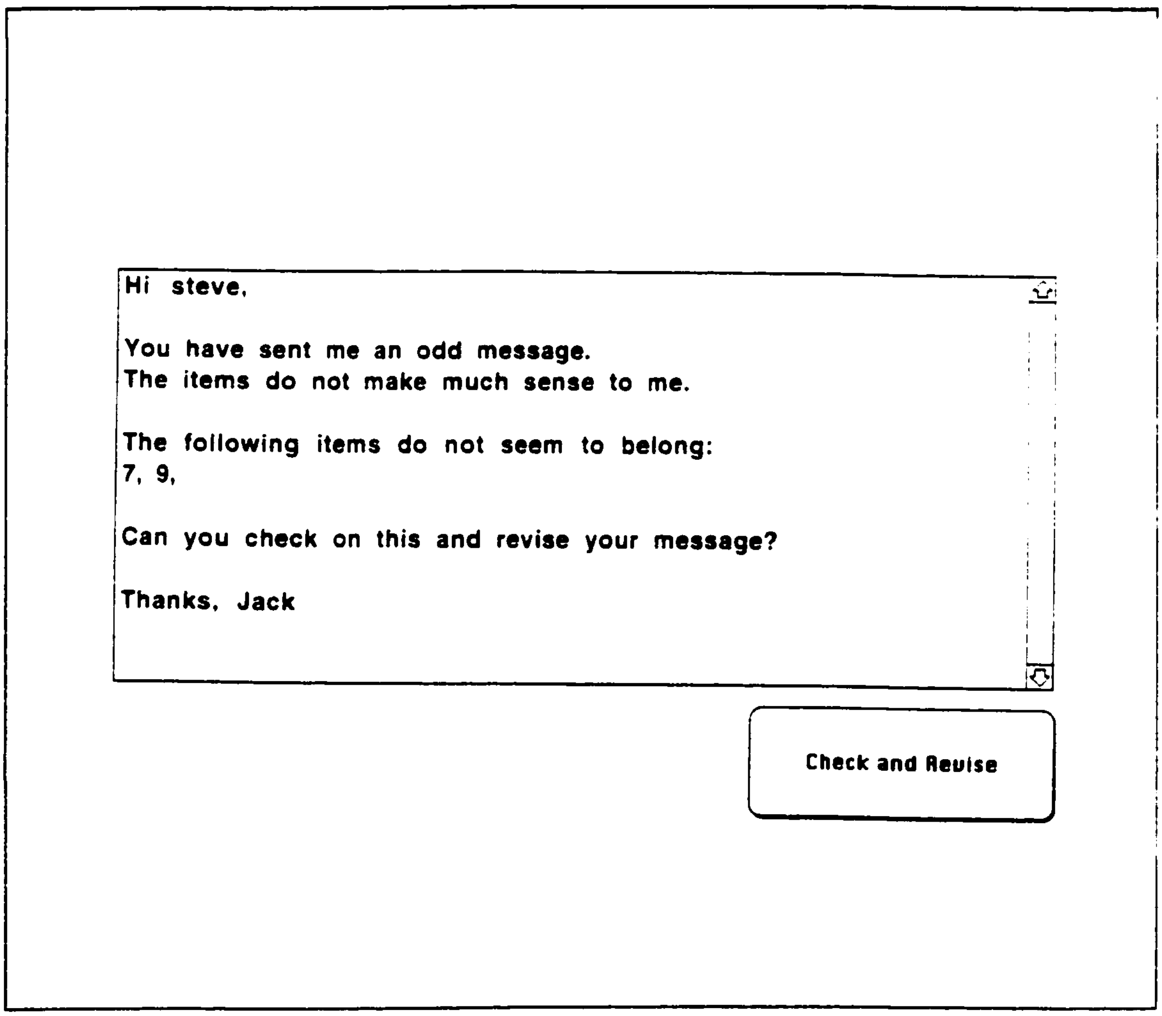


Figure A4-32: Response from Virtual Tutee to an Odd Message
for Lead Question 3 is to Ask for More Information

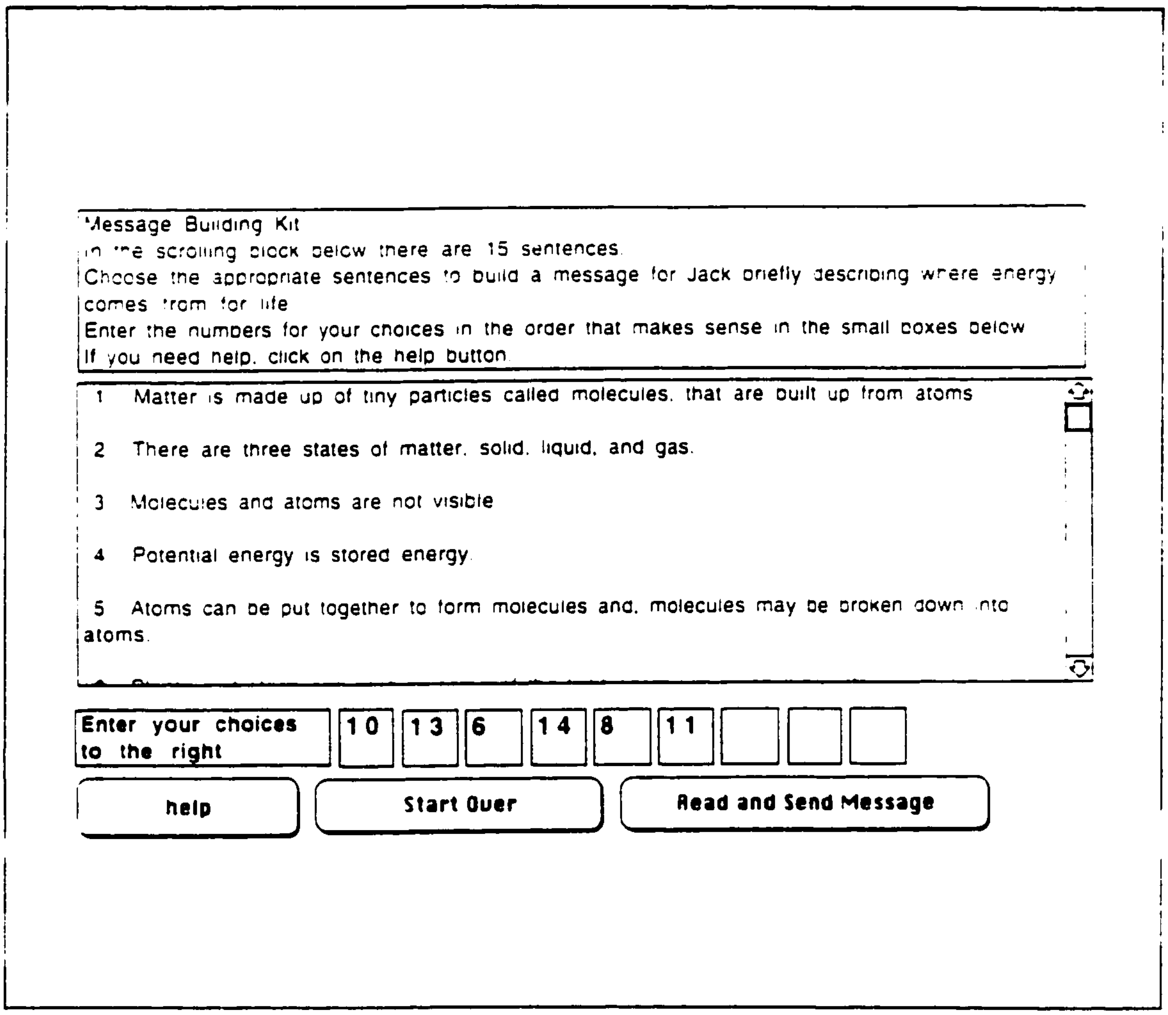


Figure A4-33: Message Building Kit for Lead Question 3
Items Selected have been Modified to Produce an Excellent Message

