Addressing The Challenges Of Designing An On-Line Environment To Support Student Learning Through The Use Of Inscriptions And Technology-Rich Resources

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ABSTRACT

In this manuscript, we describe student use of an on-line modeling tool within an environmental science curriculum that enables students to test the effects of various environmental variables on ground-level ozone levels. This study examines student construction of inscriptions within a pre-service science classroom and their subsequent use of related resources to interpret these inscriptions. We use field notes and video taped episodes to illuminate the experience of student pairs working within this web-based learning environment. Our analysis focused on students' actions and reactions to the inscriptions that they created using an on-line modeling tool, and the interaction patterns that emerged and evolved between student use of these inscriptions and their use of the available resources. We found that: (1) Inscriptions afforded in-depth discussions, (2) the use of inscriptions is a complex process that differs among groups, and (3) students did not appreciate the complexity represented in the inscription.

INTRODUCTION

A current major trend in science education reform is an emphasis toward engaging learners in authentic activities in which students are using tools and engaged in discussions similar those of practicing scientists. For example, the National Science Education Standards proposed by the American Association for the Advancement of Science (AAAS, 1993) and the National Research Council (NRC, 1996) recommend that science education be restructured so that students develop an understanding of the processes of science rather than simply solving end of chapter problems through the application of memorized formulas. At the heart of these reforms is the notion that students need to be engaged in collaborative activities that foster the development of their understanding of investigation processes through the use scientific inquiry, the ability to ask and answer useful questions, and to understand that scientific results are tentative and need to be critiqued by their peers (Blumenfeld, Marx, Soloway, & Krajcik, 1996). To this end, there has been an increasing interest in the role that inscriptions (graphs, images, computational models) play in scientific practice (Latour, 1987). Scientists construct and interpret inscriptions (3-D graphical display of a superconducting surface) and then use their interpretations in concert with their inscriptions to construct a convincing argument that can withstand critical analysis by other members of the scientific community (Latour, 1987). Despite the central role that inscriptions play in the scientific process there have been relatively few empirical studies that have examined how students actually use inscriptions within the rough and tumble environment of actual classrooms and how students use other resources to facilitate their interpretations of inscriptions (Roth, Bowen, & McGinn, 1999).

During the past year we have been researching and developing an on-line, project-based, environmental science curriculum in collaboration with ActiveInk inc (http://www.activeink.net). Our pedagogical commitments have pushed us towards the development of participatory learning environments that support learners in collaborative exploration and scientific inquiry (Barab & Hay, Barnett, & Keating, 2000). Hence, the goal of our online curriculum is to allow learners to construct contextualized, meaningful knowledge through participation in technology-rich learning environments that support learners in discussing and evaluating their evolving understandings (Barab, Hay, & Duffy, 1998). Specifically, the curriculum examined in this study is an Air Quality Curriculum Unit in which pre-service science teachers construct graphical inscriptions through the use of an on-line modeling tool to examine how different variables (e.g. temperature, sunshine) influence the formation of ground level ozone. Using this curriculum, the goal of this manuscript is to examine how pre-service science teachers used an on-line ozone modeling tool during an integrated environmental science course to construct inscriptions (graphical representations) of ozone concentrations and how students used available resources to interpret these inscriptions.

THEORETICAL FRAMEWORK

Inscription as Scientific Practice

During the past decade, there have been an increasing number of studies that document the important role that representations play in scientific practice (e.g. Lynch & Woolgar, 1990). Following Roth and McGinn (1998) and Latour (1987), we refer to these representations as *inscriptions* because this removes the ambiguity between external and internal representations (i.e. mental models as representations). From this perspective, inscriptions are representations that exist in a physical form such as a graph on a computer screen or a computer model. Because inscriptions are physical representations they can be shared, and in turn, foster social discourse around their meaning through which understandings can be developed (Roth & McGinn, 1998).

During scientific research, inscriptions (graphs, diagrams) are frequently constructed through the examination of field notes, data tables, and computer printouts. These inscriptions are then refined and usually discussed by members of a research team before they are displayed with supporting text to enhance their explanatory power and weaken possible criticism regarding the team's research (Latour, 1987; Roth & Bowen, 1994). Inscriptions also serve the crucial role of supporting explanations and interpretations by serving as a concrete referent that scientists can refer to when arguing their case (Latour, 1987). The discourse around the inscription, as well as the evolving understanding, all become part of the scientist's "distributed cognition" (Pea, 1993).

