HIGHER LEVEL APPROACHES TO KNOWLEDGE AND COMMERCIAL COMPUTER SIMULATIONS

by

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A thesis submitted in conformity with the requirements for the degree of Master of Arts
Department of Curriculum, Teaching and Learning
Ontario Institute for Studies in Education of the University of Toronto

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Abstract

An analytic matrix was created which adapted and merged Bereiter and Scardamalia's (1996) levels of approach to knowledge with concepts from Bloom's taxonomy (Krumme, 1998) and Egan's (1997) concept of understandings. This instrument was used to examine the discourse between students as they worked on a problem-based learning task using a commercial computer simulation for evidence of the presence of the eight levels of approach to knowledge postulated by Bereiter and Scardamalia in 1996. There was a particular focus on the higher levels of approach to knowledge, levels 4 ("knowledge viewed from different perspectives"), 5 ("knowledge as personal artifacts, and 6 ("knowledge as improvable personal artifacts"). In a study of 17 students from grades six to eight in three suburban schools, evidence was found that level 3 ("knowledge as representable") was necessary to group functioning and that level 4 was used consistently by these students. Evidence of levels 5 and 6 was also present, but less prominent than level 4.
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Introduction

Overview

Computer simulations have been much praised as learning tools, but little work has been done on the use of commercial computer simulations. This investigation examined the discourse between students as they worked on a problem-based learning task using a commercial computer simulation for evidence of the presence of the eight levels of approach to knowledge postulated by Bereiter and Scardamalia (1996). There was a particular focus on the higher levels of approach to knowledge (levels 4, 5, 6 and 7 respectively).

Purpose

It was the purpose of this investigation to examine the interactions between students, as they work with a commercial computer simulation game, to find the levels of approach to knowledge (Bereiter and Scardamalia, 1996) shown in such use, with a particular focus on higher levels of approach to knowledge.

Computer simulations (or microworlds in this case) are a new educational innovation that has been much heralded as the wave of the future (Papert, 1993), however much of the research in this area has focused on the use of either simulations the students have created themselves in microworlds such as Logo (Papert, 1993, Yarnall & Kafai, 1996), or on the use of limited simulations designed to illustrate one principle (such as momentum, etc.), or a limited number of such. In the former case, it has been noted that the students tended to focus on the programming aspect of the task, rather than the actual task itself, as in the study by Yarnall & Kafai (1996, on-line document) in which a science simulation was to be created. They noted
In our analyses of electronic interactions, it became clear that students made early decisions where to focus their discussions: initial attempts to discuss science content were redirected to focus on programming issues.

While this is very useful, if one is teaching computer programming, it is less useful if one is trying to teach something else (in this case, ecology).

In the latter case, the experiments are often designed by the authors of the software and the students perform these, much as they would in a laboratory, using the same virtual equipment as they would in vivo. Often, there is only a very limited capacity for the students to design and perform their own experiments. There has been considerable controversy regarding this approach, as Turkle (1997, on-line document) notes

The question of simulation is posed from preschool through the college years. Why should four-year-olds manipulate virtual magnets to pick up virtual pins? Why should seven-year-olds add virtual ballast to virtual ships? Why should fifteen-year-olds pour virtual chemicals into virtual beakers? Why should eighteen-year-olds do virtual experiments in virtual physics laboratories? The answer to these questions is often: because the simulations are less expensive; because there are not enough science teachers. But these answers beg a large question: Are we using computer technology not because it teaches best but because we have lost the political will to fund education adequately?
Obviously too, the same criticisms can be aimed at simulated experiments as at the traditional types of experiment performed in science classes. Papert (1993, p.139) comments

Traditional physics teaching is forced to overemphasize the quantitative by the accidents of a paper-and-pencil technology which favors work that can produce a definite "answer". This is reinforced by a teaching system of using "laboratories" where experiments are done to prove, disprove, and "discover" already known propositions. This makes it very difficult to constructively bring together intuitions and formal methods.

Actually, the question, "Why use simulations", can be partially answered with reference to aspects of the new curricula. In the current discussion, in Ontario, regarding the proposed new curriculum (Second deliverables, Secondary Science Grade 9 Curricula, on-line document, www.enoreo.on.ca/ecoo/test/curric/htm_docs/sci2nd.htm), we can find the following

By the end of Grade 9, students will:

- compile, interpret, and appropriately display data gathered through regular observations of the night sky to identify the motion of celestial objects (e.g. graph sunrise and sunset data and relate it to the motion of the earth); ...
- conduct investigations into how astronauts and scientists use a microgravity environment to further our understanding of crystals, fluids, combustion, medicine, materials science, and the composition of matter; ...

- design an extraterrestrial site to be colonized by humans (e.g. a space station, a moon station), explaining the underlying scientific and technological principles. ...

and (ibid, farther on)

- compile and analyze data from these investigations, and present the results and conclusions in oral, electronic (e.g. computer simulation, powerpoint slide show, video), or written form ...

These guidelines present some problems to the science teacher in that it is not always possible for students to make night observations (it is undesirable to have students out late at night in certain neighbourhoods and light pollution is a problem in cities), we can't provide a microgravity environment for experiments here on Earth and the construction of cardboard models (etc.) does not provide for a deep understanding of extraterrestrial conditions when designing space stations or extraterrestrial colonies. Commercial simulations (often designed to double as simulation games) can provide a solution here in that the students can design and perform their own experiments using the virtual environment, and can design and perform experiments in which the definitive answer is not known (as in the two scenarios chosen for this investigation). Visually attractive, and having a game-like interface, these are relatively new on the scene and less research has been focused on their pedagogical use. (A search of the ERIC database
reveals 443 papers about Logo, but only 7 papers about SimCity and 2 papers about SimEarth, the two commercial simulation programs used in this investigation).

In the case of these commercial simulation, the programming task has been largely taken over by the authors of the software and the students are free to focus on the actual scenarios (or experiments) they wish to create.

This study then, examined the discourse between students engaged in the use of a simulation for evidence of higher mental functions, as exemplified by the eight levels of approach to knowledge given by Bereiter and Scardamalia in 1996.
Overview (Levels of Approach to Knowledge)

Bereiter and Scardamalia proposed a set of eight levels of approach to knowledge in 1996. This was an attempt to find a schema for schools more suitable than the more familiar Bloom’s Taxonomy. The term approaches to knowledge was chosen because, “... there should be developmental changes in how students approach knowledge itself” (Bereiter and Scardamalia, 1996, on-line document), as students work on properly designed school tasks. These levels of approach to knowledge are reviewed and triangulated against two other schema, Bloom’s Taxonomy and Egan’s Types of Understanding. This results in the analytical matrix used to analyze the students’ discourse in this study.

Levels of Approach to Knowledge

The core of this entire investigation is the level of approach to knowledge shown by the students as they work with computer simulations. Bereiter and Scardamalia (1996) have proposed a set of eight levels of approach to knowledge.

LEVEL 0.
Knowledge as equivalent to "the way things are." Thoughts are distinguished from things, but thoughts about things are not distinguished from the way things are; hence, the possibility of false belief is not recognized.
LEVEL 1.
Knowledge as individuated mental states. Children realize that one person may know something that another does not. Thus, implicitly, there is some entity—a fact—which a person may or may not know.

LEVEL 2.
Knowledge as itemizable mental content. Children can relate things they know about a topic, and often delight in doing so. Thus, implicitly, knowledge consists of sortable items.

LEVEL 3.
Knowledge as representable. In trying to communicate what they know to a reader, students take into account what the reader already knows and is in a position to understand. Thus knowledge is no longer just something in the head to be expressed but is something to be represented, shared, interpreted by others.

LEVEL 4.
Knowledge as viewable from different perspectives. Students see that the same knowledge can appear in different contexts and can be viewed from different perspectives. This is an important step toward objectification.

LEVEL 5.
Knowledge as personal artifacts. Although constructivism is widely endorsed by teachers, it is not common for young students to view themselves as constructors of knowledge. Viewing oneself as constructing knowledge is a large step beyond viewing oneself as constructing knowledge representations (Level 3).

LEVEL 6.
Knowledge as improvable personal artifacts. A theory or other knowledge object is viewed in terms of what it can and cannot do, what its virtues are
and where it is in need of improvement, although still viewed as a personal possession.

**LEVEL 7.**
Knowledge as semi-autonomous artifacts. Students recognize that knowledge objects, like other constructed objects, can take on a life of their own and may be considered independently of their personal relevance. Thus, at this level, knowledge objects become things that one can relate to, use, manipulate, judge in various ways, and have feelings about—just like other things in the real world.

It will be considered, for the purposes of this study, that “higher levels of knowledge” begin at level 4, where the students begin to examine knowledge from alternate viewpoints.

Before we continue, it is necessary to clarify two concepts: (1) what do we mean by knowledge and (2) how will we recognize these higher level approaches to knowledge when we see them?

**The Nature of Knowledge**

The word knowledge proves to be elusive. While most people would be able to give a reply to the question, “What is knowledge”, it would be found, on close questioning, that a group of people would be apt to give a set of different definitions. Even among persons who study knowledge for a living, it is rare to get two definitions the same. It has even been suggested that education should be founded on the concept of the types of understanding (Egan, 1997), which in turn suggests that the concept of understanding can
be separated from the concept of knowledge. These variances in definition have profound implications because it gives rise to such educational philosophies as Constructivism, and Multiple Intelligences (Gardner, 1993), and to the current debate between “cognitive” vs. “situative” knowledge (J. Hewitt, personal communication, Mon, 04 Jan 1999). It would be a brave person indeed who would try to resolve such a complex controversy, and I am not that person, but in order to analyze the results obtained here, it has been necessary to arrive at an operational conception of knowledge.

In order to see where this operational conception comes from, let us try a simple thought experiment. We are in a classroom with a child who has never been exposed to reading or writing. We write a large letter "A" as a block capital on the chalkboard. We say to the child, "This is the letter A". We then point to the letter and ask the child what it is. The child replies, "That is the letter A". Well and good. The child has apparently learned something. However, on closer questioning, we find that this is all the child knows about it. The child can recognize the letter A, the child can tell everyone he/she knows that this is the letter A, but would be at a loss to explain why they should know such a thing, how the letter A might be used and, in fact, what a letter is at all. The child has an item of decontextualized information, a fact, which is unconnected to other facts and information in the child's world. In other words, the child cannot use the information given. If we were then to introduce the child to the idea that sounds can be represented by symbols, that words are made up of such sounds and can be represented by the symbols for them and give the child some experience in reading and writing, the child would begin to be able to use the knowledge gained in meaningful ways.

If we were to now continue our thought experiment and ask a linguist (highly educated) what the letter A is, we would get a very complex answer, possibly including
the word phoneme, and references to brain structures affected by alphabetic literacy vs. pictographic literacy as in the two quotes from Egan (1997) below

... the particular graphic script people use serves as a model for how they think about language. (p. 75)

The alphabet, for example, ensures that we hear our speech as made up of elements that can be broken into phonemic segments. ... Chinese readers of traditional characters do not detect such phonemic segments, but Chinese readers of the alphabetic Pinyin script do ... (p. 75)

These, of course, show a greater level of complexity of processing of knowledge than that of our naive child in the first part of the experiment, as the expert has a richer, more interconnected knowledge-base to draw upon, and also has more experience with high-level thinking skills. This implies knowledge can be processed in different ways, from straight information (simple declarative knowledge at recognition level) to progressively more complex, objective, and abstract thinking (including operations such as comprehension, analysis, synthesis, etc.).

This, obviously, does not answer, nor does it attempt to answer, all cases. Omitted here are considerations of knowledge as a social process, individual versus group knowledge, virtual knowledge, etc. A good discussion of these can be found in Audi (1998, p. 250 et seq.). For present purposes, however, it is possible to regard the levels of approach to knowledge as being signposts as to the relative level of abstraction (and therefore, complexity of processing) at which the students are working.
Identification of the Levels of Approach to Knowledge

Having arrived at an operational conception of knowledge, we can now proceed to try to find ways of identifying the levels of approach to knowledge when we see them.