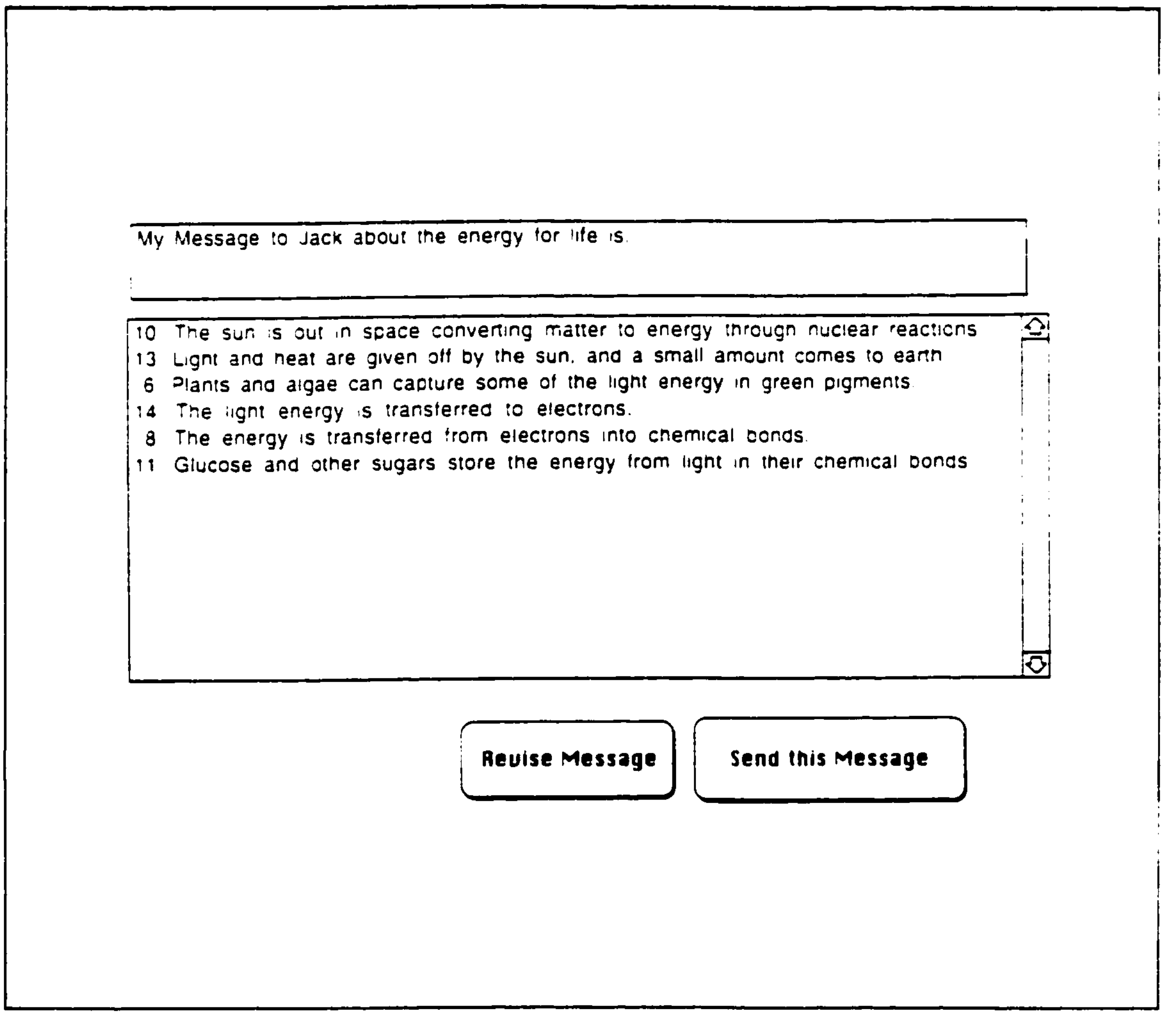


Figure A4-34: Real Student Can Read Message Constructed Before Sending

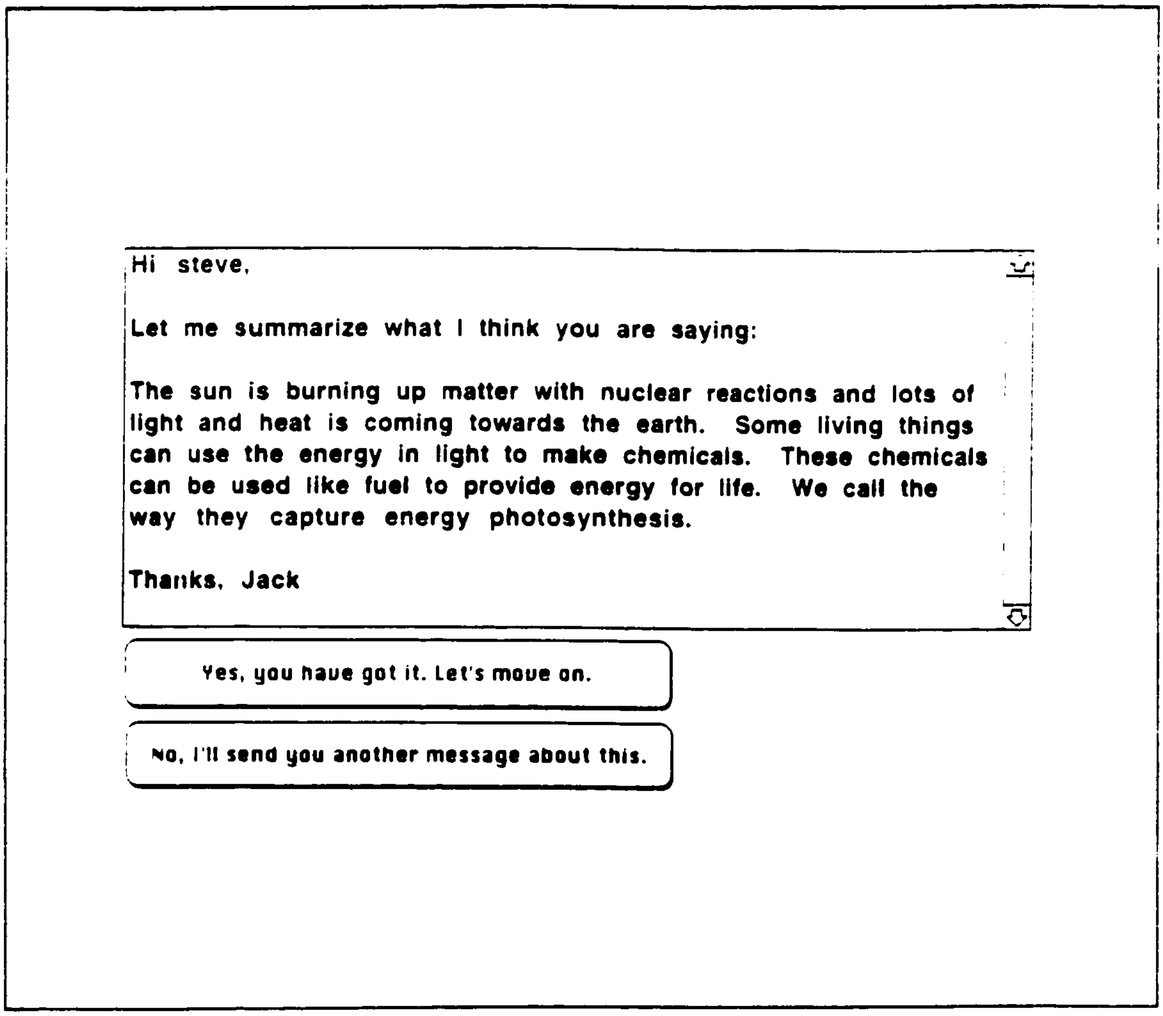


Figure A4-35: Response from Virtual Tutee to an Excellent Message for Lead Question 3 is Sub Question 1