Through the use of inscriptions scientists establish and support systems of taken-as-shared meanings by enlisting inscriptions that the scientific community has explicitly negotiated to meaning the same thing (Roth & Bowen, 1994). For example, when a chemist draws a chemical model representing how particles interact with one another other chemists know how to interpret and gain meaning from the diagram. Therefore, inscriptions (graphs) that appear in scientific journals, and conference presentations are common referents in scientific discourse. Scientists who view the inscription have a common framework upon which their understanding of the inscription is grounded and as a result engage in discourse concerning the relationship between the inscription and the natural phenomenon it represents (Kozma, Chin, Russel, Marx, 2000). As a result of this common framework, inscriptions serve as an important communication tool in that they are shareable and each member of a conversation can view the inscription and engage in a conversation concerning its interpretation (Latour, 1987). Therefore, sharing scientific inscriptions and discussing or debating their interpretations are at the root of establishing a shared scientific language and taken-as-shared scientific understandings that are crucial for the advancement of scientific discovery (Roth & McGinn, 1998; Kozma, et al., 2000).

Recently, educational researchers have begun to recognize the important role that inscriptions play in facilitating students' interactions and discussions while they are engaging in scientific investigations (Meira, 1995; Lehrer, et. al, 1998). For example, recently, educators have begun to view learning as a socio-cultural process in which learning and how one thinks and expresses ideas are the results of social interactions between and among groups of people over time within a particular culture while using the tools (i.e. inscriptions) of that culture (Lave, 1988). Hence, to fully participate in the culture of science, learners must become knowledgeably skillful with respect to how to use and interpret inscriptions as they are central to scientific discourse and arguments (Roth & McGinn, 1998). According to Meira (1995), inscriptions shape and structure the form of conversations that emerge and facilitate understanding of the relationships between various scientific phenomena. Central to Meira's (1995) framework is the establishment of taken-as-shared meanings in which groups of learners come to develop similar understandings concerning the meaning of the inscription through prolonged debate.

To date, much of the empirical work on inscriptions has focused on how scientists and students interpret and use inscriptions in constructing their arguments and how discourse is influenced by the inscription (Kozma, et al., 2000; Bowen, Roth, & McGinn, 1999). However, much like scientists students are never devoid of other resources that facilitate their understanding and interpretation of inscriptions. Since access to resources (journal articles, books) are a central component of doing science it is important to establish not only how students use inscriptions, but also how students use resources in combination with inscriptions to construct their arguments and ultimately their understanding.

Modeling as Scientific Practice

Scientists, engineers and science educators use models to concretize, simplify and clarify abstract concepts, as well as to develop and explain theories, phenomena and rules. An important value of models in science and science education is their contribution to visualization of complex ideas, processes and systems (Sabelli, 1994). A virtue of a good model is that it stimulates its creators and viewers to pose questions that take us beyond the original phenomenon to formulate hypotheses that can be examined experimentally (Penner, Lehrer, & Schauble, 1998). However, only recently have the tools that practicing scientists use to build computational models intended to visualize complex concepts and phenomena become available to students. These tools have enabled students to "do science" rather than being expected to absorb transmitted information about science, because they are using similar techniques and tools employed by many scientists to investigate natural phenomena (Penner, et. al., 1998; Stewart, et al., 1992).

Currently, many modeling initiatives support students in designing their own models, rather than educators providing students pre-developed models by experts (Jackson, Stratford, Krajcik, & Soloway, 1998; Penner, et al., 1998; Stewart, et al., 1992). When viewed from a learning perspective, the process of designing models affords students the opportunity to engage in a scientific process that begins with a set of tentatively accepted theories that co-evolve with the students' emerging understanding and in turn is transformed into artifacts that embody the students' design processes, as well as their understandings (Roth, 1996; Sabelli, 1994). During this modeling process, conversations unfold among students, among students and the teacher, among the students and their models, and the materials of their work as students attempt to create meaning through and from their constructions (Barab, Hay, Barnett, & Keating, 2000; Roth, 1996). These conversations guide the students in their examination of their model design process by evaluating their design methodologies, their justifications and arguments, as well as their existing perceptions, beliefs and understandings (Perkins, 1986; Peterson, et al., 1987). As such, students become immersed in an iterative process through which their understandings inform the development of their models (or inscriptions) and the evaluation and testing of their models inform their evolving understandings (Penner, Giles, Lehrer, Schauble, 1997).

THIS STUDY

This study occurred over a two-week period during a pre-service elementary integrated environmental science course at a large Midwestern University. There were 12 students in the class with the students working in pairs to complete the Air Quality curriculum unit. The students spent two 2.5 hour class periods on this curriculum. The trajectory of instruction in this course included a short introduction to ozone, a substantial amount of time for the students to work within the ActiveInk Network, and a 30-45 minute debriefing and discussion session that helped the students make connections between this curriculum, inquiry-based teaching and learning, and the use of such technology in an elementary or middle school classroom. For the purposes of this paper we specifically examine how four pairs of students used the on-line modeling tool to construct inscriptions, explored the on-line content resources, and engaged in conversations with one another as they worked through the Air Quality curriculum module.

Supporting Technology

The ActiveInk Network (ActiveInk) is an e-learning portal where teachers, students, and parents can explore rich, interdisciplinary projects that promote critical thinking skills, and allow students to engage in authentic investigations and projects. As part of a larger team, we recently developed learning modules for each of several environmental education domains that include air quality, wildflower diversity, water reuse, waste management, and earth systems. Each module is centered around a driving question and particular project-based artifact, such as an action plan for their community, that are explored and developed through four to six specific challenge questions. Each challenge has a set of web-based tools and resources that students can use to explore and eventually answer the challenge question and any other questions that are posed within one or more of the tools.