The work done by Bereiter and Scardamalia on the levels of approach to knowledge has been largely based on written material gleaned from the Computer Supported Intentional Learning Environment (CSILE) databases. This presents a problem in light of the current analysis as there is a significant difference in the manner in which the levels of approach to knowledge might be shown in written form in a classroom setting, and in spoken discourse in the throes of working through a computer simulation program. For example, the example of a level 6 (knowledge as improvable personal artifacts) entry (Bereiter and Scardamalia, 1996, on-line document) into the database contains the following excerpt:

Actually, we don't really agree with the speaker on some of the things. He said that the roots weren't very deep. And I figured this didn't make sense because so what if roots aren't deep? Because if the roots are very shallow in the rain forest because there's not any nutrients deep down in the rain forest. So there's not many roots. And then I asked several tundra people.

We kind of think that he's partially right but we don't understand why that would be true. We believe in that there isn't much water there, but we don't understand why it's for the tree, because obviously the tree needs water to grow. But there's not much water in the desert.
This example obviously took some time to formulate and has been thoughtfully presented. It is unlikely that students talking to each while manipulating a computer program would present quite the same aspect, but might nonetheless be functioning at the same level. As a result of problems like this, it was necessary to look at other schemes to classify knowledge for other identifiers as to what level of approach we might identify in the students' work. I was chiefly informed in this by Bloom's Taxonomy (Krumme, 1998) and Egan's (1997) types/levels of understanding, and these were used to triangulate any assignment of text units to a particular level.

Bloom's Taxonomy is a scheme of long standing and will be familiar to most readers. I have prepared a chart (Table 1 below), based on Krumme's (ibid) material, to summarize Bloom's ideas.
As can be seen, Bloom's scheme goes from basic to evaluation, a much higher and more sophisticated level. This is useful partly because it contains a list of specific actions to indicate higher levels of approach to knowledge, a list not found in Bereiter and Scardamalia's scheme.

### Table 1: Bloom's Taxonomy

<table>
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<tr>
<th>Bloom's Taxonomy</th>
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<tbody>
<tr>
<td><strong>Knowledge:</strong></td>
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<tr>
<td>Knowledge is (here) defined as the remembering of previously learned materials. Recalling appropriate information. - defines; enumerates; identifies; labels; lists; matches; names; reads; reproduces; restates; selects; states; views</td>
</tr>
<tr>
<td><strong>Comprehension:</strong></td>
</tr>
<tr>
<td>Grasping the meaning of material. - classifies; cites; converts; describes; discusses; estimates; explains; generalizes; gives examples; paraphrases; summarizes; understands</td>
</tr>
<tr>
<td><strong>Application:</strong></td>
</tr>
<tr>
<td>The use of learned material in new and concrete situations. - acts; administers; articulates; assesses; charts; collects; computes; constructs; contributes; controls; determines; develops; discovers; establishes; extends; implements; includes; informs; instructs; operationalizes; participates; predicts; prepares; preserves; produces; projects; provides; records; relates; reports; shows; solves; takes; teaches; transfers; uses; utilizes</td>
</tr>
<tr>
<td><strong>Analysis:</strong></td>
</tr>
<tr>
<td>The breaking down of material into its component parts so that its organizational structure may be understood. - breaks down; correlates; diagrams; differentiates; discriminates; distinguishes; focuses; illustrates; infers; limits; outlines; points out; prioritizes; recognizes; separates; subdivides</td>
</tr>
<tr>
<td><strong>Synthesis:</strong></td>
</tr>
<tr>
<td>Putting parts together to form a whole. - adapts; anticipates; categorizes; collaborates; combines; communicates; compares; compiles; composes; contracts; contrasts; creates; designs; devises; expresses; facilitates; formulates; generates; incorporates; individualizes; initiates; integrates; intervenes; models; modifies; negotiates; plans; progresses; rearranges; reconstructs; reinforces; reorganizes; revises; structures; substitutes; validates</td>
</tr>
<tr>
<td><strong>Evaluation:</strong></td>
</tr>
<tr>
<td>Judging the value of material for a given purpose. - appraises; concludes; confronts; criticizes; critiques; decides; defends; interprets; judges; justifies; reframes; translates</td>
</tr>
</tbody>
</table>
The second major source used to triangulate the levels of approach to knowledge is the concept of different types of understandings as indicators as to the level of approach to knowledge the student is taking as enunciated by Egan (1997). As this scheme is probably less familiar (being newer), I will spend a little more time on it.

Egan's central thesis is that the emphasis on knowledge in the educational system presents us with many problems which can be solved by looking, instead, at the kind of understanding we wish the student to achieve and proceeding from there. He states (p. 25)

By displacing "knowledge" with the category of "kind of understanding", we will not be throwing knowledge overboard. The development of the various kinds of understanding requires particular kinds of knowledge. This new category also provides criteria for determining depth and breadth of knowledge ... the knowledge that is of most worth will vary during the course of the individual's education and may be determined be the kind of understanding most actively being stimulated and developed.

This seems to me to be in some ways similar to Bereiter and Scardamalia's contention that we need to look at how students approach knowledge, rather than the specifics of the knowledge itself. They state (1996, on-line document)

Constructivist thinking convinces us that students need to be more than willing workers. They should be agents, but what are they to be agents of? Surely, the answer for a three-year-old cannot be quite the same as the answer for a thirteen-year-old, but what is supposed to change? Taking a cue from the history of
knowledge, we can speculate that there should be developmental changes in how students approach knowledge itself.

The developmental changes of which they speak are in many ways similar to the kinds of understanding spoken of by Egan and thus Egan's (1997) categories of kinds of understanding have been included in this study. These are summarized in Table 2 below.

Table 2: Egan's Understandings

<table>
<thead>
<tr>
<th>Egan's Kinds of Understanding</th>
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</thead>
<tbody>
<tr>
<td><strong>Somatic</strong></td>
<td>This is the earliest level of understanding and is based on body sense.</td>
</tr>
<tr>
<td><strong>Mythic</strong></td>
<td>Based on the understanding of binary opposites, as in good vs. evil in a fairy tale.</td>
</tr>
</tbody>
</table>
| **Romantic**                 | "A characteristic of Romantic understanding, then, is its ready association with the transcendent human qualities, or human qualities exercised to transcendent degree." (Egan, p. 90)  
"Romantic understanding, then, is a somewhat distinctive kind of understanding supported by an alphabetic literacy bent to the development of rationality. Central to Romantic understanding is a sense of an autonomous self and a relatedly autonomous reality." (Egan, p. 100) |
| **Philosophic**              | "This Philosophic layer is shaped by an even more diffuse "tool", or "mediational means"; it requires not only a sophisticated language and literacy but also a particular kind of communication that in turn requires particular kinds of communities or institutions to support and sustain it. The central feature of Philosophic understanding is systematic theoretic thinking and an insistent belief that Truth can only be expressed in its terms." (Egan, pp. 104-105) |
| **Ironic**                   | Ironic understandings are extremely detached, and result from the knowledge that all models ultimately fail. |

Implied by Egan's scheme (and therefore represented in that manner in Table 2) is the idea that these levels of understanding are hierarchical — that the higher levels of
understanding cannot be approached without some exposure to the other levels. For example, while Mythic understanding is a product of the development of spoken language, Romantic understanding is a product of literacy, with all of the special structures, social and physical, necessary to sustain this. Indeed, he quotes a fascinating example from Luria to show this (Egan, pp. 74-75). Luria posed this problem to a group of illiterate villagers.

In the far north, where there is snow, all bears are white. Novaya Zemlya is in the far north. What colour are the bears there?

The villagers were unable to answer and suggested that he (Luria) go there and find out for himself if he really wanted to know. It appears that deductive logic of this kind is a product of the kind of decontextualized thinking that is characteristic of literacy. Thus, although each kind of understanding continues to exist after the others have been mastered, the higher levels cannot be reached without exposure to the lower ones.

For the purposes of this study then, if an exchange were to appear to be level 5, but was obviously based on a Mythic kind of understanding (binary opposites), it would be classified as a lower level.

Having found other appropriate schema to augment and triangulate the scheme proposed by Bereiter and Scardamalia, it was necessary to map these onto Bereiter's and Scardamalia's scheme. This involved examining the three schemes involved and trying to find useful correspondences. First, Bloom's scheme was examined in light of the Bereiter and Scardamalia scheme.

If we examine Bereiter's and Scardamalia's levels 0 and 1, we can readily see that these are the approaches to knowledge shown by very young children, as the identifiers for
the levels are, for level 0, no possibility of false belief and for level 1, that the student may know a fact that others do not know. These levels are lower than any stages found in Bloom, and it was, in fact, unlikely that any examples at levels 0 or 1 would be found in students of the ages of those participating in the study.

Level 2 involves knowledge as itemizable mental content. Bloom (Krumme, 1998) gives as his knowledge level, "Knowledge is (here) defined as the remembering of previously learned materials". The identifiers given all involve itemizable mental content and include identifiers such as restating items, listing items and so forth. These then would seem to be useful as identifiers for level 2 behaviours, and have been included in the analysis.

Level 3 involves knowledge as representable -- something the student could express to, and be understood by, others. Cognitively, this would involve the student being able to put themselves in the place of another student and to make an estimate of what they might know and understand, then to find some way or representing the desired information in light of this estimate (as is often the case in answering a question). The portion of Bloom's taxonomy which best seems to map onto this is the comprehension category. Among the behaviours included in this category are explaining, giving examples, summarizing, demonstrating understanding and discussing. This would be the level at which many exchanges would operate as students discuss and socially negotiate various options. It was expected that this category would be one of the largest in the study.

Level 4 involves the student viewing knowledge from different perspectives. This is a critical level because it involves considerable objectification of the problem. The student has to realize that there is more than one way to view a particular problem and that the final solution may depend on which perspective the student decides is the most
important. Here, Bloom has two categories which appear to map well: application and analysis. Application was chosen because it includes such identifiers as charting, developing, reporting, solving, teaching, and transferring. To use charting as an example, a student must restructure information, thereby viewing it from a different perspective. For analysis purposes, I have included the act of interpreting a chart, diagram or graph as part of this identifier. The other identifiers in this category seem likewise to lend themselves to indicating that students have formed a different perspective on the material.

Bloom's analysis category was also chosen for inclusion in level 4. This includes identifiers such as breaking down information, diagramming, inferring, prioritizing, separating and subdividing. If a student breaks down complex information into its parts, draws a diagram, prioritizes, etc., then I would argue that they have truly viewed the problem from differing perspectives. Level 4 was also expected to be an important category in this analysis.

Two of the identifiers included in level 4 by this analysis were troubling: acting and diagramming. Since we are studying the students as they interact with a computer program, the students act every time they move about on the screen or add an icon. This can be done with no real thought. Likewise, since the information in the simulation programs was often presented in the form of a diagram which the students could alter by adding icons, and this could be interpreted as making a diagram. This would leave us with identifying almost all exchanges as level 4, which would not be valid. Therefore, simple action or diagramming were not sufficient to be included in this category. To included in level 4, an action had to be the result of a thoughtful analysis, while routine actions were placed in level 3. Likewise, merely adding an icon to the simulation would be placed in a lower level. To be included in level 4, the student had to thoughtfully interpret the display or graph, chart, etc. presented, or alter the diagram as a result of an analysis.
Level 5 was one of the more difficult levels to identify, as it involves students viewing themselves as constructors of knowledge. Unless the student were aware of Constructivist educational theory, they are unlikely to express that they are constructing knowledge. Bloom's category of synthesis was of great help here, and includes identifiers such as adapting a concept, collaborating, combining ideas, designing, planning and rearranging. A key idea, implied by the concept of constructing knowledge and synthesis is the idea of theorizing, and theorizing was included as an identifier for this level. Again, as with level 4, the identifiers had to be applied with thought. For example, since the students were working in groups, collaboration was always present, but to be included in level 5, it had to be a collaboration that led to theorizing or some other synthesis of ideas.

Level 6 involves further objectification of the knowledge and applied critical judgment of the knowledge in terms of what it can and cannot do. Here, Bloom's evaluation category seems to apply. Identifiers include appraising, concluding, criticizing, defending, interpreting, etc. Again, thoughtful application of the categories was required. In looking at a student's criticism of an idea, criticism by itself was not enough. The student had to criticize and give reasons, apply an alternate theory or indicate the knowledge as improvable in some aspect in order to be included as a level 6 exchange. This represent the highest level of Bloom's taxonomy. It was necessary to look elsewhere for identifiers for level 7 and the triangulation of level 7 is discussed below.