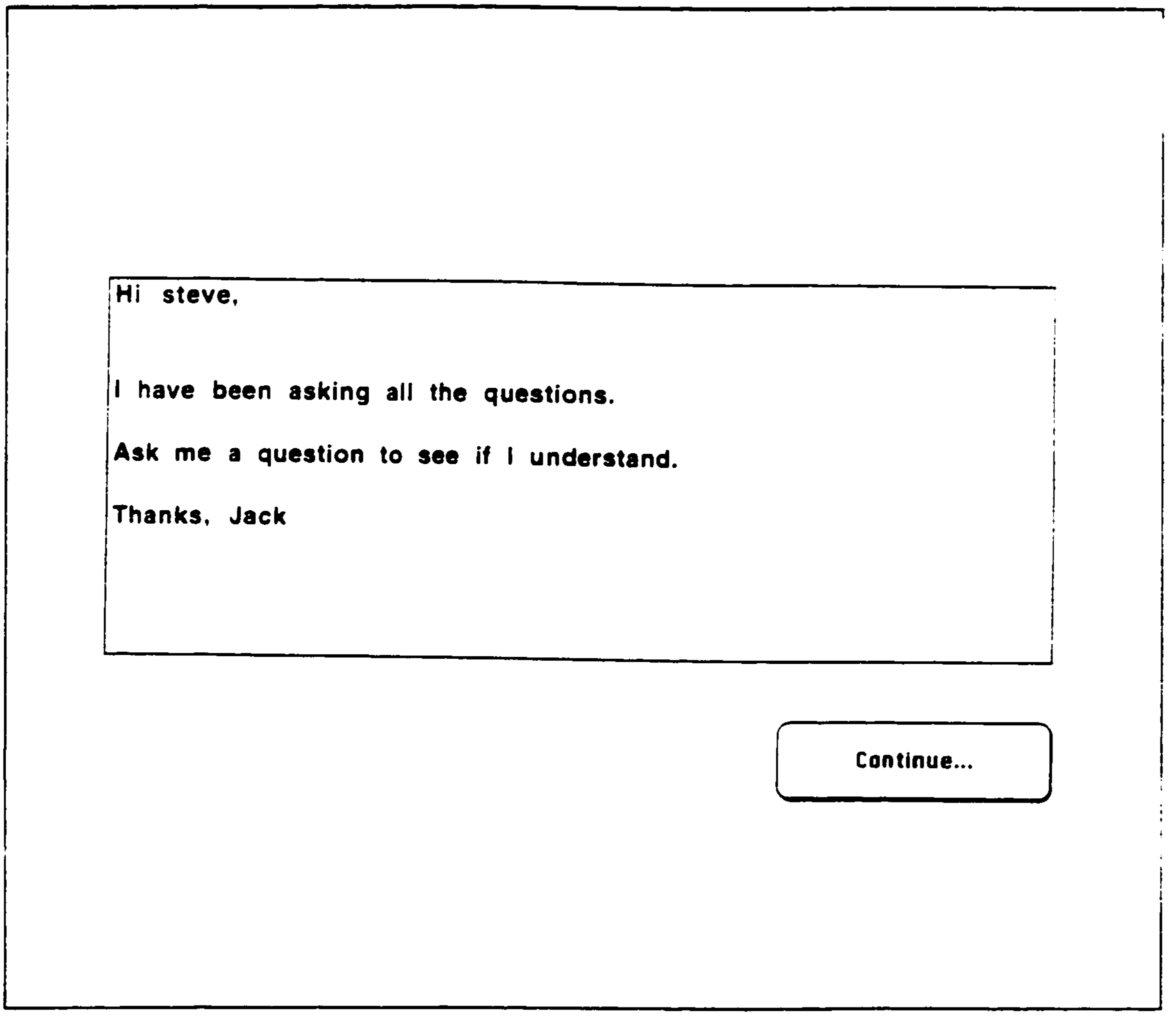


Figure A4-36: After Sub Question 1 of Lead Question 3 is Answered.
The Virtual Tutee Asks the Real Student to Ask Questions