The Air Quality module used in this classroom supports high school and college level student inquiry into the impact of ground-level ozone on people and the environment. In this module, students are challenged to determine the chemical components and variables (e.g., volatile organic compounds, temperature, air flow) that influence the formation of ground-level ozone, develop their understanding of how these variables effect ground-level ozone and to explore and discuss the human health effects of ozone (Figure 1). The driving question for this module is “How is ground-level ozone a problem for people and the environment, and what can I do to address this problem?” The associated challenges are not meant to be explored in a linear fashion (see Figure 2) in that through both the web-based interface and the intent of the curriculum, students are afforded considerable flexibility in the manner in which they choose to approach the challenges within an ActiveInk module. The challenges for the Air Quality module are:

- What are the factors that affect ground-level ozone?
- Does ground-level ozone have health effects?
- Is ground-level ozone a widespread problem?
- What can be done to reduce ground-level ozone?
- What can my community and I do to reduce ground-level ozone?

<u>The Ozone Modeler Tool</u>. The central tool for two (numbers 1 & 3) of the above challenges is the Ozone Modeler Tool (Figure 3) that enables students to manipulate five different environmental variables and model the environmental conditions that may lead to changes in ozone levels and potentially "Ozone Action Days." Ozone Action Days are days on which ozone levels have risen to a point at which residents should be concerned about the impact on their health and alter their behavior accordingly. Students choose from three different cities, manipulate the environmental variables they wish to test, write a hypothesis and prediction, and then run the modeling tool. The resulting output is a graph that depicts the ozone levels in parts per million (ppm) over a three day period (Figure 4). The graphs produced are based on actual data for each of the following cities: Houston, Indianapolis, Tulsa. The modeler is intended to be run multiple times so students can test what happens when they manipulate each environmental variable and draw conclusions about the effect of each on the ozone levels in these urban areas. Students can save each run of the modeling tool to the ActiveInk server so they can return to previous runs or use their graphs and results in presentations, reports, and/or action plans.

Within each challenge there are also several resources available to support the student investigations. These resources are intended to be used in conjunction with the modeling tool and answer questions that arise during student tests of the modeler. Most of the Air Quality resources in the challenges with the Ozone Modeler Tool are a combination of text and graphics (What Are NO_xs?; What are VOCs?; Chemistry of Ozone; and Modeling Ozone Patterns); however, one resource is a clickable Shockwave Flash resource that uses text and animated graphics to summarize many of the important aspects from the other resources.

Data Collection

At least two researchers attended each day as the ActiveInk Air Quality curriculum unit was implemented and took detailed field notes on students' interactions with each other, the ozone modeler tool, and the other on-line curriculum resources. Following these observations each researcher entered their field notes into an online database where other researchers could review them. Complementing the researchers' field observations each student pair were video recordings for each student pair, which allowed us to capture student gestures, dialogue, and their use of the online modeling tool and related content resources. In addition we also have pre-post test data with respect to their understandings of Ozone and what contributes to its production as well as in-depth interviews with the students. Lastly, we interviewed the teacher multiple times throughout the unit to determine his interpretations of the value of integrating this technology into his curriculum, and especially how it supported (or did not support) students' evolving understandings with respect to issues of air quality. For the purpose of this study, we have chosen to focus on the video-taped episodes of students using the Ozone Modeler Tool and the accompanying field notes.

Data Analysis

Similar to Kelly and Crawford's (1996) approach of examining student discourse evolution around the use of computer generated inscriptions we focused our analysis on students' actions and reactions to the inscriptions that they created using an on-line modeling tool, and the interaction patterns that evolved between student use of these inscriptions and their use of the available resources. To this end, we transcribed a total of nearly 20 hours of classroom episodes for these four pairs of students in which the students were using the on-line modeling tool and the associated content resources. Analysis began with writing up case studies describing how each of the four pairs interacted with the modeling tool. Because of journal space limitations, abbreviated versions of the case studies are presented below. From here, we read through the case studies and generated cross-case interpretations and assertions (Merriam, 1998). These assertions, rather than being imposed on the data, emerge from our examination of the cases and each assertion was based on consensus among the researchers. This analysis allowed us to examine in detail how pairs of students used the ozone modeling tool within the context of the on-line environment and how the inscriptions they created influenced their understanding of the relations between variables that impact the formation of ground-level ozone.

RESULTS

In this section we present the interactions of four student groups as they worked with the Ozone Modeling Tool and the content resources. Each group had a particular approach concerning how they used the modeling tool, the inscriptions they created and the content resources.