Egan's (1997) concept of understandings as the basis of education was also mapped onto Bereiter's and Scardamalia's levels of approach to knowledge. Level 0 was mapped onto somatic understanding, as this is the first level of understanding and is the preverbal level. Level 2 was mapped onto both the somatic and mythic understandings. (Each level is retained as others are added as these levels of understanding continue to CO-
exist). Mythic understanding, is a product of verbal cognition and deals with binary opposites such as good and bad. A student saying, "Something bad just happened" is responding at a Mythic level. Level 3 adds romantic understanding (a product of literate cognition) to the others. Levels 4 and 5 would add philosophic understanding to the others. Philosophic understanding is a product of specialized literate communications Logical and deductive reasoning (consonant with the Luria example given earlier) would be associated with this level of understanding. Finally, levels 6 and 7 would both add ironic understanding. This was particularly important in trying to identify any level 7 exchanges, as there was nothing in Bloom to assist here.

Level 7 then, involves the consideration of knowledge objects independently of their personal relevance. In ironic understanding, the student is aware that all models ultimately fail and that the knowledge object can be manipulated and judged in various ways, according to the needs of the moment. It was thought unlikely that level 7 exchanges would be encountered.

When completed, these mappings were put in the form of an analytic matrix (Table 3) and this was used as the primary analysis tool for the study.
## Table 3: Analytic Matrix for Levels of Approach to Knowledge

<table>
<thead>
<tr>
<th>Level of Approach to Knowledge</th>
<th>Analytical Understanding</th>
<th>Identifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 0</strong></td>
<td>Somatic</td>
<td>No possibility of false belief.</td>
</tr>
<tr>
<td>Knowledge as equivalent to &quot;the way things are&quot;</td>
<td>Highest level is a product of pre-verbal cognition</td>
<td></td>
</tr>
<tr>
<td><strong>Level 1</strong></td>
<td>Somatic/Mythic</td>
<td>The student recognizes that he/she may know a fact others do not know.</td>
</tr>
<tr>
<td>Knowledge as an individualized mental state</td>
<td>Highest level is a product of verbal cognition</td>
<td></td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Somatic/Mythic</td>
<td>The student defines; enumerates; identifies; labels; lists; matches; names; reproduces; restates; selects; states; views</td>
</tr>
<tr>
<td>Knowledge as termizable mental content</td>
<td>Highest level is a product of verbal cognition</td>
<td></td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>Somatic/Mythic/Romantic</td>
<td>The student classifies; cites; converts; describes; discusses; estimates; explains; generalizes; gives examples; paraphrases; summarizes; understands</td>
</tr>
<tr>
<td>Knowledge as repressentable and capable of being expressed to, and interpreted by, others</td>
<td>Highest level is a product of literate cognition</td>
<td></td>
</tr>
<tr>
<td><strong>Level 4</strong></td>
<td>Somatic/Mythic/Romantic/Philosophic</td>
<td>Characterized by: Application: The student acts; administers; articulates; assesses; charts; collects; computes; constructs; contributes; controls; determines; develops; discovers; establishes; extends; implements; includes; informs; instructs; operationalizes; participates; predicts; preserves; produces; projects; provides; records; relates; reports; shows; solves; takes; teaches; transfers; uses; utilizes ... and ... Analysis: The student breaks down; correlates; diagrams; differentiates; discriminates; distinguishes; focuses; illustrates; infers; limits; outlines; points out; prioritizes; recognizes; separates; subdivides</td>
</tr>
<tr>
<td>Knowledge as viewable from different perspectives</td>
<td>Highest level is a product of specialized literate communications forms. Graphing, etc. would be an example</td>
<td></td>
</tr>
<tr>
<td><strong>Level 5</strong></td>
<td>Somatic/Mythic/Romantic/Philosophic</td>
<td>Students view themselves as constructors of knowledge. Characterized by: Synthesis: The student theorizes; adapts; anticipates; categorizes; collaborates; combines; communicates; compares; compiles; composes; constructs; contracts; creates; designs; devises; expresses; facilitates; formulates; generates; incorporates; individualizes; initiates; integrates; intervenes; models; modifies; negotiates; plans; progresses; rearranges; reconstructs; redefines; reorganizes; revises; structures; substitutes; validates</td>
</tr>
<tr>
<td>Knowledge as personal artifacts</td>
<td>Highest level is a product of specialized literate communications forms.</td>
<td></td>
</tr>
<tr>
<td><strong>Level 6</strong></td>
<td>Somatic/Mythic/Romantic/Philosophic/Ironic</td>
<td>Knowledge objects judged in terms of what they can and cannot do, still viewed as personal artifacts. Characterized by: Judging and evaluation of material for a given purpose. The student appraises; concludes; confronts; criticizes; critiques; decides; defends; interprets; judges; justifies; reframes; translates</td>
</tr>
<tr>
<td>Knowledge as improvable personal artifacts</td>
<td>Highest level is produced by the realization that all models ultimately fail.</td>
<td></td>
</tr>
<tr>
<td><strong>Level 7</strong></td>
<td>Somatic/Mythic/Romantic/Philosophic/Ironic</td>
<td>Consideration of knowledge objects independently of their personal relevance. The student uses, manipulates and judges in various ways (consonant with ironic understanding), can relate to, and have feelings about, the knowledge object.</td>
</tr>
<tr>
<td>Knowledge as semi-autonomous artifacts</td>
<td>Highest level is produced by the realization that all models ultimately fail.</td>
<td></td>
</tr>
</tbody>
</table>
"Any teacher who can be replaced by a machine - should be!"

(Clarke, 1984, p. 69)

"... even when mental action is carried out by individuals in isolation, it is inherently social in certain respects and it is almost always carried out with the help of tools such as computers, language, or number systems."

(Wertsch, 1991, p.15)

"As has been pointed out, all artifacts - both material and symbolic - are embodiments of the knowing that was involved in their production (Wartafsky, 1979) and can thus, in appropriate circumstances, make that knowing available to others ..."

(Wells, 1997)

The Simulations

Overview

Overviews of both the rational for use and of the workings of the two commercial simulation games used in this investigation are given. Descriptions of the programs and figures from the various screens (significant to the students in solving the problem-based task) are given.

The Simulation Games/Programs

Two commercial simulation programs were used in this investigation, SimEarth and SimCity Classic, both from Maxis software (www.maxis.com). These simulations have many of the attributes of a microworld as described by Rieber (1996, on-line document)

A microworld is a small, but complete, version of some domain of interest. People do not merely study a domain in a microworld, they "live" the domain, similar to the idea that the best way to learn Spanish is to go and live in Spain. Microworlds can be naturally found in the world or artificially constructed (or induced). A child's sandbox is a classic example of a natural microworld. Given buckets and shovels, the sandbox becomes
a "volume and density microworld" for the child. In contrast, artificial microworlds model some system or domain for the user.

The Logo microworld described by Papert (1993), perhaps the best known of these, is designed so that the student must program all content that appears on the screen, using a special language designed for the task. He (ibid, p.5) goes on to describe why it is of advantage for a student to work with such a microworld

In my vision, the child programs the computer and ... establishes an intimate contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model building.

However, some studies have revealed that the act of programming can interfere with the learning of other content.

The simulation games used in this investigation, however, these are less open-ended than Logo, and have a considerable amount of pre-programming aimed at specific theoretical ideas incorporated in their design by their authors. An advantage of this is that it removes many of the basic programming tasks from the student and leaves the student free to concentrate on the particular experiment they have devised or scenario upon which they are working. The programming done by the student is in the form of the placement of icons, which have a behaviour or behaviours associated with them, on a concept map of the microworld involved. As the student places the icons, these behave according to the theoretical rules programmed into them by the authors. Therein lies both the strength and the weakness of using such simulations in the classrooms. Because the rules are programmed in by the authors, we lose control of the content and may not know the
assumptions upon which the simulation is based. Sherry Turkle (1997, on-line document) notes

Simulations enable us to abdicate authority to the simulation; they give us permission to accept the opacity of the model that plays itself out on our screens.

and Teague and Teague (1995, p. 22) state, regarding SimCity,

Several pitfalls with this computer simulation were experienced. Some students developed an overly simplified sense of reality with regard to factors such as population, crime, pollution, and taxation. The solutions ... brought adequate responses from the computer, but did not mirror the complexity of the actual program's possible consequences.

While these are valid concerns, they do not preclude the use of these programs in classrooms. Regarding SimCity, it has been noted by several authors (Teague and Teague, 1995, Kolson, 1994, Turkle, 1997) that, although the simulations are flawed, their use is nonetheless recommended. Quoting Paul Starr, Turkle (ibid, on-line document) states

... this very abdication of authority (and acceptance of opacity) corresponds to the way simulations are sometimes used in the real worlds of politics, economics, and social planning. Perhaps screen simulations on our personal computers can be a form of consciousness-raising. Starr makes it clear that while it is easy to criticize such games as SimCity and SimHealth for their hidden assumptions, we tolerate opaque simulations in other spheres. Social policymakers regularly deal with complex systems that they
seek to understand through computer models that are used as the basis for actions. Policymaking, says Starr, "inevitably relies on imperfect models and simplifying assumptions that the media, the public, and even policymakers themselves generally don't understand." He adds, writing about Washington and the power of the Congressional Budget Office, America's "official simulator," "We shall be working and thinking in SimCity for a long time." So, simulation games are not just objects for thinking about the real world but also cause us to reflect on how the real world has itself become a simulation game.

The reason why, even though flawed, these simulation games are recommended by various authors may be found in the nature of computer simulations themselves. Neelamkavil (1987, p. 1), tells us

A given problem defined by a mathematical/logical model can have a feasible solution, satisfactory solution, optimum solution or no solution at all. Computer modeling and simulation studies are primarily directed towards finding satisfactory solutions to practical problems.

This, then would appear to be part of the answer: we are able to deal with problems in a satisfactory way when we use simulation programs like SimCity and SimEarth.

Another part of the answer can be found in the many authorities (Kay, 1995, Mestel, 1995 and 1996, Clarke, 1984, among others) who find that learning with simulations is, indeed, a new and better way to learn. Kay (1995, p 148) perhaps expresses this best,
Computers can go beyond static representations that can at best argue; they can portray and test conflicting theories. The ability to "see" with these stronger representations of the world will be as important an advance as was the transition to language, mathematics and science from images and common sense.

There is perhaps, some hyperbole here, but teachers find (Teague and Teague, 1995, p.22)

Two characteristics -- realism and relevance -- seem to separate simulations from outright games and make their use an excellent teaching and learning activity.

Since SimCity is the best-documented of the two simulations, I shall start with it.

**SimCity Classic**

Neelamkavil (1987, p.1) noted that simulations are oriented towards providing satisfactory solutions to practical problems. Many authors have been looking for a simulation that will answer all cases of particular classes of urban problems, and have therefore been disappointed with SimCity Classic. Kolson (1994) gives an extensive analysis of the flaws in SimCity, among them (my paraphrase),

- The Sims behave in too rational a fashion. We do not see the Sims (citizens of SimCity) ever responding other than rationally to a situation. In real urban situations, he notes that citizens may respond emotionally.

- Opposition to the city government does not exist, except where the government has made decisions that rational citizens would find unpopular. Certainly, there is no organized opposition.
City government has more power than any real government, especially with regard to expropriating private property.

And, as noted above, there are other oversimplifications to be found in the program which can lead students a bit astray. Of course, these same authors do find that SimCity has a place in the classroom, and I would argue that these more simplistic assumptions make the program all the more appropriate for students in elementary and secondary schools than a more complex simulation would be. (It should also be noted that many of the problems identified in SimCity Classic have been corrected in SimCity 2000).