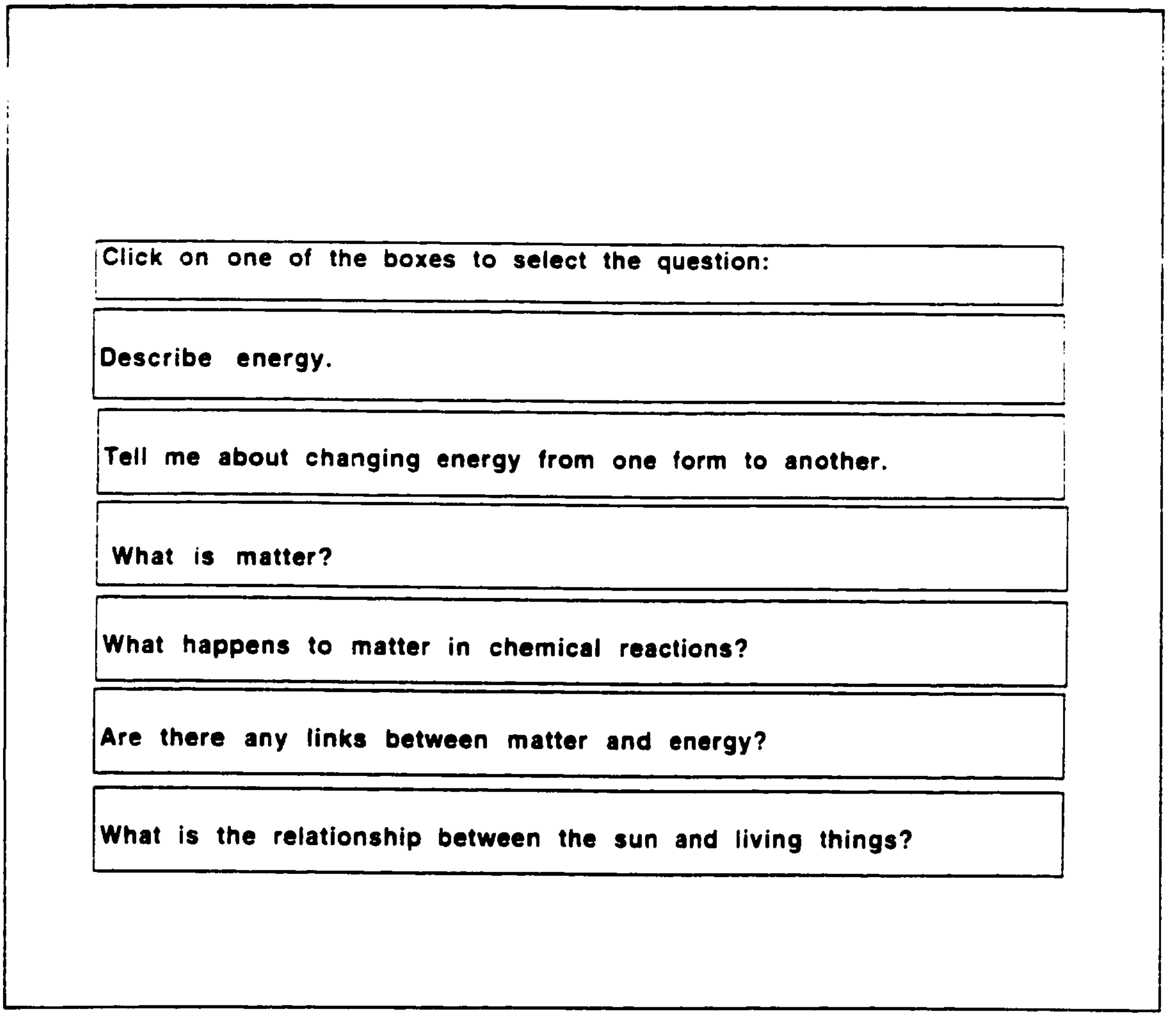


Figure A4-37: A Menu of Possible Questions is Provided to the Real Student

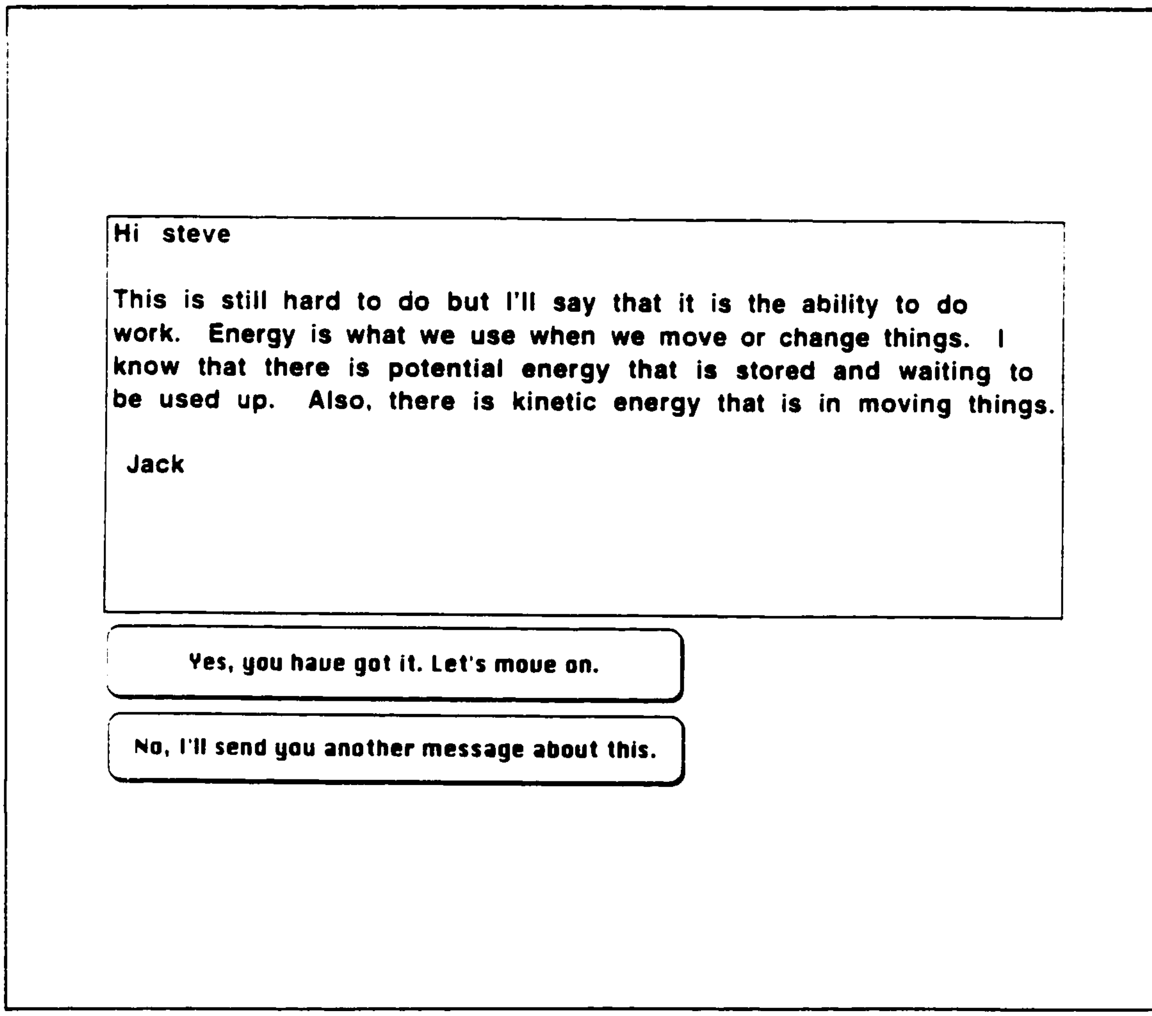


Figure A4-38: The Virtual Tutee Response to the First Question

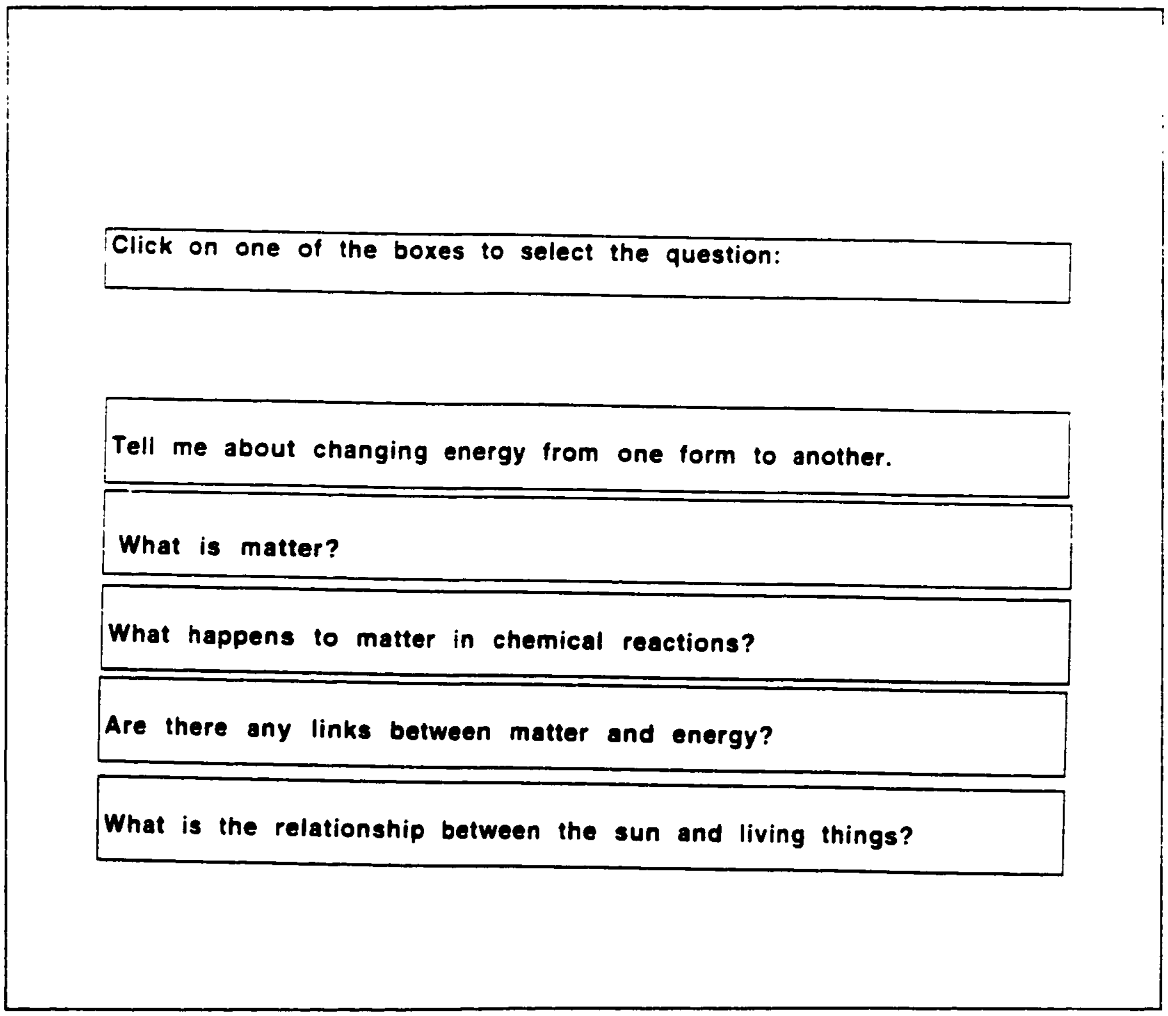


Figure A4-39: Choosing "Let's Move On" Returns the Real Student to Question Menu from which the Previously Asked Question is Missing

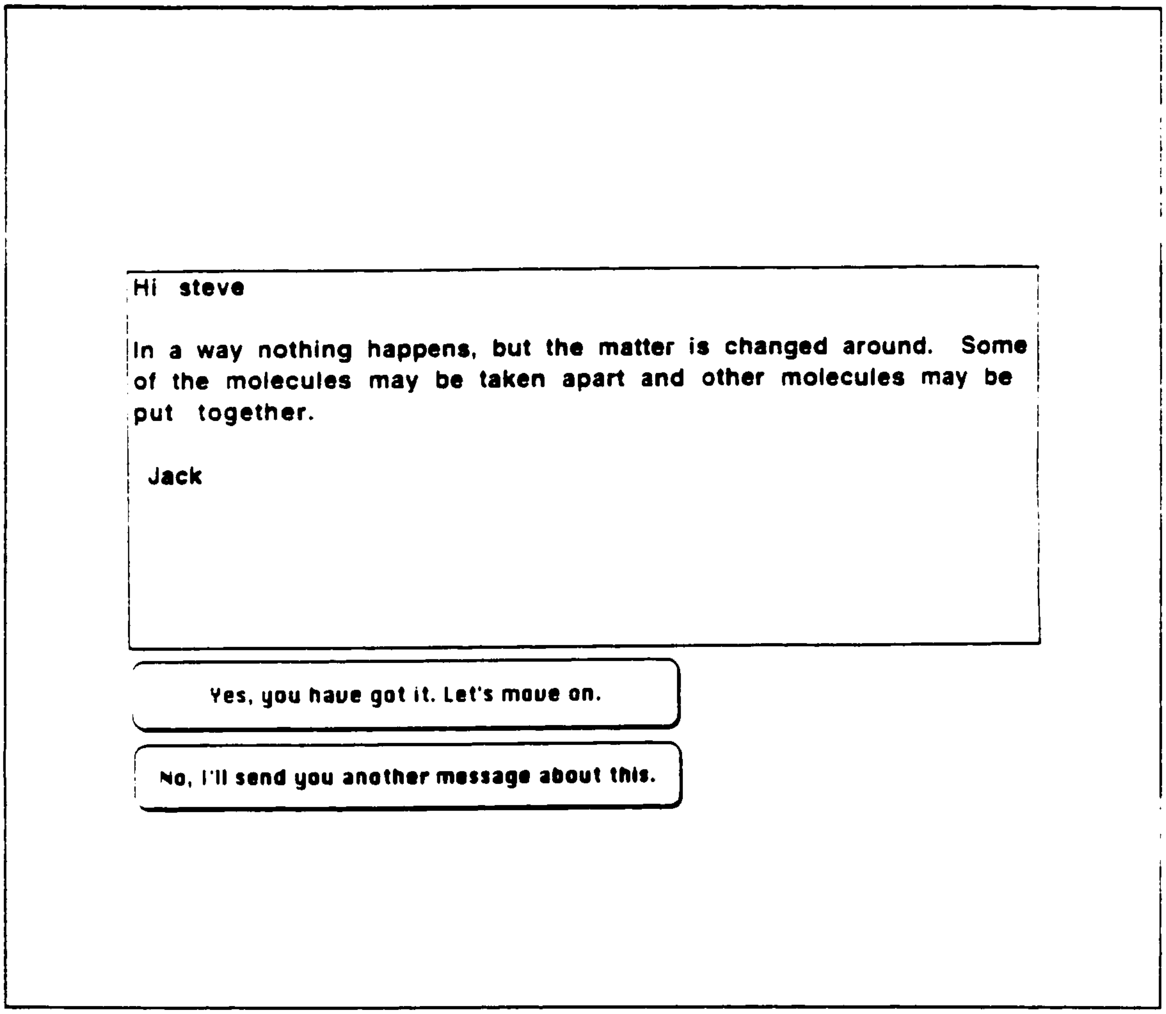


Figure A4-40: The Virtual Tutee Response to the Fourth Question: What Happens to Matter in a Chemical Reaction?