Student Group #1: Ann and Travis

Generally, at the beginning of the unit both Ann and Travis had little knowledge of the environmental conditions that led to the formation of ground-level ozone. They also believed that ground-level ozone was something that was of little concern to them, and had little background knowledge concerning the environmental variables and chemicals or the relationships among them that leads to the formation of ozone. When Ann and Travis began one of the challenges in which the ozone modeler tool was embedded they first decided to read the various resources available to them within this section of the on-line curriculum. Ann and Travis systematically went through each of the available resources, starting with What are VOCs, then moving to Chemistry of ozone, and finishing with What are Nitrogen Oxides. Initially, they focused on detailed reading the resources frequently pointing to the computer screen, but they soon began to simply skim the resources as seen in the interactions below:

Speaker	Comments	Actions
Ann:	Are you understanding [asking Travis] what this is supposed to mean	Asking Travis a question about one of the resources. Pointing to the computer screen [reading about Volatile Organic Compounds (VOCs)]?
Travis	I think it has something to do with um, well the more of the VOCs the more ozone is formed, but I'm not sure. What do you think?	Reading the on-line resource
Ann	Maybe we should go use the modeler	Pointing to the icon that

Travis	Ok, maybe that will help us figure out what this means	Pointing to the resources on the computer screen.

From this interaction we see that Ann and Travis began their investigation of ground-level ozone in a manner that is quite similar to that of professional researchers. They first began to conduct an information search or literature search (using the resources) to uncover what is already known about ground-level ozone. However, the resources did appear to be confusing to Ann and Travis as they experienced difficulties in establishing the relationships between the variables described within. However, through their struggles they concluded that they would need to use the Ozone Modeler Tool if they were to develop a more complete understanding of the science content relevant to this investigation.

Initially, Ann and Travis had difficulty in understanding how to use the modeling tool, but quickly determined that they could manipulate the variables that they had just been reading about in the content resources. Much like their initial reading of the content resources their initial modeling attempt was quite systematic in that they chose to leave all the variables at their default setting because Travis believed they needed to "set a baseline so they would have some idea of what a normal level of ozone was and once we know that we can tweak the variables to find out what causes the most ozone". Upon running the model they produced a graph (inscription) that showed ground-level ozone concentrations well below the Environmental Protection Agency's (EPA) guidelines for declaring an ozone action day (0.085 ppm). However, in the first graph they created with the modeler, Travis and Ann quickly noticed that the ozone concentrations decreased over time (3 days) as seen in the following exchange:

Speaker	Comments	Actions
Ann:	Ok, hmm, it looks like the ozone levels go down.	Pointing to the graph with an emphasis toward day 2 and day 3 of the model.
Travis	Ok, so lets go back and run it again by changing something.	Clicking on the back button to return to the ozone modeler tool.

Upon returning to the ozone modeling tool Travis and Ann began to discuss the meanings they were developing from the resources and how those meanings would influence their use of the modeler and in turn the type of inscription they would create with the ozone modeler as presented in the below interaction:

Speaker	Comments	Actions
Travis	Ok, lets change the temperature and make it sunny	Changing the sunlight variable from cloudy to sunny and increased the temperature
Ann	Ok, so our hypothesis is that the hotter it is the more ozone will produced. So the ozone levels will go up the sunnier it is.	Typing in their hypothesis into the textbox area on screen.
Travis	Ok, lets run the model	Clicking the run button
Ann	Ok, so it looks like the ozone levels are higher. But why are they higher? Why does sunlight matter?	Pointing to the screen (Figure 2).
Travis	Well, I think I remember reading that the sunlight does something to speed up the chemical reactions, uh, maybe it has to do with the VOCs or something. Lets go back and check.	Returning to the resources page that discusses VOCs.
Ann	Ok, there it talks about that ultraviolet light increases the speed of the chemical reactions.	Skimming through the resources quickly looking for clues concerning the influence of sunlight.

Here we see Ann and Travis using the ozone modeling tool, their inscription (graph of ground-level ozone), and the content resources reflexively. That is, Ann and Travis first used the resources to develop a minimal background so they could use the modeling tool, then ran the ozone modeler with the hypothesis that sunlight increases ozone formation, and then questioned their results to try to determine why sunlight makes a difference. Through that questioning they determined they needed to know how sunlight effects the chemical reactions that form ground-level ozone and how VOC's play a role in this process. It is important to note that although Ann and Travis were able to draw a scientifically accurate conclusion from their investigation regarding the relationship between sunlight and increased ozone levels, they transcripts and videos suggest that they may mistakenly equate sunny days with warm days. Both temperature and sunlight contribute to ground-level ozone proliferation, but we can easily imagine a very sunny day in winter, on which ozone levels would not increase to the same extent as a summer day with a similar level of sunlight.