Since the flaws in the program have been so well documented, I would like to focus here on the advantages of using SimCity. Among the advantages to be found in the simulation are the many and various metacognitive supports which are built in and take the form of concept maps. Two comments, one by Jegede et al, (in Johnston, 1995, on-line document)

The heuristic of concept mapping - a kind of metacognitive strategy - assists learners in understanding concepts and relationships between them, in seeing the hierarchical, conceptual, propositional nature of knowledge.

and one by Novak (1996, on-line document)

Concept maps ... are valuable tools that help students "unpack" the knowledge in text, laboratory or lectures, and they are powerful tools for curriculum designs. These metacognitive tools show promise not only for the improvement of learners, but also for the empowerment of teachers and curriculum planners.
both indicate the importance of such metacognitive supports in teaching and learning. Thus their presence in commercial simulation games is of great significance, but has been largely overlooked by educational critics of the program.

There might be some disagreement about the value of the map of the city as a learning tool, and as a concept map, but I would argue as follows. Knowledge can be represented in various ways. A city, for example, can be described in words, in drawings, photographs, sound recordings, video recordings or as a map. In the simulation program SimCity, the city is represented as a map with a series of stereotypical icons representing various features common to many cities. Thus, there are symbols for roads, for electric power lines, for water sources, for vegetation, for elevation, for trains, etc. I would argue that each time a student, working with such a simulation, places an icon on the map of the city, there are several things happening at once. First, the student is completing a thought of the form, "I think that the city should have this item here, at this spot on the map". Second, the student is making an experiment, in the form, "I will try this thing in this spot and see what happens". Third, the student creates a concept map of their current state of knowledge about cities, using the knowledge embedded in the program to assist him/her. This last corresponds to level 5 in the eight levels of approach to knowledge given by Bereiter and Scardamalia (1996), as the city is viewed as personal ("my city") or level 6 (the city is improvable). Thus, the city map can be viewed as a knowledge object.

This has implications which relate to the psychology of learning. Many current theories of learning rely heavily on the work of Vygotsky, a Russian psychologist active in the first half of this century, whose work has only lately become available in the West. There are two of his ideas in particular that are relevant to the above. First, the idea that the act of placing an icon on the city map completes a thought. Vygotsky was of the opinion
that a thought was not complete unless expressed in words, and this has been expanded in recent years. Wells (1997) states,

In his exposition of the concept of psychological tools, Vygotsky himself made clear that the means of semiotic mediation are not limited to speech. He also included: "various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps and mechanical drawings; all sorts of conventional signs; and so on (1981, p. 137). To these, we might also wish to add the various modes of artistic expression, such as dance, drama and musical performance. All these modes of representation are simultaneously means of communication and tools for thinking with, both when with others and when alone."

Secondly, the program relates to the concept of the zone of proximal development (zpd), defined as "... the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." (Vygotsky et al, p. 86). In this case, the guidance is provided by the programming team and embedded in the program itself. Central to the concept of the zpd is the idea that learning must lead development. Vygotsky says, "Thus, the zone of proximal development enables us to propound a new formula, namely that the only "good learning" is that which is in advance of development." (Ibid., p. 89). Since the programming team is considerably more knowledgeable about cities than any children or most adults, the program is designed to be in advance of their development in this area. One possible interpretation of the zpd concept is that the program fulfills the definition of "adult
guidance" (above) and is suited for learning in the zone of proximal development. As noted by Sanagavarapu et al. (1994, p. 2)

The role of adult interaction on children's metacognitive development has been illustrated in several micro-genetic analyses of the teaching-learning interaction (Gauvian & Rogoff, 1989; Moss, 1990; Paris, Newman, Jacobs, 1985). Various studies exemplified the fact that dyadic interaction structured by adults, provides the social or cultural guidance necessary for the development of metacognitive abilities.

The Workings of the Program

When the student begins to work with the simulation, he/she is presented with a map of a landscape, showing topographical features such as rivers and mountains. This can be random, or (as was done by Findley, 1996) it can be a re-creation of the terrain of an existing city.

The student then proceeds to work on the simulation by placing icons representing various structures commonly found in cities on the map in the places of their choice. There are icons to represent various kinds of buildings (fire departments, churches, residential and commercial, etc.) and services (roads, bridges, etc.). Since each icon has a behaviour associated with it, the student can immediately begin to see changes in their city as a result of the presence of the new icon(s) (unless the simulation is paused). The student does not need to remember what has gone where and how it is doing -- it is right in front of them, easily seen. The student may have trouble interpreting what they see, so a number of other metacognitive supports are provided. Figures 1 and 2 show some of these.
Figure 1: City Evaluation Window

<table>
<thead>
<tr>
<th>PUBLIC OPINION</th>
<th>STATISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the mayor doing a good job?</td>
<td>Population - 34980</td>
</tr>
<tr>
<td>43% Yes</td>
<td>Net Migration -27440</td>
</tr>
<tr>
<td>57% No</td>
<td>(last year)</td>
</tr>
<tr>
<td>What are the worst problems?</td>
<td>Assessed Value - $31020000</td>
</tr>
<tr>
<td>12% TAXES</td>
<td>Category: CITY</td>
</tr>
<tr>
<td>10% POLLUTION</td>
<td>Game Level: Easy</td>
</tr>
<tr>
<td>10% HOUSING COSTS</td>
<td>Overall City Score</td>
</tr>
<tr>
<td>8% TRAFFIC</td>
<td>(0 - 1000)</td>
</tr>
<tr>
<td></td>
<td>current score 430</td>
</tr>
<tr>
<td></td>
<td>annual change -70</td>
</tr>
</tbody>
</table>

Figure 2: Graph Window
Figure 2 (above) is of particular interest. This window allows the students to virtually instantly draw graphs of the various factors shown at the tool bar at the left of the window (finances, as shown by a "$" icon, crime, as shown by a gun and knife, etc.) over time, and more than one factor can be shown at the same time. In Figure 2, we can see the crime rate (lower curve) plotted against spending (upper curve). The interpretation of such graphs is important in light of the current study in that the examination of such graphs represents an alternate perspective on the problem of creating a city, which would correspond to level 4 in the levels of approach to knowledge (Bereiter and Scardamalia, 1996, on-line document), and can assist in the synthesis of ideas to create theories about interrelationships between factors in the simulation (a level 5 approach to knowledge). The evaluation window (Figure 1) functions in a similar manner.
In this sequence of figures, abstracted from a video clip of a working session with SimCity, the students are trying to see if their seaport is functional, and look for evidence
of a ship arriving or leaving. Figure 3 shows them working in the Edit window, examining their tax status. In figure 4, they decide to move to the Map window (another perspective), and a student points to the icon which would open this window. The second student agrees and in the figure 5, the students have opened the Map window and are examining it for the presence of ships (indicated by a letter "S", not visible at this resolution). This demonstrates that the students do indeed take a different perspective when they make use of these alternate displays.

**SimEarth**

The SimEarth simulation is based on James Lovelock's Gaia hypothesis, and the behaviour of the icons is consistent with that hypothesis. This hypothesis can be briefly described (Hunt, 1998, on-line document) as

... the theory that Earth acts like a superorganism, with all its biological and physical systems cooperating to keep it healthy.

In terms of the simulation then, if flower icons are placed, they increase atmospheric oxygen levels and decrease atmospheric carbon dioxide levels according to the average amounts we see for those kinds of plants in those numbers, animal icons decrease atmospheric oxygen and increase atmospheric carbon dioxide similarly and they have other effects (such as the reflection or absorption of sunlight) based on the predictions of the Gaia hypothesis. The Gaia hypothesis, which has a firm mathematical foundation, is not without its detractors, as noted by Lovelock (in Hunt, ibid, on-line document)
"The DMS paper went down very well," says Lovelock, "but biologists were not satisfied. They opposed Gaia because they could not see how organisms had evolved to behave in a way that regulates the planet."

This can, in fact, enhance the use of the program, as there is considerable information regarding the Gaia hypothesis available to students (particularly on the Internet). As a result, the assumptions upon which the program rests are not totally opaque to the teacher and are readily available for discussion with regard to the simulation: in fact, these are less opaque than the assumptions embedded in SimCity Classic. In addition, SimEarth comes with an excellent on-line manual which explains the assumptions and provides an introduction to the Gaia hypothesis (by Lovelock himself) and to Earth Sciences in general. (Oddly enough, there was no similar manual for SimCity Classic).
The Workings of SimEarth

Figure 6: Startup options available to students.

In this study, students chose (from among other options, see figure 6) to work on the Mars simulation, which is automatically in the "Experimental" mode. This choice was encouraged because of the motivational aspect of work on Mars at this time (NASA, the European space agency and the Russians are sending a new probe to Mars about once every six months at present, and this receives a lot of press coverage, of which most students are aware).

When the simulation opens and the Mars simulation has been chosen, the student is presented with an accurate map of the Martian surface (see figure 7 below), however, in rectangular form. The same map can be projected in the form of a globe, the more usual view for astronomers, but harder to work with in a simulation. In this respect, and in
respect to the metacognitive supports given the students, the program is very similar to SimCity Classic, and similar arguments supporting their use and effect on student performance can be advanced -- I will not repeat them.

Figure 7: Terrain Map

As can be seen, the topography is shown, with higher areas being indicated by lighter colours and lower areas being indicated by darker colours. No other icons are present at this time. Various controls are present to alter the display to show water and temperature, or to not show these, as the student chooses.

As well, and of great significance to this study, there are menu items (the menu bar is standard and not shown) which allow the student to see graphs of the history of the microworld, including rainfall amounts, atmospheric gases (see figure 8 below), and
windows showing the general state of the "health" of the planet (the Gaia window, figure 9), and the content of the atmosphere at a particular moment (figure 10).

**Figure 8: History Window (Graph showing Levels of CO₂, O₂, and Rainfall vs. Time)**
Figure 9: Gaia Window showing the general "health" of the planet.

![Gaia Window](image)

Figure 10: Atmospheric Composition Graph.

![Atmospheric Composition Graph](image)

As figures 8 and 10 show, the students need to able to interpret both line and bar graphs when using this program.

Another display of which the students made great use is shown in figure 11, which shows a simulation in progress.
Figure 11: Simulation in Progress

Figure 11 shows the Edit window. Present in both SimCity and SimEarth, the Edit window is the window in which the actual work of placing icons, etc. is done by the students. It allows them to focus on a smaller area of terrain and place various icons with great precision. In the display shown above, we can see several features of this window and of the icons. On the left is a tool bar with a series of icons presenting a number of options. Some of these icons (those at the top) open to rather extensive menus of options including animals and biomes which are available to the students. Those nearer to bottom allow the student to control various aspects of the display, to choose whether to show or not show various aspects of the program. In figure 11, we can see examples of this. Here, boreal forest icons have been placed (showing as small groups of pine trees). In SimEarth, each icon represents an area about the size of the greater metropolitan area of
Toronto or Chicago, not an individual plant or group of plants. There are similar icons for other biomes and for animal groups. While Figure 8 is in greyscale here, in the original simulation window, colour is used to code and identify various features of the terrain and the condition of the planet. Thus, the students can see variations in the terrain (showing as various shades of brown squares). White, striated squares represent water ice, and the blue squares with little concave white marks represent liquid water. Of particular interest to the students are the yellow squares, part of a display which shows the temperature. Normally, this is turned off by the student, but in Figure 11, it has been turned on to show how temperature varies over this area. This is seen in Figure 11 as gray squares evenly distributed over the whole figure. If a forest fire were to be going on, or a volcano present, some of these squares would show as red. Once placed in the Edit window, the icons affect the display of the Map window as well, so that the students can get an overview of their planet and assess its condition easily.
Figure 12: Video Clip 4

Figure 13: Video Clip 5
Figures 12 and 13, abstracted from a video clip, show the students using SimEarth. In figure 12, the students have a menu open and are choosing to display the Atmosphere Graphs window. In the background can be seen the Edit window, with (at the bottom of the screen) many white squares showing the encroaching ice which is the major problem in the Mars Scenario after water is added to the planet. They are having some success with plant life, which shows as green squares on the screen (gray squares here). Figure 13 shows the Atmosphere Graphs window appearing. In the video clip, the students can be heard discussing the levels of various atmospheric gases, and what these mean in terms of the recent actions they have taken. Again, we see the Atmosphere Graphs window allowing the students to rapidly obtain an alternate perspective on the problem.
Method

Overview

This study examined the discourse between students as they worked on a problem-based learning task using a commercial computer simulation for evidence of the presence of the eight levels of approach to knowledge postulated by Bereiter and Scardamalia (1996). There was a particular focus on the higher levels of approach to knowledge (levels 4, 5, 6 and 7 respectively). Two urban schools, and one suburban school participated in the study, providing a sample of 17 students ranging from grades 6 to 8. The students were first interviewed to provide demographic data and to give them an overview of the study. The problem-based task was then presented to them and their discourse during the problem-solving process was tape recorded over a number of sessions and subsequently analyzed using mixed qualitative/quantitative techniques. At the end of the sessions, the students were given a pencil-and-paper assessment instrument and interviewed as to the learning achieved.