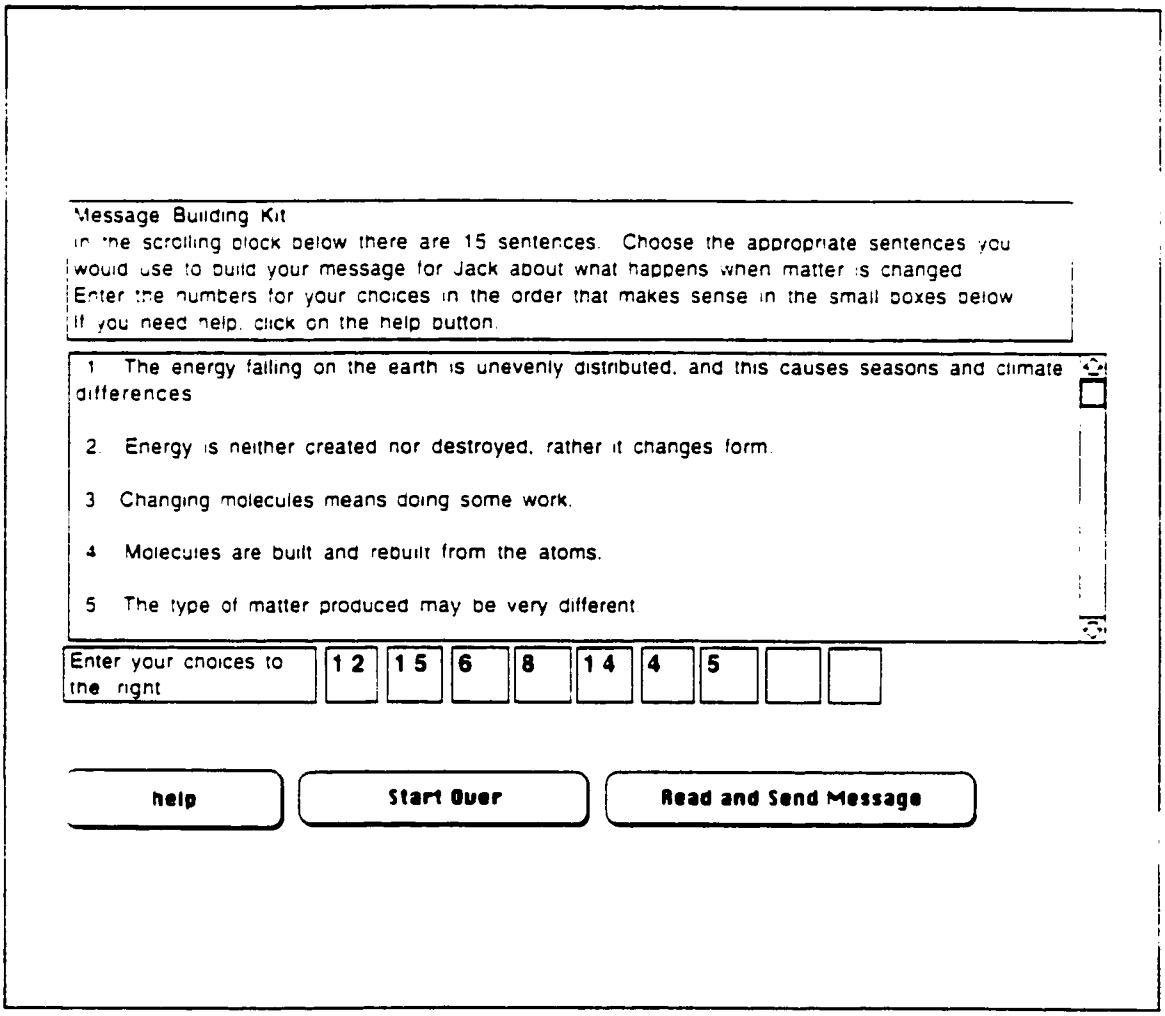


Figure A4-41: When the Real Student Chooses to Send a Message after a Response. A Message Building Kit is Provided. Odd Items Have Been Chosen.