Following their discussion and evaluation of their findings, Ann and Travis decide they should investigate another variable. As reflected in the following discussion, they choose to examine how Air Flow impacts ground-level ozone formation:

Speaker	Comments	Actions
Travis	Ok, lets change the air flow, or whatever that is, and see what happens.	
Ann	Ok, let's change it all the way up.	Changes the Air Flow rate from 0% to 20%.
Travis	So our hypothesis should be that ozone goes down and our prediction will be that it goes down.	Runs the ozone modeling tool.
Ann	Ok, so it looks like the ozone levels are lower than before.	Pointing to the graph on screen (Figure 3).
Travis	So, whatever Air flow is it must reduce ozone	Pointing to the graph focusing on day 2 and day 3.
Ann	Yeah, but what is Air Flow?	Clicking to go back to the online resources. Systematically skimming each resource to find information.

We see that Ann and Travis are going through a similar process as they did during their initial experience in using the ozone modeling tool. During this particular iteration they began their inquiry by asking how Air Flow influences the formation of ground-level ozone. To this end, they changed the level of Air Flow and ran the modeler. They then used the resulting inscription in combination with their previous inscription to conclude that increased Air Flow reduces ozone concentrations. Here the graph or inscription plays a larger role in their discussion than previously because they now have multiple inscriptions that they can draw upon in determining the impact of Air Flow. Despite their correct interpretation of their graphical inscriptions they could not determine why Air Flow decreases ozone concentrations in part because they skimmed through the content resources without carefully reading and discussing them and they continue on to investigate how temperature impacts ground-level ozone formation:

Speaker	Comments	Actions
Travis	Ok, now lets change the temperature and make it sunny.	Changing the temperature variable to a lower setting and the sunlight level to a higher setting.
Ann	So ozone should go up right?	
Travis	Probably, I think because of the sunshine	Typing their hypothesis and prediction.
Ann	Hmm, looks like it stayed about the same I think.	Referring to graph in Figure 4.
Travis:	Ok, so sunshine seems to be very important	Ann types in their results and states that they were right about the effect of sunshine on ozone concentrations.
Travis	Ok, now lets reduce the air flow to the lowest value, but keep the temperature the same.	Changing the parameters and runs the model.
Travis	So ozone level should go down because their will be less heat right.	
Ann	So air flow has to do with heat?	
Travis	I think it does.	Changing the air flow parameter back to 0% exchange and runs the model.
Ann	Ok, so it looks like the ozone levels went up. Do you know why that happens?	Pointing to the graph on their computer screen (Figure 5).
Travis	Not sure, I bet that animation might tell us though. It was that one there.	Clicks on the Ozone formation resource, and watches the animation.
Ann	Do you see anything?	Looking at the on-line animation showing ground-level ozone formation
Travis	No, but I think I heard Mike tell another group that air flow was sort of like wind, so perhaps if it is windy there is less ozone.	Searching for the answer in the resources. Skimming the text base resources until they find the answer.

Initially, Ann and Travis began their inquiry by reading the background resources; however, as their inquiry deepened they began to reflexively use their constructed inscriptions and the content resources in developing arguments concerning how certain variables influenced the formation of ground-level ozone. For example, Ann and Travis would manipulate the ozone modeler variables to construct a graph and then refer to the resources to gather additional information concerning why or how the variable would effect ozone concentrations. Further, the inscriptions themselves served to foster discussion, particularly when the students were struggling to understand the relationship of the manipulated variable to the level of ozone represented in their graphical inscriptions. For example, Ann and Travis changed the level of sunshine during one run of the modeler and then later changed the Air Flow. However, to make sense of the changes they compared the two inscriptions to determine the impact of each variable by examining the general slope or trends in the specific graphs. During this time, they made a misinformed prediction that as the Air Flow decreased, the ozone levels would go down because of some connection between Air Flow and heat. They soon remembered the instructor mentioning a relationship between Air Flow and wind patterns and were able to use the accompanying resources to verify their ideas. Therefore, Ann and Travis began to interpret their inscriptions by using specific features of the graphical display in conjunction with their experiences to reflect on and explain their evolving understanding to one another.

Student Group #2: Heather and Jami

Similar to Ann and Travis, at the beginning of the unit neither Heather nor Jami had an understanding concerning the variables that influence ground-level ozone or about the relationships between those variables. However, unlike Ann and Travis above, Heather and Jami immediately began their work by starting with the ozone modeler tool rather than systematically reading through the content resources. They begin their inquiry by changing the temperature and hypothesizing how different temperatures would influence the formation of ground-level ozone as shown in the interactions below.

Speaker	Comments	Actions
Jami	See we need to change the temperature to these numbers [changing the temperature]. So we can change it to be either high or low.	Pointing to the variable temperature within the ozone modeling tool.

		Changing the temperature.
Heather	Ok, so if the temperature is high we will…	
Jami	We will probably have more ozone I bet, because there is just more energy around, … or at least that is what I remember Mike (the instructor) saying before about something	
Heather	Typing in their hypothesis, being read by Jami	
Jami	Ok, so the higher the temperature the higher the ozone concentration will be	
Jami	Ok, so our prediction will be that if we increase the temperature the ozone levels will go up	[clicks on run]. Graph appears on the screen.
Heather	Ok so now we need to go back and change something else and see what happens.	Looking and pointing to their new graph.