Description of Participants and Schools

Four local school boards were approached and asked if they would like to be involved in the study. The two school boards which agreed to participate sent the information along to all principals in the system and from among those, three schools (all K-8 schools) decided to become involved in the study. Of the three schools which participated, one was suburban, and two were urban.

In the suburban school, I was told that a relatively large part of the school population was identified as special needs, either for social, economic or financial reasons. The five students with whom I worked at this school were part of an enrichment program,
and had already participated in projects which used computers in creative ways, including a recently-completed project involving the Lego-Dacta system. The teacher for the program remained actively involved in the project at all times, the only teacher to do so. The physical set-up at this school was different from the others (where I was in a computer room) in that I was in a special education room in which there was only one computer. As a result, this school was the only one at which the study could run the way it was originally intended. As will be described later, the study ran a little differently at the other two schools. Two students were in grade five, two older students were both in grade seven and one student was absent each time I asked about age and grade, but was most probably in grade six (as I had been told one student would be). In consultation with their teacher, these students decided to use the Mars simulation (part of the SimEarth simulation game) in their part of the study.

Figure 14: Physical set-up at the Suburban School (Special Education room)
At the first of the urban schools, nine students initially volunteered to participate and five remained at the end. The four students who withdrew did so after the initial interview. While no reasons were given for the withdrawal, it may have had to do with the timing of the study, which conflicted with lunch periods and track and field practice. The five students who remained in the study ranged from grade six to grade eight. At this school, it was decided to do the study during the lunch period, as that was the time when the computer room was available. This made it possible to run up to three groups of one to three students at once. The computers used were located adjacent to each other and this allowed for a lot of interchange between groups, so that some times it was like working with a super-group of students instead of the smaller sub-groupings. There was a table in this computer room at which pencil and paper work could be done, but no chairs around it, and this affected the manner in which the study was run at this school. It was not possible to integrate the study into the classroom routine and it was made available to the students as a voluntary enrichment program. This school was in a more urban area than the other two, and was very near a height of land which overlooked the city. This may have had an impact on the study, as the principal of this school decided that the SimCity Classic program was the most appropriate for his students, and the city map which is created as part of the simulation looked in some ways not too dissimilar to the view one saw in traveling from the school area to the downtown area. It is probable that all of the students were familiar with this view.
Figure 15: Physical Set-up, First Urban School

Table with computers

Central Table (not computers)

Table with computers

Block of three adjacent computers which were used in this study
At the second urban school, all students who started the project remained in the study until the end, but at this school too, there was some disruption due to track and field. There were seven students in the study, ranging from grades six to eight. Again, it was not possible to integrate the study into the classroom routine, and the study was conducted as a lunch time enrichment program (again due to the availability of the computer room). These students also decided to use the SimEarth Mars simulation for the study. The study was conducted in the computer room, but the computers were not adjacent to each other, making for fewer interchanges between groups, but the room also functioned as a drop-in centre for interested students at the lunch periods, so there were frequent interruptions. These seemed to be part of the normal functioning of the computer room and did not appear to affect the students' ability to work. There was also a high ambient noise level in this room as there was as half wall between this room and an adjacent classroom. At some times the noise from the other class (it was, after all, their lunch period) drowned out the students who were participating in the study. The students appeared to be quite used to this. There was no table in this computer room at which pencil and paper work could be done, and this affected the manner in which the study was run at this school.

Figure 16: Physical Set-up at the Second Urban School
It should be mentioned that the principals and staff at all participating schools were extremely cooperative and helpful and that the students' behaviours were exemplary during the study. It was a pleasure to work with them.

**Method of Data Collection**

As can be seen in Figure 17, the general method of data collection was very simple. The students were arranged around the computer in as convenient a fashion as possible, with the microphone between them and the computer. The investigator stood or sat behind the students as was convenient in the physical situation, and tried to be as unobtrusive as possible, but was available to act as a guide should they encounter problems with the software, as some concern had been expressed by participants about using unfamiliar software.
In some sessions, a video camera was used. The camera was hand-held and placed where it could record the on-screen events, but not the students. As the physical layout of each classroom was a little different, this general pattern was modified where the situation demanded. Sessions away from the computer were conducted at a convenient table or a carpeted floor, with the microphone and audio tape recorder placed between the participants and the interviewer.

Student interactions were recorded using an audio tape recorder. The schools were kind enough as to provide additional tape recorders so that multiple sessions could be run. Voice activation was turned off on the tape recorders and the tape was started and ended manually as the session began. Each session began with the investigator identifying the date, school and participants. The investigator made no notes during the sessions so as not to distract the participants. If significant events occurred during the session, the
investigator dictated these into the tape recorder as soon as possible after the session. The length of each session varied according to the wishes of the teacher.

As soon as possible after the end of each session, the investigator labeled and transcribed the tapes as described below. Because of the time involved in transcribing, some transcription was done by a professional transcriber.

**Initial and Final Interviews**

At the initial interview, which did not involve any on-line work, the students were interviewed about demographic information such as age, sex, grade, and computer experience, and there was also a short discussion of the nature of the assignment.

At the final interview (again, no on-line work, and conducted after the problem-based task had been completed), the students were asked what they felt they had learned from the assignments and what they felt about using the simulations as learning tools.

**The Assignments**

The assignments involved project-based learning in which the students had to create as close to an ideal situation as possible from a nearly empty microworld. At the school using SimCity Classic, the students were asked to build an ideal city. At the schools using SimEarth, the students used the Mars simulation in which they had to terraform the planet Mars, making it suitable for human habitation. In the former case, the assignment would fit into the curriculum as an urban geography project, and in the latter case, the assignment would fit into the curriculum as an ecology project.
The first on-line session involved familiarizing the students with the programs and the interface. SimCity Classic provides no tutorial except for an on-line manual, but this appeared to be no impediment to the students, and I was present to provide support and assistance if they needed it. SimEarth provides a written, on-line tutorial and all students went through the tutorial (except for one who was absent at the beginning of the study). Again, I was present to assist, should they need help. At this first session, the students were encouraged to explore the programs and the interface -- to play around with them and to become familiar with them. Subsequent on-line sessions were used to work directly on the assignment.

Originally it was envisioned having the students work with an on-line session followed by an off-line session in which they reflected on the results of their on-line session. Because of the physical set-up at two of the schools, this proved to be impossible and unpopular with the students (in one case there was no space to write, and in the other, furniture had to be rearranged and replaced at the end of the session). In the end, I decided to let the students decide how they would work in their unique situations and see what the results were. Thus, at the suburban school, the students worked with one session on-line and one off-line as originally intended and at the two urban schools, the students worked with all sessions on-line.

The Tests

At the end of the study, the students wrote a short test (of my composition) to see what their writing might reveal about what they had learned while using the simulations and to compare what they wrote with what they actually did during the on-line sessions. One student was absent on the final day and was neither interviewed nor tested.
There were two test instruments (see Appendix A), one for the students who had used SimEarth and the second for the students who had used SimCity. Each consisted of five, essay-type questions, and encouraged the students to expound on why they had answered as they did. All questions were based on the theory underlying the problem-based task given to the students.

**Analysis Method**

The tape recorded data were transcribed using the following transcription procedures:

- Pauses are indicated by dots. Each dot represents about one second. Longer pauses are indicated by a dot, number of seconds and another dot as follows: .6. NB: Periods are also used at the ends of sentences.

- Emphasis is indicated by ALL CAPITALS, as you see here.

- Exclamation marks, questions marks, etc. are used as normal in English to indicate the intonation of the speaker.

- An asterisk is used to indicate unintelligible utterances. One asterisk is used for each word judged to have been uttered.

- Slashes (/) are used to indicate overlapping of speech. The parts which overlap are enclosed between pairs of slashes. E.G. /I think that this should go here/ would indicate that this part overlaps with a following utterance also enclosed between slashes.

- Hyphens are used to indicate incomplete starts or unfinished statements, unless there was a pause, indicated by a dot (.)
• Comments by the observer are sometimes used to clarify the transcribed text. These are placed in parentheses and indicated by the letters OC preceding the comment.

• Speakers are identified by a letter or letters to the left of the page, followed by a colon (E.G.: "D:" indicates that I am speaking). If the speaker cannot be identified, a question mark followed by a colon is used (E.G.: "?:").

After the tape recorded data were transcribed, they were saved in text format and prepared for importation into the NUD*IST software package for coding and analysis. The code groupings are given in the discussion of the data, below.
Analysis Techniques

Overview

Data were analyzed using a mixed analysis technique. Where there were statistically significant numbers of data to analyze, statistical techniques were used. Most of the analysis, however, was done using standard ethnographic qualitative analysis techniques. The main vehicle for this was the NUD*IST analytical software package (version 4, Macintosh edition, Qualitative Solutions and Research, 1998). Transcribed interviews were prepared and imported into NUD*IST and coded for analysis. Code groupings used for analysis are shown in figure 18 below. (Numbers in brackets beside the labels indicate the node numbers assigned by the NUD*IST analysis program, and are of no special significance).
Figure 18: Coding Groupings for Analysis

(1) Demographics
(2) Knowledge Levels
(3) Interface
(4) Coordination exchange
(5) Social Exchange
(6) Learning (SimEarth)
(7) Learning (SimCity)
(8) Test Results
(9) Video Examples

A fuller discussion of these will be given below.
The Analysis

The unit of analysis was the exchange. Wells (1998, p.5) explains the concept of the exchange:

In the co-construction of a text, the smallest building block is the Move, for example, a 'question' or an 'answer'. However, it is the Exchange -- in which such reciprocally-related moves combine -- that constitutes the minimal unit of spoken discourse. Every exchange consists of an Initiating move and a Response move (either of which may on occasion be non-verbal); under certain conditions, there may also be a third, Follow-up move.

Cohen (1995, p. 56) gives a further definition of the exchange as "... an initiation plus all the utterances following until another initiation occurs ...". Exchanges were sometimes quite short, as in a simple question and answer, or longer, as in an initiation and the discussion which followed. Efforts were made to keep the analysis units as short as possible, but some exchanges proved to be quite lengthy, especially if the discussion was proving fruitful.

Exchanges consist of combinations of individual text units. A text unit is a spoken utterance by one student and consists of the initiation of speech by that student until he/she ceases to speak or is interrupted by the utterance of another student. Example 1, below, illustrates this point.
Example 1: Example of Exchanges

<table>
<thead>
<tr>
<th>Description:</th>
<th>Exchange:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiation:</td>
<td>R: Whoa! Roads, roads are necessarily needed. Oooo, right across the tracks</td>
</tr>
<tr>
<td>R speaks and identifies a problem</td>
<td></td>
</tr>
<tr>
<td>C responds with a solution.</td>
<td>C: OK, let's put a bridge in somewhere. People like to drive over bridges.</td>
</tr>
<tr>
<td>R agrees (tacitly) and wants to refine the plan.</td>
<td>R: Where do we put the bridges? Where do the bridges go?</td>
</tr>
<tr>
<td>C supplies an idea.</td>
<td>C: Over water?</td>
</tr>
<tr>
<td>R starts to suggest a location, but is interrupted.</td>
<td>R: Yeah, put in -</td>
</tr>
<tr>
<td>C interrupts with a suggestion as to location.</td>
<td>C: Up.</td>
</tr>
<tr>
<td>R refines this suggestion.</td>
<td>R: Over this place a bit.</td>
</tr>
<tr>
<td>C further refines R's idea.</td>
<td>C: Now have it go straight and go right down there.</td>
</tr>
<tr>
<td>R questions the plan before acting.</td>
<td>R: Are you sure you want bridges?</td>
</tr>
<tr>
<td>C supports R's proposed action.</td>
<td>C: Yep!</td>
</tr>
<tr>
<td>R concludes the exchange.</td>
<td>R: Okaaay.</td>
</tr>
</tbody>
</table>

In my analysis scheme, the above would constitute an exchange, with each time we have a different speaker constituting a text unit. As can be seen, an exchange can vary in
length, as can a text unit. That having been said, most text units are not particularly long and this exchange is typical of many.