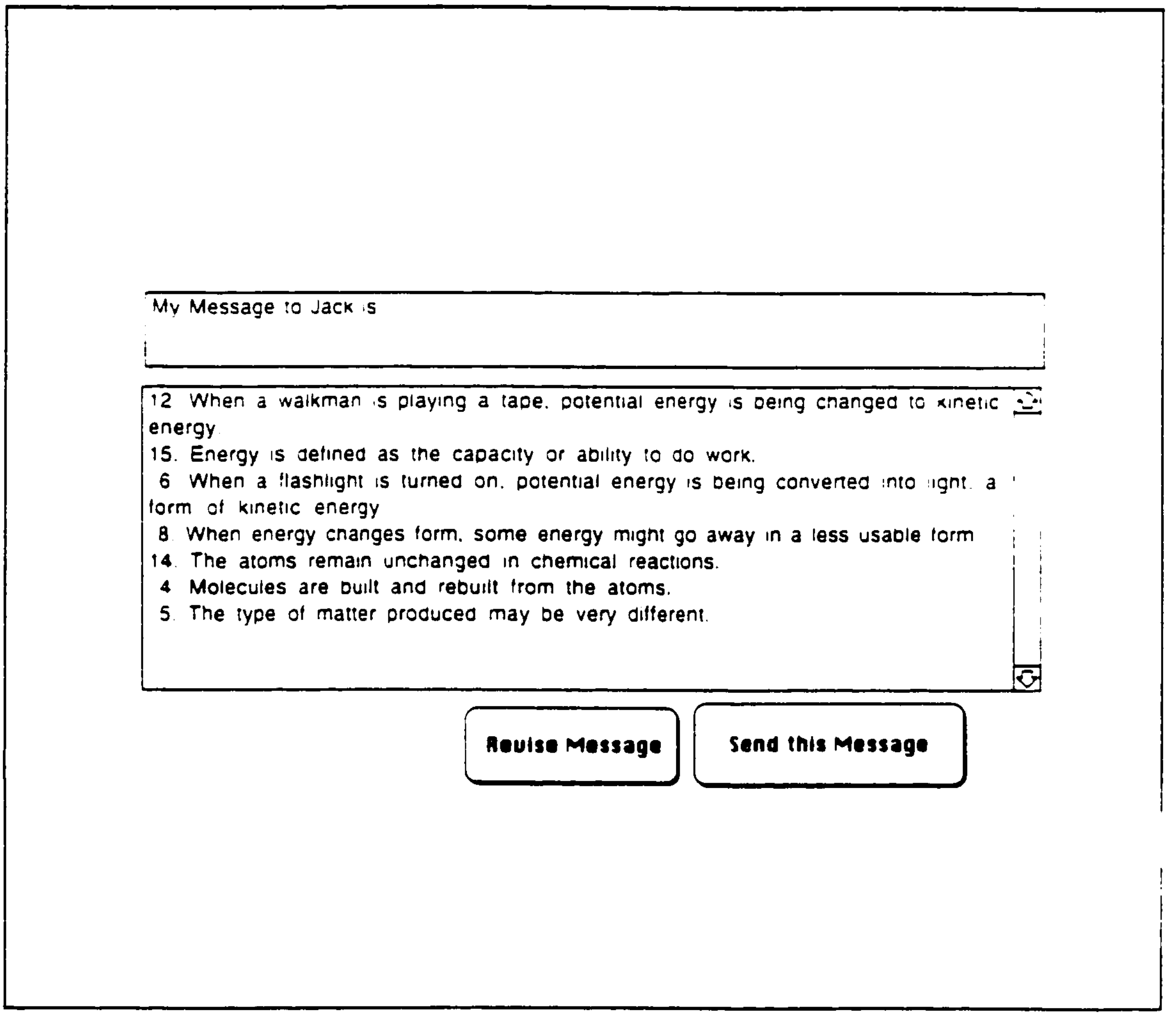


Figure A4-42: Real Student Can Read Message Constructed Before Sending

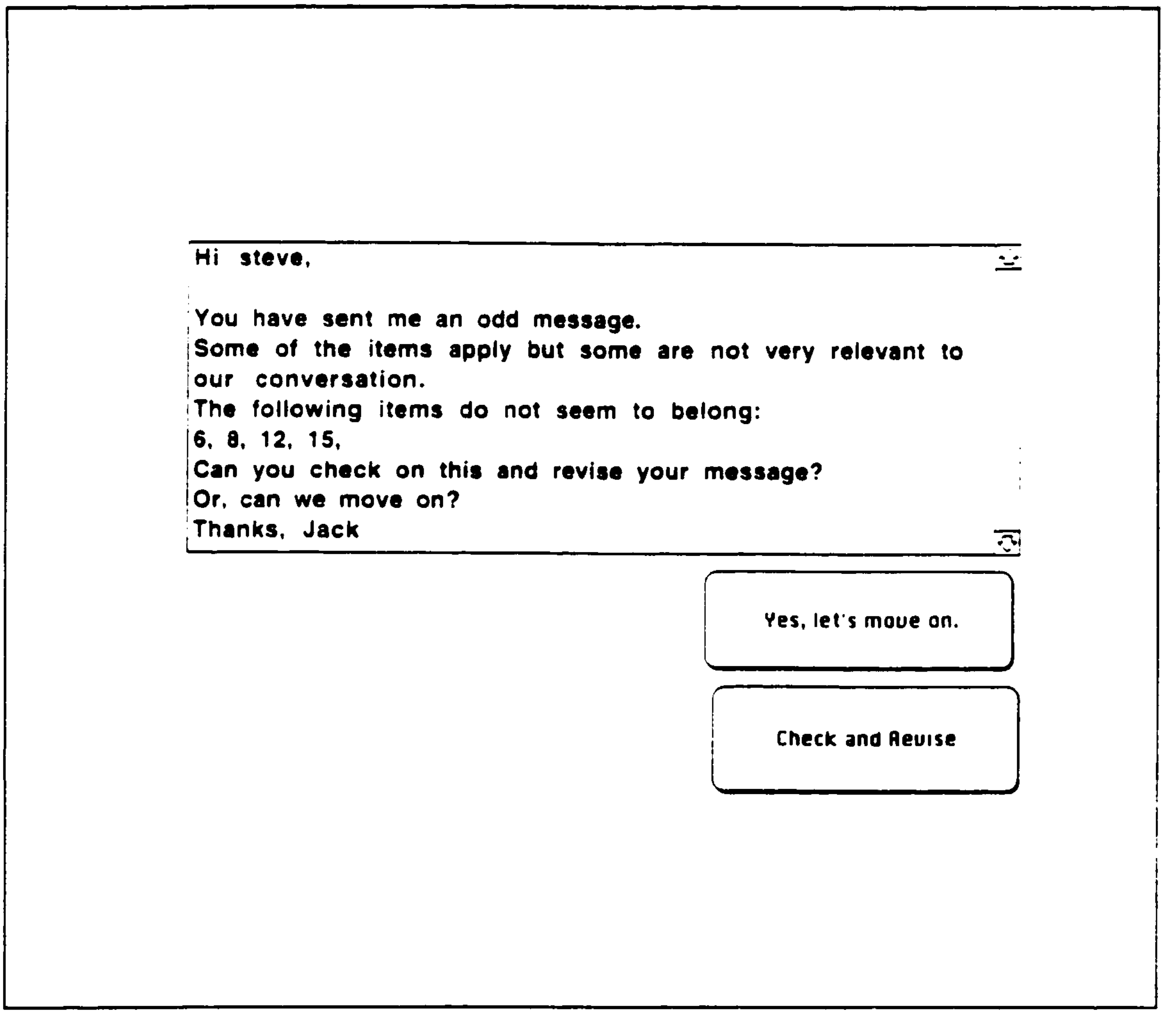


Figure A4-43: The Virtual Tutee Response to an Odd Message

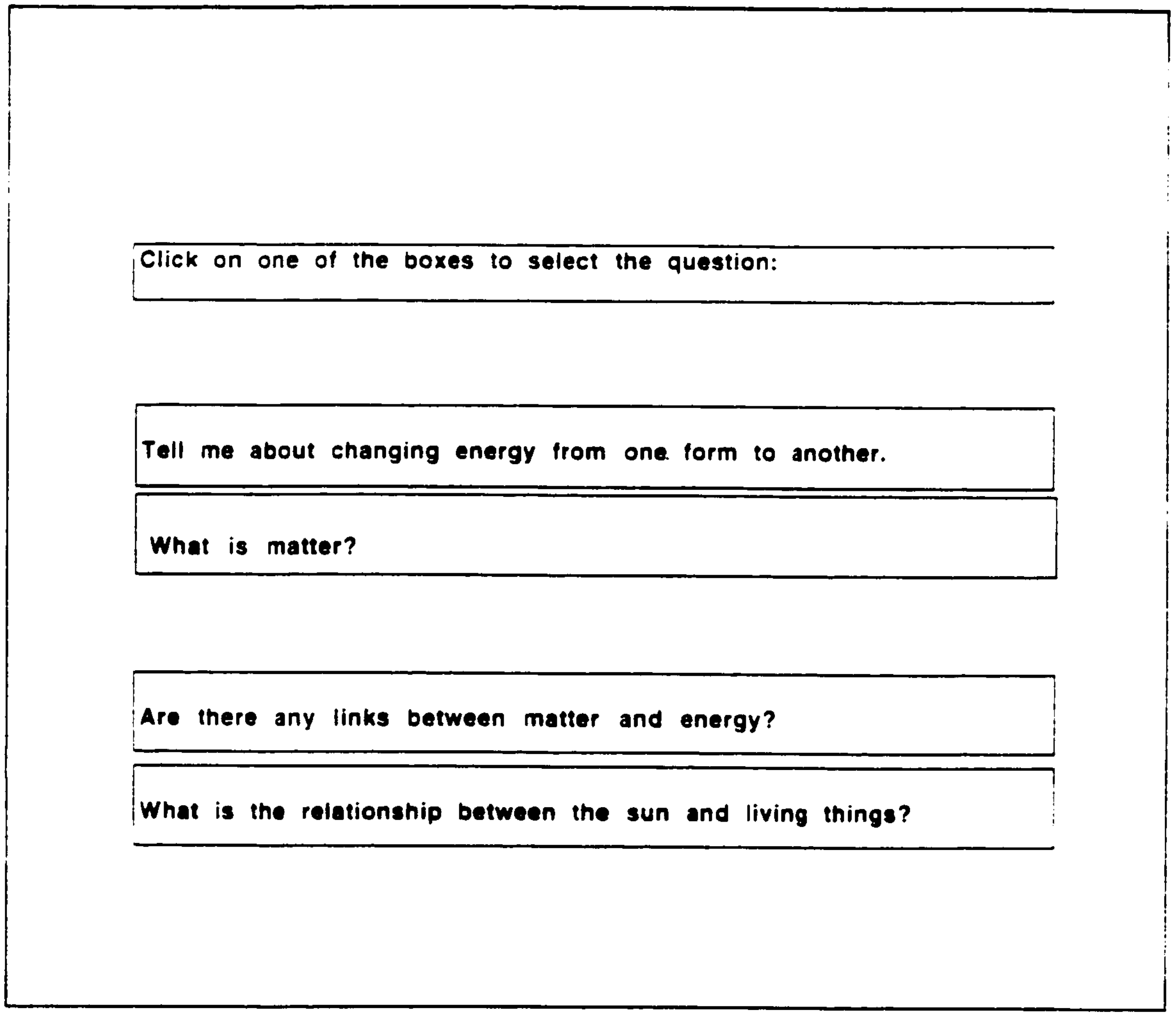


Figure A4-44: Choosing "Let's Move On" Returns the Real Student to Question Menu from which the Previously Asked Questions are Missing