Through this interaction we see that discussion centered on the modeling tool is central to how Heather and Jami try to make sense of their task. However, the inscription did not serve to foster discussion in this instance and, in fact, much of their discussion was focused around how to use the ozone modeler and what will happen when they manipulate a particular variable. Heather and Jami also approached using the modeling tool differently in that they did not choose to run any initial trials of the modeling tool in order to establish a baseline for comparison and/or discussion. However, despite not discussing the meaning of their graph, they continued to explore the ozone modeling tool and manipulated other variables as shown below:

Speaker	Comments	Actions
Jami	What do you think we should change?	Clicks on Back button.
Heather	I don't know, just go back and change something and see what happens.	Pointing the variables they can change.
Jami	Ok…	Decreases the temperature and runs the modeler. Graph appears.
Jami	So it didn't change. No wait I think it did change. Look it goes down.	Tracing her finger over the graph. (see Figure 5) Referring to decline in the peak levels of ozone

		during the three day period.
Heather	I think it did that before though.	
Jami	Ok, lets go back and look again	[Looking at the variable settings that they picked this time]
Jami		Changes the temperature up one more, down another
Heather	Ok the whole thing moved down	Looking at the graph.
Jami	Ok, so that means that ozone decreases as the temperature goes down.	Pointing to their graph.
Heather	Typing in their findings, discussing with BrG: The lower the temperature the lower the ozone concentrations will exist.	Saves their file.

In this interaction Heather and Jami used multiple inscriptions to help make sense of their findings. Initially, they increased the temperature and found that ozone concentrations increase, next they decided to decrease the temperature and then struggled concerning their finding. That is they were unsure of the effect of temperature. However, this confusion appeared to arise from the fact that their inscription shows a three day period and that over that time, under the given condition they used in their model ozone concentrations decrease over time. Heather and Jami apparently had a difficult time in interpreting the graph to start with. However, they go back and run the model and then find that the ozone levels across the whole graph moved down so the total ozone concentrations are decreased. Heather and Jami then decide that they should manipulate other variables such as the amount of Nitrogen Oxides and Air Flow below:

Speaker	Comments	Actions
Jami	Ok, lets increase the Nitrogen levels.	Increasing the levels of nitrogen oxide
Heather	Want to change the weather too? [do not change it]	
Heather	Waiting for the graph to show, begin discussing the air flow. [Error on graph]	
Jami	I think it (air flow) will blow a lot of the	

	stuff out if it is a windy day.	
Heather	Ok, so we should change that to be larger.	Referring to Air Flow
Jami	Ok, so our hypothesis will be how much will ozone concentrations change when it is windy.	Typing their hypothesis into the available text box
Jami	Ozone concentrations will go down when the air flow increases. Hmm, but why.	
Heather	Why does the air flow matter?	Students click on the Air Flow link in the ozone modeler and read about what Air Flow. Students appear to interpret Air Flow as meaning windy.
Jami	You know what I am trying to say, the wind will just blow all the stuff out. It will circulate and disperse the ozone	Runs the modeler. Graph appears.
Jami	See before the ozone levels were way up here	Looking at the graph, traces her hand over it.
Heather	Ok, so it did bring it down, you were right.	
Jami	So the windier it is the ozone concentrations will be dispersed.	

Generally, the students are experimenting and changing variables to simply observe the effects of the variables on ozone concentrations and this process sparked exploration. For example, these students ran the ozone modeler and found that ozone concentrations were lower with greater air flow levels. The results of this iteration resulted in further investigation concerning the effect of Air Flow and led to a discussion concerning why Air Flow might be lower. However, at this point the students are still unsure as to what Air Flow actually means and click on the word Air Flow to get the definition for Air Flow and interpret the definition of Air Flow (the amount of air flowing in and out of the city) to mean windy. Using this information they discuss how their inscription shows that increased Air Flow reduces ozone concentrations. Through this iterative process the students decide to run the modeler again and make the prediction that “the greater the airflow, the less buildup of ground-level ozone because the airflow will circulate and disperse the ozone molecules.” Upon running the ozone modeler again they concluded that increased Air Flow does indeed decrease ozone concentrations. However, the students were not fully satisfied with their findings and begin to inquire into where the ozone goes if it is not in the city they are studying:

Speaker	Comments	Actions
Heather	Where does it (ozone) go?	
Jami	I don't know. Blown out of the city? [laughing]	Run the modeler again, changing the air flow to an even higher value
Jami	So it really should go down now right?	
Jami	It should if last time it went down, by looks like half. Uh, look at it, it is much lower now, so we were right	[pointing to their graph]. Saves their file and goes back to the modeling tool.