In the case of some exchanges, double codings were used. This occurred when students were obviously working at different levels. In such a case, where one student might be operating at level 3 and one at level 4, the exchange would be coded as both a level 3 and a level 4 exchange.

The Codings

The codings used (see Figure 18) were as follows:

Demographics
Demographic data (age, sex, grade, school, etc.) were collected during the initial interview.

Knowledge Levels
These were the eight levels of approach to knowledge (Bereiter and Scardamalia, 1996). There was one node for each level, from 0 to 7 (although I did not expect to find any level 0 exchanges).

Interface
These were exchanges which dealt with the interface and interface-related matters.

Coordination Exchanges
These were exchanges which dealt with the coordination of group activities.
Social Exchanges
These were a group of exchanges which dealt with social matters unrelated to the
 task at hand. Greetings and discussions of lunch, the whereabouts of other students, etc.
 were included here.

Learning (SimEarth) and Learning (SimCity)
These were the nodes at which the data from the final interviews were coded. In
these interviews, the students were asked if they felt they had learned anything from the
experience, if so, what, and so forth.

Test Results
The results of the SimEarth and SimCity tests were coded at this set of nodes.

Video Examples
A small number of video examples were extracted from the videotapes made.
although NUD*IST will not allow the clips themselves to be imported and coded,
descriptions of each clip were imported and coded, making analysis of the clips easier.

Use of Perl Scripts

In order to get a more fine-grained analysis, Perl language scripts were used to
write very long NUD*IST program command scripts. These command scripts are part of
the macro language in NUD*IST and allow the automation of certain routine codings, but it
can take a long time to write some of them. The use of the Perl language made it possible
to write very large command scripts (some exceeding 2 Mb in size), very quickly. While a
number of different scripts were tried, the most successful involved coding each text unit of
each document at its own node. This allowed for NUD*IST matrix searches for approach
to knowledge level codings of each text unit in each document.
Data and Analyses

Summary of Demographic Data

The demographic data revealed nothing startling about either the students or the schools. There was a slightly higher participation level of males versus females, but the size of the sample and the non-random nature of one of the classes studied more than accounts for this.

The Distribution of Students by Sex

There were 13 male and 4 female participants in the study. Originally, the sample contained a higher proportion of females participants, but four of these dropped out after the initial presentation of the study. It was not possible to interview these students as to their reasons for dropping out, but it is likely that the combination of lunch time sessions and conflicts with the track and field practices were factors in this.

Figure 19: Table showing the distribution of students by sex and school

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suburban School</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Urban School - SimCity</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Second Urban School - SimEarth</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Examination of figure 19 shows why this sex distribution is so skewed towards males. In the suburban school, the participants were the members of a special group withdrawn from regular classes, and it happens that this particular year, there were no female students in this quite small group. We can see that there is a much better representation of female students in both of the urban schools, although there is still an over-representation of male students. It is difficult to explain why this might be so. When
asked, the female participants generally responded positively to the experience of using computers in this manner, as in example 2 below:

**Example 2:** Female responses to computer use

D: Ok, did you like working this way? Or would you have preferred to learn about this stuff from an encyclopedia or a textbook, or...?
A: I liked it better on the computer 'cause, 'cause you can vis, visualize it and, you, you can see what like, see what you're doing and, so- And do it yourself instead of just reading about it from a book.

This response was quite typical of the responses of the female students in general to the experience. I would therefore conclude that it was not the aspect of working with computers that reduced female participation, but rather the presence of external factors such as track and field (which also had an impact on male participation).

**The Distribution of Students by Grade:**

At the suburban school, there was a quite even distribution of students over grades 5, 6 and 7 (see graph 3, Appendix B). In the two urban schools, we see the SimCity school having a larger number of grade six students and the SimEarth school having a larger number of grade seven students. This leads to the overall distribution in which grade six and seven students are seen to predominate. However, it should be noted that the students worked in age and grade related groupings in the suburban school (most of the
time), but in the other two schools they frequently changed their groupings and these did not always reflect segregation by grade. This led to the senior students having a lot of contact with the more junior students. Because of the fluid nature of the groupings, it was not possible to further analyze this data to see if the students in lower grades were working at the same levels of approach to knowledge as the students in the higher grades.

The Distribution of Students by Age

Students aged 12 and 13 years constituted the largest single groups of students, with younger students being less well represented. It is likely that older students would have had a greater opportunity to become familiar with computers and might have had a greater interest in participating in a study. It should be noted that participating students missed their lunch recess at the two urban schools, and this may have affected the level of participation both in general, and in the lower grades.

Levels of Approach to Knowledge

Figures 20 and 21, below, show the results of the analysis in terms of the levels of approach to knowledge -- the major purpose of this investigation. Figure 20 shows the results in terms of the number of text units coded and figure 21 shows the data in terms of the number of analysis units (exchanges) coded.
Number of text units coded at each level vs. the levels of approach to knowledge
As can be seen, level 3 exchanges clearly predominate, with level 4 exchanges being the second largest grouping, and quite close to level 3 in terms of both text and analysis units. There were no level 0 or 1 exchanges, but levels 5 and 6 were both present. No level 7 examples were found. While no examples of level 5 or 6 were captured on video, some level 4 examples were captured.

Examples of level 5 and 6 exchanges are given below, in examples 3 and 4 below.

In Example 3, two students discuss their examination of a graph of atmospheric conditions. They reach some conclusions, and one student, L, has obviously synthesized a
theory she is having a little trouble articulating. She creates a simile in which she likens the interplay of the atmospheric gases and temperature to a dance. (At the time she is speaking, she is also viewing the line graphs of the gases in question and sees that they respond in sequence, one affecting the other).

**Example 3: Level 5 Exchange (Knowledge as personal artifacts -- synthesis)**

J: Our air pressure is going down, so I guess we stop the animals right now.
L: The water vapour is going down too.
J: Yeah, that's like really important. 17.
L: What do you have, all cold ones? 8. Oh, it's cold down here.
J: No, it's got more *
L: It goes like, it goes like the dance, like the * string's hot, so we should put something around here. Sorta like -
J: Sorta like what?
L: What about some grass?
J: OK.

In example 4 (below), Dn, P and D discuss their plan to terraform Mars. Level 6 was chosen because Dn clearly views his plan as improvable, as shown by his statement that he knows that he needs to warm the planet up, but doesn't quite know how. The discussion then turns on various of his ideas as to how to do this.
Example 4: Level 6 (Knowledge as improvable personal artifacts).

D: OK, well what's your plan then, exactly?

Dn: Oh, OK. first we need water . . oxygen, plants, gonna raise the temperature 'cause it's minus 53. Celsius. see, you need, need to raise that to that. something that's livable.

D: How are you going to do that?

Dn: Ah .5. don't know.

D: OK, you don't know. Maybe -

Dn: Well, with the water. the water could. if you got the water heated, the water could heat the air, OK, and then, uh .8.

P: Stuff in the oceans, sort of like * *

Dn: Does Helium heat. real fast?

D: Aaah, Helium, in fact is a very, very light gas -

Dn: Oh, it's not the one that gets heated?

D: No.

Dn: Oh.

D: It'll tend, actually, to, ah, go off in space rather than stay on, on your planet.

Dn: Right. . need something, an atmosphere that keeps the heat in .6.

D: OK, now I'll give you a hint there. It's called the Greenhouse Effect. If you were to go to the library or to a science book and look up the Greenhouse Effect, you might get some hints on how to do that. so that might be a step you might to take.

Dn: That's what. we have. too much of now.

D: Here. but we're on /Mars now/. 
Dn: /* */ right.7. * no (OC: know?)
D: OK, well, you said your first step is to put water in. OK, that 
sounds like a good first step. (OC: This is a hint given in the 
manual). How are you going to do that?
Dn & P: (OC: Together). Ice meteors (OC: Another hint from the 
manual).
D: Yeah.
Dn: .4. Have a couple of ice meteors hit the Earth, er, Mars -
D: I was going to say (OC: laughs) your aim is a little off there.
Dn: .3. -then put some, ah, .4. ah, carbon dioxide, or if there's already 
some there, put some, ah . little cells in the water.
D: Uh huh.
Dn: To, so they could make . the . uh . oxygen . then, ah .6. then start 
getting much of, a lot of other, ah, kind of, ah, gases in the 
atmosphere . . like what we have on Earth and, ah, I don't know, then try 
to raise the temperature, and get , ah, ground, get some, ah, that could 
plant some stuff in

Further analysis was performed on data at various levels. Of significance were 
analyses performed on levels 3 and 4. It was found, in examining both the level 3 and 
level 4 exchanges, that these contained significant sub-groupings, notably Coordination 
exchanges and Interface exchanges.

Analysis of the Levels of Approach to Knowledge

It is clear that most of the activity among students in these tasks was at level 3 or 
level 4. For the purposes of this study, it was considered that higher levels of approach
to knowledge started at level 4, where the students begin to take alternate perspectives on knowledge. Thus, higher levels of approach to knowledge were demonstrated in this study, but it was disappointing to find that levels 5 and 6 were not better represented. It had not been expected to find level 7 examples.

In addition to these levels of approach to knowledge, additional sub-codings were identified within the various levels of approach to knowledge. Most of these proved to be of insufficient frequency to be counted as important groupings, but some were felt to be quite important. Among these were Coordination exchanges and Interface exchanges.

Coordination exchanges were defined as those exchanges necessary to facilitate the functioning of the group. They included discussions about what was to happen next, and where on the concept maps of the microworlds the students wished to work. Example 5 illustrates a typical Coordination exchange.

**Example 5: Typical Coordination Exchange**

B: We should have,
A: We have fire departments.
B: Mmm hmm. Let's go unpause.
B: Oh, there's no power. Wait.
A: Yeah there is. There is.
B: Oh there it is ok.
A: Go around.
B: Why? .9.
A: Ok, there, there, there. Let's leave it alone, now. Leave it alone.

As can be seen from the example above, coordination of the activities of the group formed a large part of the exchange, which is basically a level 3 discussion about options. In this example, the two students, A and B, first discuss fire departments, but then find it necessary to unpause the simulation, which required non-verbal agreement from the other student. After that, A instructs B as to which part of the concept map he/she thinks they should be exploring.

It would be very difficult indeed to imagine that group work could proceed smoothly without such coordination. Graph 8 (below, following the discussion of interface exchanges) shows the relative percentages of level 3 exchanges which also involved Coordination exchanges.

The second major grouping of exchanges which played a major role in level 3 exchanges was the Interface exchange. Interface exchanges were defined as those exchanges relating to the nature of, using, or coordinating the use of, the computer interface. Such exchanges included discussions about where to find lost files, how to start the program, what certain icons meant, and who should be controlling the mouse or other aspects of the simulation at a given point in time. Example 6 illustrates a typical Interface exchange.
Example 6: Typical Interface Exchange

L: What happened to our planet?
R: Nothing!
L: What the heck just happened?
R: I clicked * and nothing came on.
L: What is that, then?
R: ** came to our planet.
L: How * is it?
R: That's what I just tried to find and I clicked on that and it just appeared.

Again, it would be difficult to imagine students collectively using a computer program (on a single computer) without having some discussion over who would control the mouse, or who would not have occasion to discuss the interface (particularly in the early stages of usage). Figure 22, below, shows the relative percentages of level 3 exchanges which involved Interface exchanges.
Once we take Coordination and Interface exchanges into account, we can see that only a relatively small number of the exchanges (19%) in no way involved coordination or interface issues.

Level 4 exchanges similarly showed fairly large numbers of Coordination and Interface exchanges. Figure 23 shows the relative percentages of Interface and Coordination exchanges involved in level 4 exchanges.
Figure 23: Graph of the relative percentages in level 4 exchanges involved in both interface and coordination exchanges

Here it can be seen that the level 4 exchanges had a much smaller amount of time occupied by coordination and interface issues.