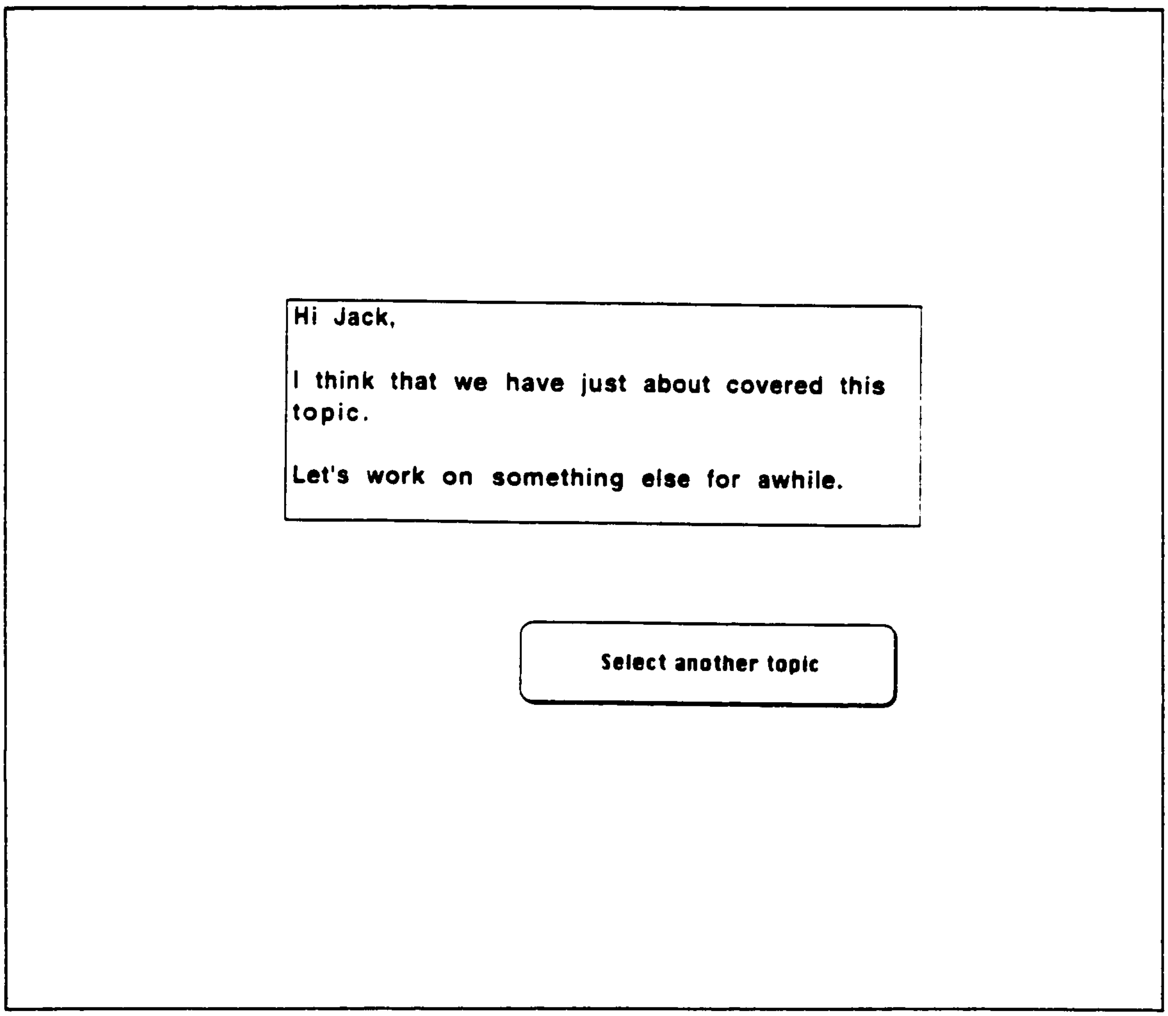


Figure A4-45: After Four Questions have been Answered, the Real Student is Offered the Opportunity to Select Another Topic or to Quit.

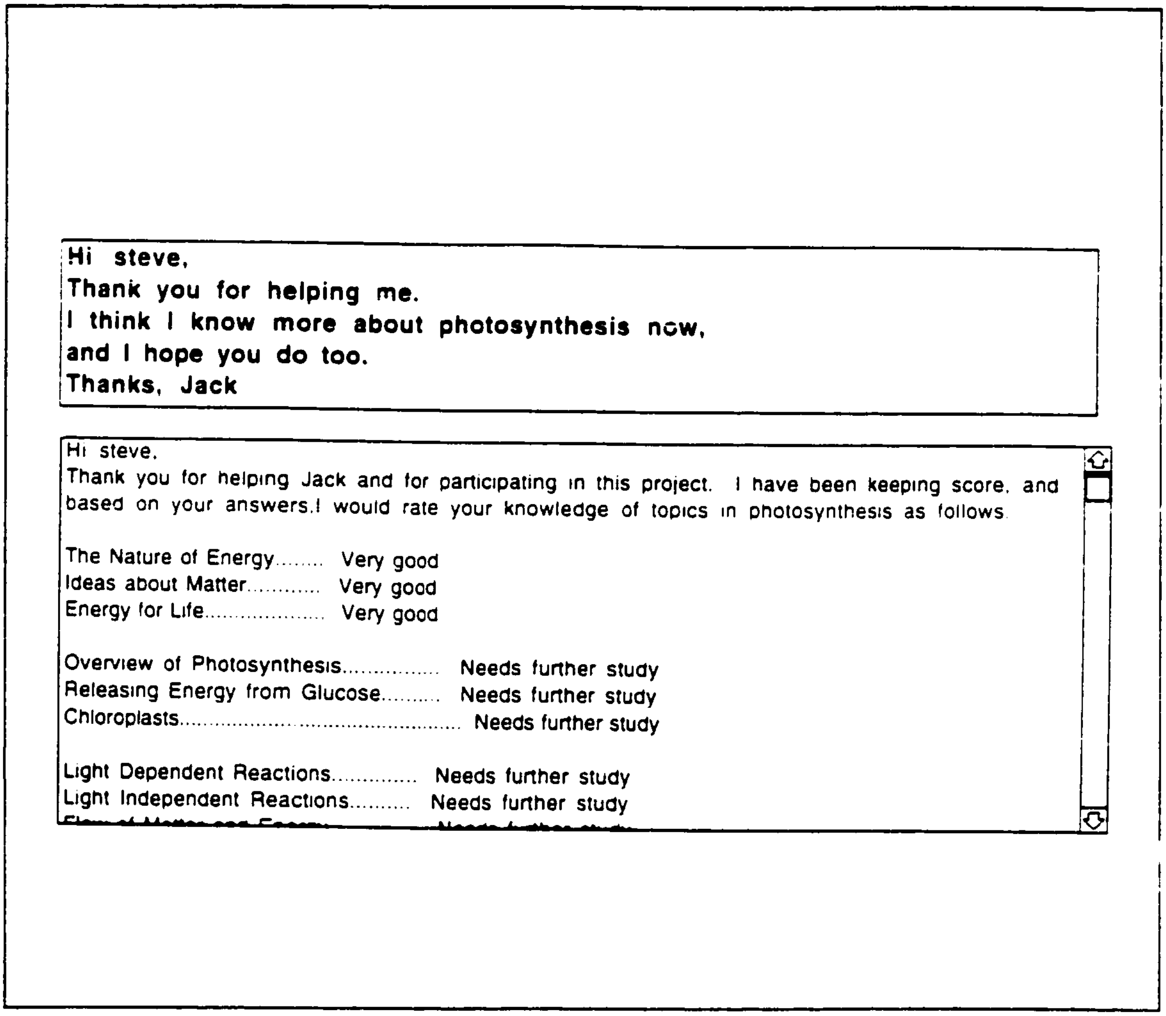


Figure A4-46: When the Real Student Has Chosen to Quit, the Final Card Contains a Message from Both the Virtual Tutee and the Virtual Professor.

APPENDIX 5

CONSENT FORM AND SAMPLE ATTITUDE QUESTIONNAIRES

INFORMED CONSENT FORM

Thank you for agreeing to participate in this experiment.

We would like you to help us evaluate a new system for learning about biology. During this session you may be using a computer assisted learning (CAL) format.

As you can see, you will be using a Macintosh computer, with a mouse for cursor movement and to initiate task actions. If you have had some experience with the Macintosh, the basic task interactions, such as pointing, clicking, dragging, etc., will be familiar to you. If you have not used this type of computer, a few introductory instructions will be provided. You do not have to be an expert on computers to learn to use the test systems. They have been designed to be user friendly.

The subject matter to be studied in the lesson is about photosynthesis. For the purposes of the experiment, you will be asked to answer questions about the subject matter that appear to be tests. Your performance on these tests will NOT influence your course grade in any course and will NOT be made available to any teacher within this college beyond the experimenter. Your full name should appear on this form and on an identification form. You will be assigned a random user number which will be used to track your progress. This number will appear on all other documents. When asked by the computer for your name, you may give a first name, nickname or even a made up name. After the data has been collected and analyzed, all references that connect your name and the user number will be destroyed.

If you are currently taking a biology course this information may be of use to your study of the course, but your performance here will not effect your course grade in any way. If you are not a student of biology, we hope that your participation in the experiment will provide you with a general knowledge of the subject matter.