In this iteration, Heather and Jami use their previous graphical inscriptions as baselines so they can determine if Air Flow truly does impact ozone concentrations. Hence, Heather and Jami's use of multiple graphs to help them interpret their current inscription and to verify their previous interpretations. The use of multiple inscriptions is important because other students often appeared to be basing their conclusions on single observations. Following their investigation of Air Flow, Heather and Jami decide that the amount of sunlight should be examined to determine its impact on ozone formation:

Speaker	Comments	Actions
Heather	Want to make it all sunny now. What do you think will happen. I don't know maybe we should change the air flow and the temperature first	[max out both values]
Jami	Ok, so the greater the temperature the greater the ozone concentration buildup, but the greater the wind the smaller the ozone concentrations buildups.	
Heather	So the ozone concentration will be more or less?	
Jami	I think it will be a little higher	
Heather and		Looking at their graph and it does show that

Jami:		ozone concentrations are higher.
Heather	Ok, so it increased with temperature.	
Jami	OK, so now what do you think we need to do?	

The students increase the temperature and try again. They do go to the bottom of the page this time and decide to fill out the text boxes and save their work. They seem to have come up with a reasonable hypothesis about changing temperature. The graphs make it easier for the students to compare and contrast their findings and through this comparison the students can make claims concerning the impact of changing Air Flow and how it impacts the formation of ground-level ozone.

Speaker	Comments	Actions
Heather	Ok, since we have already used the modeler, should we read some of the materials (resources) about ozone.	Pointing to the computer screen
Jami	Ok, starts with What is VOC's.	Reads the content resources about Volatile Organic Compounds
Jami	Ok, so it appears that the more VOC's the higher the ozone levels will be.	Continue reading the resources with little discussion.

After four iterations of using the ozone modeler the students decide that they should read the content resources. However, in their reading of the content resources the students do not return to reinterpret their inscriptions, but simply read the content resources to either verify their previous findings or learn about the other variables. The students do not return to the previous inscriptions to re-interpret their findings nor do they again use the modeler to test how the other variables influence the formation of ground-level ozone. It is not clear why these students have shifted in their approach.

Student group #3: Mary and Ryan

Mary and Ryan like the other groups had little initial background knowledge concerning ground-level ozone and how it is affected by different environmental variables. Mary and Ryan, similar to Heather and Jami, jump right into using the Ozone Modeler Tool and begin to explore how to manipulate the variables in the ozone modeling tool:

Speaker	Comments	Actions
Mary and Ryan		Open up the ozone modeling tool
Ryan	Point to the screen. Look there is a place for us to enter our hypothesis.	Start exploring how to change the parameters
Mary	Ok, I see. Looks like we can change the temperature up to 80 degrees.	
Mary	So lets say the higher the temperature the higher our ozone concentrations.	
Ryan		Typing in their hypothesis.
Ryan	What is our prediction.	
Mary	Ozone concentrations will go up.	
Ryan	Typing them in. [runs the modeler]	
Mary		Gets a graph of ozone concentrations.
Mary and Ryan		Looks at the graph that shows ozone concentrations are higher.
Mary	So our hypothesis is correct. The higher the temperature the higher the ozone concentrations. Well we knew that (sounding a bit unsure)	Pointing at the graph.

It is important to note, that Mary and Ryan did not run the modeler with the baseline values, hence their interpretations of their graphical inscription with the temperature raised is partly based upon their previous understanding of what factors influence the formation of ground-level ozone. They have also based their interpretation on a single trial.

Speaker	Comments	Actions
Mary and Ryan		They go looking around at the other tools.
Instructor	Do you understand what you are looking at when you look at the model?	

Instructor	You go over here to learn more about it [pointing to the resources] Don't just accept anything on there without trying to understand it.	
Ryan		Clicks on an Ozone Formation animation that shows how the variables in the modeler interact with one another.
Mary	Ok, I see what happens, the Oxygen goes away and binds with the other oxygen.	
Ryan and Mary		Laughing at the sunlight coming in an breaking apart the molecules in the Ozone Formation Animation. They go on the read about the chemistry of ozone.
Ryan and Mary		Finish reading the other content resources

Ryan and Mary were relatively unengaged in this unit and were primarily trying to find the quickest way to answer the questions they had before them. There was little conversation or dialogue between them and any information that they could glean from their graphs or the content resources was quickly interpreted and translated into something they could use to answer questions within one or more of the tools.

Student group #4: Renee and Jacob

Both Renee and Jacob began the project with little knowledge of ground-level ozone and in fact believed that ozone was a major factor in global warming. Further, it is interesting to note that our pre-interviews indicated that neither Renee nor Jacob believed that ozone was a serious environmental issue. They began their work with the Ozone Modeler Tool by simply jumping into using it without consulting the content resources or the ozone modeler tutorial. In the following interactions we pick up Renee and Jacob as they are beginning to use the ozone modeler:

Speaker	Comments	Actions
Jacob	Want to do what they already have in here once and then we can adjust them the next time around.	
Renee	Yep	
Jacob		Examining and commenting on the default variables in the ozone modeler
Renee	It is a pretty hot day, so…	Pointing to the default temperature
Jacob	It doesn't have the time or day, but it does look like it is going to be hot.	Nodding his head
Renee	Ok.	Typing: "We think the ozone levels will be high due the temperature." Runs the modeler
Jacob	So it is going down. I wish it had more numbers along the side.	Looks at their 3 humped graph with a downward slope
Renee	It looks like it is around 0.6 or so? Do we need to do another prediction?	Pointing to their graph.
Jacob	Maybe we can predict what is going to happen next.	
Renee	Ok	Typing: Results show that ozone levels are actually decreasing
Renee	What your prediction correct?	Reading a question on screen.
Renee	Hmmm, ….	No our results were not correct. The ozone levels appear to be going to down over time. Not sure why this is.