Levels 2, 5 and 6 did not have significant number of exchanges involved in coordination or interface issues. This can be clearly seen in figure 24, which shows the number of Coordination exchanges and Interface exchanges compared to the total number of text units for all levels. ("TU" stands for “text unit” on this graph).
Factors which Interfered with Higher Levels of Approach to Knowledge

A number of factors seem to interfere with the production of higher levels of approach to knowledge by the students. Several of these were considered significant enough to be coded. These included Off Topic and Social exchanges.

Off Topic exchanges were defined as exchanges which had nothing at all to do with the problem under study. Examples 7 and 8 illustrate such exchanges.
Example 7: Off Topic exchange

R: Their cars are driving! (OC: referring to another group; laughs).
Ra: What do you, what do you think cars are supposed to do? ... They fly.
R: Oh, yeah. Cars love to fly.
Ra: Yeah, that's why they keep their doors open.
R: You know, they like that Atlantic to fly over, too.

Example 8: Off Topic exchange

A: M, stop playing with Encarta 98.
M: Shut up. ...
A: Don't look at Enc-, Encarta 98. ... Mind maze?

While not terribly numerous, such exchanges tended to move the students away from the problem they were studying and sometimes they were not wholly successful in returning to it. Although the students were usually able to return to the problem at hand and work constructively, sometimes they were not able to return to the previously initiated topic, as in Example 9 below.
Example 9: Example showing students returning to original topic

<table>
<thead>
<tr>
<th>Text Unit #</th>
<th>Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R: Here. Now we need a /commercial/</td>
</tr>
<tr>
<td>2</td>
<td>Ra: /Commercial/ ...</td>
</tr>
<tr>
<td>3</td>
<td>R: And in here we'll have our fire department. 'Cause everyone knows commercials are famous for burning.</td>
</tr>
<tr>
<td>4</td>
<td>Ra: Yeah. And shooting *</td>
</tr>
<tr>
<td>5</td>
<td>R: Just like the London burning bridge. No, that was when it was falling. Never mind!</td>
</tr>
<tr>
<td>6</td>
<td>Ra: ***, you're not all there, are you?</td>
</tr>
<tr>
<td>7</td>
<td>R: I never am all there. .5.</td>
</tr>
<tr>
<td>8</td>
<td>Ra: * insane</td>
</tr>
<tr>
<td>9</td>
<td>R: I don't see you doing much. You're just sitting here, na na na na (OC: laughs). ... Quick, now, what should we build. Airport!</td>
</tr>
<tr>
<td>10</td>
<td>Ra: We can't afford it.</td>
</tr>
</tbody>
</table>

In text units 1, 2, and 3, we can see an initiation about fire prevention. In text units 4 to 9, we have an off topic exchange, and in lines 9 and 10, we see a new initiation, the older one having apparently been forgotten. It should be noted, however, that in a large majority of such cases, the students did return to the problem they had been discussing before they went off topic.
Another species of exchange that interfered with higher levels of approach to knowledge was the Social exchange. Social exchanges were defined as those whose purpose was social and not at all directed at solving the problem. Typical of this type of exchange is example 10 below.

**Example 10:** Social exchange

R: * you on the internet *?
?
*: * *
R: WWW F*
B: Yeah.
R: I haven't watched wrestling.

This example illustrates three features found in the Social exchanges. The first is that it was also often classed as an Off Topic exchange. It obviously had nothing to do with the problem at hand, and by their nature, such exchanges are often off topic. Second, it relates to some feature of the environment which distracted the student, in this case, a nearby computer. Usually, the students were pretty good about working, so some distraction was necessary to pull them away from their work. Third, the exchange featured the presence of a student who was not part of the study. I have no idea who the unknown student in Example 8 was, but they were not part of the study and dropped in to the computer room on their lunch time to surf the internet. Such interruptions were not infrequent, and usually, they students didn’t allow themselves to be distracted for very long, but nonetheless these interruptions provide a barrier to achieving higher levels of approach to knowledge.
Periodicity in Levels of Approach to Knowledge

As part of the analysis of the material, each text unit was coded at its own particular node and a matrix search was performed to find all levels of approach to knowledge at all text units in all documents. This resulted in a large matrix of results showing the total number of text units coded at text unit 1 - n in all documents and for all knowledge levels (where n is the total number of text units in that document). Thus, it was possible to make a scatter plot of the total of all level 2 approach to knowledge codings (in all documents) vs. text unit number. Most dramatic of these were the level 3 and 4 scatter plots, given as figures 25 and 26 below.

Figure 25: Graph of level 3 codings

Level 3 Scatter Plot
As can be seen there is both a trend and a periodicity in this data for both levels 3 and 4. The downward trend (from higher numbers of codings at lower text unit numbers to lower numbers of codings at higher text unit numbers) is easily explained. Most of the documents were not that long, and there were more documents with smaller numbers of text units than larger ones. Logically, it follows that there would be a downward trend in the number of text units coded in any manner in such a case. The periodicity, however, is less easily explained. In order to make further sense of this data, figure 27 (below) was plotted, this time with the data from both levels 3 and 4 on the same graph.
Levels 3 & 4 Scatter Plot

Figure 27: Graph showing the scatter plots of levels 3 and 4 codings
As can be seen from the level 3 and 4 scatter plot, there is a clear anti-parallel trend to the data. This can be most clearly noted near text unit number 50, where we see a peak in level 3 activity corresponding to a valley in level 4 activity and at about text unit number 175, where we can see a low amount of level 3 activity corresponding to a large amount of level 4 activity. At other points in the graph, we can also note this anti-parallel trend.

Examination of figure 28 (below), a similar scatter plot of level 4 activity against level 5 activity, shows it to be quite different. Here, the graph shows the two curves to be complementary in some places -- peaks in level 4 activity correspond to peaks in level 5 activity, but not in others. That this set of data is less clear may relate to the smaller number of level 5 codings.
Analysis of the Test Material

The written tests given at the end of sessions were analyzed and the responses were classed as "good", "acceptable" or "poor". Good answers were grade appropriate or above, contained clear evidence of reasoning based on the principles the students were supposed to be learning and were generally correct or close to it. Acceptable responses were grade appropriate, made some use of the principles the students were supposed to be learning and were more correct than wrong, although they may contain errors. Poor
answers were either not attempted, contained no reasoning based on the learned principles or were very incorrect.

Table 4: SimCity Test: Numbers of responses in each of the categories into which the responses were grouped.

<table>
<thead>
<tr>
<th>SimCity Test Question #’s</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q3</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Q4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Q5</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>15</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: SimEarth Test: Numbers of responses in each of the categories into which the responses were grouped.

<table>
<thead>
<tr>
<th>SimEarth Test Question #’s</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>8</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>7</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Q3</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Q4</td>
<td>2</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Q5</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td>27</td>
<td>26</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 6: SimCity Test: Numbers of text units in each of the categories into which the responses were grouped.

<table>
<thead>
<tr>
<th>SimCity Test Question #’s</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>8</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q3</td>
<td>6</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Q4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Q5</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>36</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 7: SimEarth Test: Numbers of text units in each of the categories into which the responses were grouped.

<table>
<thead>
<tr>
<th>SimEarth Test</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>39</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>7</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Q3</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Q4</td>
<td>2</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Q5</td>
<td>5</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td>58</td>
<td>28</td>
<td>7</td>
</tr>
</tbody>
</table>

Examining these results by school, we can see the results of the SimEarth Test from the two schools which used SimEarth in figures 29 and 30 below:

Figure 29: Graph showing results of the SimEarth Test in the suburban school
Figure 30: Graph showing the SimEarth Test results for the suburban school

![SimEarth Test - Suburban School](image-url)
Figure 31: Graph of the SimCity Test: Total answers to questions as percentage categories.

SimCity Test: Responses by percentage and category

- Acceptable: 12%
- Poor: 2%
- Good: 86%

Figure 32: SimCity Test: Total numbers of text units as percentages of total answers.

SimCity Test: Responses by percentage of text units given

- Acceptable: 16%
- Poor: 2%
- Good: 82%
Figure 33: SimEarth Test. Total answers to questions as percentage categories.

SimEarth Test: Responses by percentage and category

- Poor: 12%
- Good: 45%
- Acceptable: 43%
Figure 34: SimEarth: SimCity Test. Total numbers of text units as percentages of total answers.

As can be seen from the graphs above, a clear majority of answers to all questions were in the “good” category, with the SimCity results being overall better than the SimEarth results. This last result may in fact be an artifact of the smaller sample size in the SimCity group.

This is an important result, in light of the fact that there was little or no direct instruction involved in any of these sessions. Students learned the principles through the program itself, or by researching textbooks or by questioning the teacher as questions arose. The written test itself was structured so that the questions were open-ended, with no single correct answer for any of the questions. Nonetheless, many students gave very
clear, well-reasoned answers with good use of supporting facts. Examples of such work are given below:

Example 11: SimEarth test question and “Good” response.

**Question:**

*You have been given the mission to terraform Mars. What are the first five (5) things you would do and WHY would you choose those things?*

**Answer:**

*First:* I would make an atmosphere out of oxygen, carbon dioxide, methane.

*Second:* I would monitor the heat, air pressure, and atmosphere and see if it is stable enough to add plant life. If yes, add life, if no, add more CO2.

*Third:* Once the atmosphere is ready to support life, add boreal forests and some insect or ice age life.

*Fourth:* Add jungles and other kinds of forests. If the planet is not stable enough to support trees, add swamps.

*Fifth (sic):* Try to add people to your planet.

I would choose these because it the most logical way.
Example 12: SimEarth Test Question and “Good” response.

Question:

Incredible as it may seem, your Mars is getting too hot. Give as many ways as you can think of to solve this problem. For each way you give, tell WHY it would work.

Answer:

If Mars got to hot you could add trees. Trees lower the CO2 level and since CO2 helps warm the planet, the trees would make it colder. You could also crash meteors into the planet's land, so you create dust particles that reflect the sun's heat away. You could also lower the water vapor levels by not crashing anything into the water.
Example 13: SimCity Test Question and “Good” response.

Question:

Your city has a traffic problem. Give as many ways as you can think of to solve this problem. For each way you give, state WHY you think that this will work.

Answer:

1. You could expand the roads to make the roads wider this will lower the traffic problem on one small road.
2. You could make your city bigger this will spread out traffic more because there are more roads to drive on.
3. You could also take out houses so the population will be lower therefore the traffic will be not as crowded.

Example 14: SimCity Test Question and “Good” response.

Question:

You have a bare piece of ground with no city on it. What are the first five (5) things that you would put in and WHY would choose to put in these things?

Answer:

1. Put a powerplant, so when you build they have power.
2. Industrial so when people come they have a place to work.
3. Houses, so people can live there.
4. Roads, so people can drive to work.
5. Power lines, so people can see in the dark, and for other private reasons.
All of these responses show strong indications of the formation of theoretical constructs, evidence of level 5 approaches to knowledge.

A second significant result from the test results is that there is clear evidence of considerable transfer of knowledge from the simulation medium to the pencil and paper medium of the test. This would seem to imply that the students are capable of applying the knowledge they acquired through use of the simulations to other situations, a characteristic of deeper learning.

The Final Interview

The results of the final interviews were somewhat disappointing. On the days on which these interviews were conducted, the students did not seem disposed to talk at length about the experience and gave somewhat brief answers. Apparently, they would much rather work with the simulation programs than talk about them. In general, their answers support the test results, showing that the students had learned from the experience, and were able to use the correct terminology and make appropriate use of supporting fact, except in the case of one student who felt that the whole exercise was for me to teach him how to play a computer game (see example 15 below).
Example 15: Example showing a student who has not really understood the purpose of the exercise

B: Well, you see, ah, well I've learned, I like got SimCity 10 days before, and I didn't know how to use anything, so, ah, so when I came here, I, ah, I, this was quite a bit easier than SimCity 2000 and so when I build SimCity, I put the, ah, foundation in and nothing would appear, no houses would come up and say cash flow's 13,000, then I go to current cash flow and it's -13,000. I got real ticked off, then I came here and it showed me that it needs, like, power and everything and I found out how to use a power plant from my friend and this taught me most of everything I know. THANK-YOU!

D: OK.