During this session, you will be asked to study a chapter from a college level introductory biology textbook. Depending on your role in the experiment, you will then be asked to perform several specific tasks. There may be students present in the room who are doing, or appear to be doing very different tasks. While you are performing some of the specific tasks, we may be timing how well the system helps you with these tasks. Therefore, we would like for you to work through each task without taking a break; you can take time to relax between tasks if you wish.

Because we are interested in how well this system works, we will be asking you for your reactions in a separate questionnaire at the end of the session. Remember that you are helping us to evaluate the system; we are not evaluating you. You should feel free to say whatever you think about any aspect of the system or the tasks you are asked to perform.

Before we begin, do you have any questions?

Please read the next page carefully, and fill in the information at the bottom.

You have been solicited as a research participant for our evaluation of the design for a new interactive computer system. This evaluation is being conducted by Stephen G. Taylor, as part of research project at Concordia University. While the researcher is a teacher at Champlain Regional College, St-Lambert, the college is not responsible for the research project and the information obtained by the researcher shall remain his property. You may obtain further information about the project by contacting the researcher at the college.

Your evaluation session will be run by the researcher himself who will be glad to answer any questions that you have about the project. As a participant, you have certain rights, which are listed below.

You will be asked to perform various tasks during the session that are similar to those performed by a student studying for a test. These may include reading a text chapter, answering study questions, communicating with another student by way of a computer, answering test questions about the subject matter, and answering questions about the systems in use. We expect that you will take the assigned tasks seriously and that you will attempt to study the information as if you did have a test on the subject matter

It is understood by both the researcher and the student participant that it is the study methods and computer systems that are being evaluated. We are not in any way evaluating you. We expect the session to last about three hours, and that you will stay in the room during the session, unless you ask permission to leave Your name will not be associated with any data that are collected during this evaluation session. You will NOT be paid for your participation in the experiment. There are no known risks associated with this evaluation.

You have the right to completely withdraw from the session at any time for any reason, but please inform the researcher that you are withdrawing.

You may see your data, if so desire. If you decide to withdraw your data, please inform the researcher immediately, or within one week following the session. Otherwise, identification of your data might not be possible because of our efforts to ensure anonymity.

You are requested not to discuss this session with other people who might be in the group from which other participants could be drawn, such as other students in this college. At the conclusion of the research project, you may examine a copy of the final report by contacting the researcher. Copies of the report will be available at the college and university libraries.

Finally, we greatly appreciate your time and effort for participating in this research project.

Your signature below indicates that you have read this consent form and that you voluntarily agree to participate.

Do you have any questions?

SIGNATURE______________________________ DATE________________

NAME:_________________________________

ADDRESS:______________________________

PHONE______________

PRE-SESSION ATTITUDE QUESTIONNAIRE

Please answer the following questions to provide us with an indication of how you react to computers and computer assisted learning programs. Your responses will be kept confidential.

1. **Experience with Tutoring:**

A. Have you ever used the services of a tutor to study for a course?

___Yes ___No

If yes,

- How many courses? Circle an answer: 1 2 3 4 5 more than 5

- For your most recent experience, how many hours of tutoring did you take?

Circle an answer: Less than 2 3-4 5-6 7-8 9-10 more than 10

- How satisfactory was this experience?

Circle an answer: Very Good Satisfactory Poor Unsatisfactory

B. Have you ever been a tutor for another student? ___Yes ___No

If yes,

- How many courses? Circle an answer: 1 2 3 4 5 more than 5

- For your most recent experience how many hours of tutoring did you do?

Circle an answer: Less than 2 3-4 5-6 7-8 9-10 more than 10

- How satisfactory was this experience?

Circle an answer: Very Good Satisfactory Poor Unsatisfactory

C. To what degree do you agree with the statement below?

Teaching someone else about a subject matter helps me learn about it.

Circle the appropriate item:

Strongly agree Agree Disagree Strongly disagree

2. **Experience with Computers:**

If you have never used a computer, check here _____ and move on to Section 3

A. At about what age were you introduced to computers? _____

B. Do you have a computer at home? ____Yes ____No

C. Do you share that computer with other family members? ____Yes ____No

D. Do you use the computer facilities in this college? ____Yes ____No

E. About how many hours a week do you spend using a computer?

Circle an answer:

Less than 1 hr   1-3 hrs   3-6 hrs   6-9 hrs   9-12 hrs   More than 12 hrs

F. Have you taken a course in computer programming? ____Yes ____No

G. How well do you operate a computer mouse? Circle an answer:

Very well   well   poorly   Not at all

H. How often have you missed a meal or stayed up too late because of becoming involved in using a computer? Circle an answer:

Daily   Weekly   Occasionally   Rarely   Never

3. **Computers in Education**

Did you use computer assisted learning programs to study material for high school courses that were not specifically arranged to teach you about computers?

____Yes ____No

Have you used computer assisted learning programs to study material for college courses that were not specifically arranged to teach you about computers?

____Yes ____No

Have you ever used computer tutoring programs to assist your learning in a high school or college course?

____Yes ____No

Have you ever taken a course given by electronic mail or from the internet or world wide web?

____Yes ____No

4. **Reactions to Computers and Study Approaches**

For each of the following statements, please circle the appropriate answer to express how strongly you agree with the statement.

I would like to know more about computers.

Strongly agree Agree Disagree Strongly disagree

I do not like the idea of learning about school subjects through computers.

Strongly agree Agree Disagree Strongly disagree

Being able to use a computer is an important skill in the modern world.

Strongly agree Agree Disagree Strongly disagree

I am eager to learn about new applications of computer technology.

Strongly agree Agree Disagree Strongly disagree

I am relaxed and content to spend the time learning how to use a new program.

Strongly agree Agree Disagree Strongly disagree

I like to read a book about a subject matter.

Strongly agree Agree Disagree Strongly disagree

I like to answer study questions found at the end of a chapter to assist me in mastering the subject matter of a textbook chapter.

Strongly agree Agree Disagree Strongly disagree

I like participating in small group sessions to assist me in mastering the subject matter for a course.

Strongly agree Agree Disagree Strongly disagree

I like tutoring as a way of learning about a subject matter.

Strongly agree Agree Disagree Strongly disagree

I like making class presentations as a way of learning about a subject matter.

Strongly agree Agree Disagree Strongly disagree

POST-SESSION ATTITUDE QUESTIONNAIRE

Please answer the following questions to provide us with an indication of how you liked the computer aided instruction package that you have just used.

1. **Reaction to the Computer Program**

   How useful were the instructions for using the program? Circle an answer:

   Very Good   Satisfactory   Poor   Not satisfactory

   How would you evaluate the Message Building Kits? Circle an answer:

   Very Good   Satisfactory   Poor   Not satisfactory

   How would you evaluate the Help aspect of the program? Circle an answer:

   Very Good   Satisfactory   Poor   Not satisfactory   Did NOT use the Help

   Over all how well did you like using the computer assisted learning package? Circle an answer:

   Very pleased   Pleased   Did not like it   Did not like it a lot

   While using the program did you ever feel that Jack might be a real person communicating with you electronically? Circle an answer:

   Often   Sometimes   Rarely   Never

2. **Study Guide**

   How would you evaluate the Printed Study Guide? Circle an answer:

   Very Good   Satisfactory   Poor   Not satisfactory

   How does the study guide compare with a general college textbook? Circle an answer:

   Very Similar   Similar   Not Similar

3. Tests

How well did the printed test questions evaluate your knowledge of photosynthesis? Circle an answer:

Very Well   Satisfactory   Poor   Not satisfactory

How similar is the printed test to a college level test? Circle an answer:

Very Similar   Similar   Not Similar

4. General Reactions to This Study Approach

For each of the following statements, please circle the appropriate answer to express how strongly you agree with the statement.

I am less afraid of computers after this experience.

Strongly agree   Agree   Disagree   Strongly disagree

I would like to know more about computers.

Strongly agree   Agree   Disagree   Strongly disagree

I do not like the idea of learning about school subjects through computers.

Strongly agree   Agree   Disagree   Strongly disagree

I would prefer to read a book about a subject matter.

Strongly agree   Agree   Disagree   Strongly disagree

I would prefer to answer study questions found at the end of a chapter rather than work with a computer program.

Strongly agree   Agree   Disagree   Strongly disagree

I liked the computer based tutoring as a way of learning about a subject matter.

Strongly agree   Agree   Disagree   Strongly disagree

I have learned a lot about photosynthesis through using this approach.

Strongly agree Agree Disagree Strongly disagree

Teaching someone else about a subject matter helps me learn about it.

Strongly agree Agree Disagree Strongly disagree

How likely is it that Jack is a real person communicating with you electronically.

Very likely Maybe Not likely Impossible

How satisfactory was this experience?

Circle an answer: Very Good Satisfactory Poor Unsatisfactory

5. **Please feel free to add any of your personal comments in the space below:**