Although B does seem to understand the relationship between a successful city and various of the program elements (finances, power, etc.), he does not seem to relate it to anything outside of the game (for example, to a real city). However, other students were more successful in articulating their learning, as in example 16.
Example 16: Example showing a student successfully articulating his/her learning

P: I learned about the, how the greenhouse * work* and about all the uh, gases and that and *, and how much there is.
D: And how much there is.
P: Yeah. Of the gases.
D: Right. How much is there?
?: Percentages.
P: * different amounts. (OC: laughing)
D: Different amounts. Oh, give me an idea.
P: There should be about 20% oxygen.
D: Should be about 20% oxygen, ok.
?: 2% methane.
D: I'm asking P.
P: Yeah, yeah, that.
D: 2% methane, ok.
P: And a lot of uh, nitrogen and just a bit of carbon dioxide.

Here, P is able to accurately give the approximate composition of Earth's atmospheric gases and the percentages in which the major gases appear, and makes mention of one of the key effects that we were working with in the simulation, the Greenhouse Effect.

In example 15 we can see that the use of the simulation has led to a very positive attitude on the part of one student. He seems to be viewing himself as an active constructor of knowledge, although he is not able to articulate it as well as P in the previous example.
Example 17: Example showing a student who views the use of simulation as a positive experience

R: I learned that uh it's, pretty hard to do things but if you put your mind to it you know, you can get some things done. We learned about different uh, * gases, different um, little magnetics, uh... You know, the stuff. **

D: Stuff.

R: Yeah, stuff. Good stuff.

D: Good stuff.
Discussion

The demographics in this study show nothing remarkable -- there were no special schools (although there was one small special class), there were no special settings with remarkable equipment, and even the simulations themselves were simulations which had been around for some time, lacking the cutting edge graphics and sound of more modern (post-Mystian) software. The students themselves were from a number of grade levels and the only real anomaly appears to be that a smaller number of girls chose to participate, and other evidence shows this to be not significant.

The core of the investigation was the analysis of higher levels of approach to knowledge shown by students. It was not expected to find level 0 or level 1 interactions between students of the ages of these students, although some level 2 interactions were expected. The findings reflect that this was the case. The principal part of the study begins with the analysis of levels 3 and above.

It was found that there were a very large number of level 3 interchanges between students, larger than any other group of interactions. However, it was also found that the level 3 interactions could be further broken into three other groupings -- Interface exchanges, Coordination exchanges and other exchanges. Though necessary, these interactions are not at a high thinking level and so it was inevitable that these should occur mostly at level 3, as this level is characterized by discussion of the kind needed to coordinate group actions. Thus, it should be considered that such level 3 interactions are necessary to group functioning and that these cannot be said to interfere with the production of higher level thinking, but rather, are necessary to it, if the students are to work in groups.
Likewise, it is also inevitable that we should find some of these Coordination exchanges at level 4 as well, because this level requires us to take differing perspectives on knowledge and the perspective of choice for a group must be socially negotiated and the choice coordinated between group members if the group is to be successful. It can therefore be argued that the presence of such level 3 and level 4 interactions is necessary to produce level 5 or 6 interactions.

If we examine the Interface exchanges, we can argue in a similar fashion. In solving any computer-based problem, it is likely that there should be some interface problems. Students working in a traditional manner often have problems with the textbook interface and are unable to find the relevant material without assistance, and it would be unreasonable to expect that the students could assimilate a new and different interface, and later, make effective use of that interface without some discussion of the interface and how it should best be used. Thus, again, it would be expected that levels of approach to knowledge characterized by discussion, and (see above) coordination would also be the loci of Interface exchanges.

If, however, we examine levels 3 and 4 in light of the above, we can see that, in fact, the students are working at a higher level than they appear to be. For example figure 22 shows that the Coordination and Interface exchanges, taken together, account for more than 80% of the exchanges in the level 3 category. The number of level 3 exchanges involving other exchanges constitute fewer than 20% of the exchanges.

Likewise, if we examine level 4 in the same light, we can see a higher level of work. Here, Coordination and Interface exchanges, taken together, constitute fewer than 40% of the exchanges and more than 60% are involved in other exchanges more closely
focused on solving the problem by taking alternate views of the data and the problem. Thus, in terms of discussion solely focused on the problem (as opposed to coordination of group activities or interface issues), level 4 appears to form the larger group of interactions, and it can be concluded that the students are consistently performing at level 4 or higher.

Because level 5 and 6 exchanges occur in smaller numbers, it has not been possible to derive any patterns or significant conclusions from these, other than to say that they are present. This however does provide evidence that the students can reach these high levels of approach to knowledge when using commercial computer simulation games.

A picture then emerges of the students’ work on these projects. A considerable portion of their level 3 work, and some of their level 4 work, involved necessary actions to maintain and coordinate the group actions. The bulk of their problem-solving work was at level 4, and involved considerable time taking alternate viewpoints by making use of the metacognitive supports provided in the computer programs. Represented schematically in figure 35 below, we can see a kind of structure in which level 5 and 6 exchanges are supported by the more numerous level 3 and 4 exchanges.
Figure 35: Figure showing levels 5 and 6 being supported by levels 3 and 4

This is a more complex picture than originally anticipated, as it implies that level 3 and 4 exchanges are necessary precursors to levels 5 and 6 work. This in turn would imply that we need to focus some attention on the elements which facilitate the transitions between level 4 and 5 work, and between level 4 and 6 work. It might be possible to identify a set of triggers or catalysts which move students to higher levels of approach to knowledge.

The data resulting from the scatter plots are the most puzzling to try and explain. Clear patterns emerged quite unexpectedly. Close examination of these showed an antiparallel pattern when levels 3 and 4 were compared. If we think about this, it does make sense, as it can be argued that when students are working at level 3, they cannot be
working at level 4 and vice versa. However, this does not explain why this should be happening at close to the same text units as frequently as it does, given that these sessions were taking place on different days and at different times -- even on different months. Nonetheless, the patterns are clear. Likewise, we have seen that there is a kind of correspondence between the patterns seen when levels 4 and 5 are plotted together. Again, it can be argued that level 4 exchanges support and lead to level 5 exchanges, but why does this occur at approximately the same text unit numbers in a number of different sessions?

One possible explanation of this is that the patterns which have emerged are some kind of artifact resulting from the data collection or coding procedures. While I do not reject this, data collection was as carefully done as was possible under the circumstances available, over a period of months, and all codings were examined twice (and emendations made) on different dates, most of the time, some months apart. This would seem to reduce the possibility of there being some kind of rhythm in the data collection or coding processes, but it cannot be entirely ruled out.

A second possible explanation is that we are seeing some kind of rhythm in the dynamics of group work. If we take, for example, the beginning of a session, we normally see exchanges in the form of greetings and questions about what we are doing today and so forth. Example 18 is typical of this kind of exchange. Here, one of the boys has started because he arrived a little early and there is some discussion as another student joins him, and some time is spent telling the new student about the changes which have been made to their project.
Example 18: Example showing an exchange involving greetings, etc.

R: 'Kay, I've started a -
C: Is this on?
R: Yeah.
C: Did you say your name?
(OC: This refers to the students identifying themselves for the tape recorder as they start their sessions).
R: I've put a couple of residential, just a road around.
C: Looks good.
R: OK, ah -
C: But you got crime.
R: Oooookaay.
C: if I've got it on pause. yes.
R: Let's, let's keep it on pause. OK. Let's see.
C: I gotcha.
R: And I /first */
C: */ */ this guy here?
R: /iii just click here. Crime. /I just */ -
C: /You're, ah, not bad down here. .3.
R: So -
C: Turn the music off.
R: Ooops.
C: There you go.

It can be seen from this that it is extremely unlikely that we will get any high levels of approach to knowledge until the students have begun to get a real grasp on the problems
of the day. This, then, implies a rhythm in the sessions -- initial grappling with the problem, gradually greater engagement and finally solving or abandoning the problem, followed by initial grappling with the next problem, etc. This could, indeed, cause the kind of periodicity in the levels of approach to knowledge that we have seen, but only within a single session. It does not explain why these should happen together, in different sessions, at different schools, and at different times, unless we also postulate that students at this level also can only work at a particular pace.

Alternately, these results could be artifacts caused by the random pooling of periodic data in a relatively small set. On the basis of a single study, it would be pointless to speculate further as to the significance of these graphs.

The results of the pencil and paper tests were generally very good. This is to be expected when the assessment has been closely matched to the course expectations, as was the case here. As well, deeper learning, as described by Carol Johnston (1995), benefits from a problem-based approach and this affects assessment results. She notes (ibid, on-line document)

The influence of assessment instruments on learning outcomes has already been alluded to. Where exam questions or assignment tasks elicit factual or descriptive responses students will tend to adopt a surface approach to learning as deeper learning is relatively unrewarded, White (1992). This has implications for course design as assessment instruments should be developed which require a greater degree of analysis and synthesis. Tasks developed during the course should also encourage and reward this type of thinking. Problem solving tasks provide this type of challenge.
Analysis and synthesis were emphasized on the tests given the students, as this closely matched the task given the students. This is significant in light of the fact that most students who would be learning using simulation games would need to take some kind of traditional assessment test at the end of the unit of study. Had the students been unable to transfer their learning from the computer environment to the more traditional pencil and paper environment, it would have been difficult to recommend the use of commercial simulations as learning tools, even though we have found higher levels of approach to knowledge. However, this study suggests that simulations like SimCity, at least, can elicit high-level, goal-directed discourse among students at the junior to intermediate level.

Overall then, we can see that the use of commercial computer simulations can foster higher levels of approach to knowledge and that the knowledge acquired transfers to traditional types of assessment instruments. There is still much to be done in this regard to make such simulations truly suitable for educational use. Efforts need to be made to find ways in which the students can be encouraged to move more readily between levels 4 and 5, and between levels 5 and 6. One possible way of doing this would be to add tracking sub-routines (already present in some programs) to log the students’ actions for later analysis and reflection by the students. Were the students themselves required to analyze and label their own actions as to level of approach to knowledge, it is likely that they would have a clearer idea of what we mean by higher levels of approach to knowledge, a clearer idea of the specific type of thinking we want, and a clearer idea of how it is manifested.

The analytic matrix created for this investigation proved to be of great use in identifying the various levels of approach to knowledge, and could, potentially, be applied to other investigations using transcribed interviews or material culled from online databases.
References


Available: http://www.maxis.com


Available: http://www.enoreo.on.ca/eco/curric/htm_docs/sci2nd.htm


Available: http://science.coe.uwf.edu/narst/research/metacognitive.htm


Available: http://itech1.coe.uga.edu/faculty/lriebel/play.html


Available: http://www.oise.utoronto.ca/~gwells/zpd.discussion.txt


Appendix A

SimEarth Test

Please answer all questions on the paper provided. Answer in full sentences and as completely as possible. Thanks again for doing this!

1. You have been given the mission to terraform Mars. What are the first five (5) things you would do and WHY would you choose those things?

2. Mars is very cold and your boss wants to be able to go sun bathing near the equator. How could you solve this problem, without killing your boss? WHY would you choose this solution?

3. You have lovely forests growing on Mars, but suddenly you find that there are very large numbers of forest fires destroying large areas of forest. WHAT is the problem, and HOW could you solve it? WHY would this work?

4. What is the relationship between plants, animals, heat and oxygen on your Mars? Explain as fully as you can.

5. Incredible as it may seem, your Mars is getting too hot. Give as many ways as you can think of to solve this problem. For each way you give, tell WHY it would work.
SimCity Test

Please answer each question on the paper provided. Answer each question in full sentences and as completely as possible. Thanks again for doing this!

1. Your city has a traffic problem. Give as many ways as you can think of to solve this problem. For each way you give, state WHY you think that this will work.

2. The residents of your city are angry at the mayor because housing costs are rising too high. Give as many ways as you can think of to solve this problem and state WHY each method would work.

3. Your city has little or no money. What are some ways to solve this problem and WHY would they work?

4. You have a choice between building new roads or building public transit in an industrial area of your city. The area already has some roads. Which solution would you pick and WHY should you pick that particular solution?

5. You have a bare piece of ground with no city on it. What are the first five (5) things that you would put in and WHY would choose to put in these things?