In the above interaction Renee and Jacob used the modeler to construct an initial inscription that showed the ozone concentrations for a particular city (Houston) on an average day. However, Renee and Jacob did not engage in discussion concerning the meaning of their graph despite the fact that they noticed that the graph had a downward slope over the three day period that the graph was representing.

This is troublesome, because they misinterpreted the resulting graph. Their hypothesis was that "We think the ozone levels will be high due to the temperature." However, the resulting graph, or inscription, showed the ozone levels decreasing over the subsequent three-day period. Again this is due to their lack of knowledge in terms of establishing a baseline of data and their inability to correctly read and interpret the graph. The students did acknowledge that their initial prediction was incorrect, but did not comment about why that might be the case. During this interaction, both Renee and Jacob were essentially guessing at what they believed needed to be done and eventually decided that they should read the ozone modeler tutorial and the content resources.

Speaker	Comments	Actions
Jacob	Ah, see maybe we should have manipulated the variables to start off with.	Pointing to the ozone modeler tutorial screen.
Renee	Which ones?	They read the ozone modeler tutorial
Jacob	Maybe we should go over there and read and see what they say	Points to the Content Resources and suggests that they should be read. Students then read the resources.
Renee	Oh!, I think we can do much better now.	
Jacob	Ok, lets go back and fill in what we think contributes to ozone levels	Referring to a question in the curriculum.
Renee	What kind of answer are they looking for?	
Instructor	They are looking for things that were in the model. That you could change and see the relationship between those things. That is how I interpreted it.	Pointing to the students' computer screens.
Renee	Oh, that thing where you can pick the three cities (the ozone modeler).	
Instructor	Yep that is how I interpreted it.	
Renee	Do you remember?	
Jacob	I remember some of them, but lets go back and check.	
Renee	So temperature, location, and sunlight.	They are reading the variables listed in the

		ozone modeler tool
Renee	I will remember VOC, and sunlight and you remember these two.	Begin to type in the factors that influence the formation of ground-level ozone.

From above we see that Jacob and Renee choose to read the content resources and after reading the resources believe they can use the modeler much better in figuring out the relationships between the variables that influence the formation of ground-level ozone. The instructor enters the episode and provides the students some guidance concerning how to answer some of the questions they are expected to answer by working with the modeling tool. However, the students rather than returning to the modeling tool to test their understanding of the content resources, simply decide to memorize the variables that they can manipulate in the ozone modeling tool as the variables that influence ozone formation. This information is used to answer several questions in one of the other tools within this particular challenge. Hence, the students only determine that the variables that influence ground-level ozone and do not investigate the relationships between the variables. For some reason, even though these students were on the right track, they choose the path of least resistance and simply decided to find the "correct" answer within the resources and other tools.

DISCUSSION & CONCLUSIONS

Through our observation and analysis we found certain patterns emerging concerning how students use the ozone modeling tool, content resources, and developed interpretations from their inscriptions. We found that students' interpretations were mediated by both discussion with and about their inscriptions and how and to what extent they used the content resources (see Figure 6). In particular, if students were to be engaged in rich conceptual conversations there needed to be an interplay between the inscriptions, discussion, and use of the content resources. That is, when students took advantage of the content resources their conversations about their inscriptions enabled the transformation of their inscription from a "object" to a tool through which they could develop understandings concerning how different variables influenced the formation of ground level ozone. However, as the students inquiry deepened it became clear that the technology could be interrupting the relationship shown in figure 6 and be more like that shown in Figure 7. That is, the ozone modeler "black boxed" the process of actually constructing inscriptions because the students did not have a hand in collecting the data that went into the model nor were they able to create the form of the resulting inscription. As a result, the students often did not realize the relationship between the referent (their inscription) and the referred (the variables being manipulated). Hence, in these instances, the discussions that ensued around the inscriptions focused more on the features of the inscription (such as ozone levels decreasing) rather than on the relationships between the variables that lead to the formation of the inscription.

In the following discussion we examine the above issue in more detail by putting forward three assertions that represent the core relationships concerning students use and construction of inscriptions to learn science. Specifically, upon examination of student interactions we put forth the following three assertions: (1) Inscriptions afforded in-depth discussions, (2) the use of inscriptions is a complex process that differs among groups, and (3) students did not appreciate the complexity represented in the inscription.

Assertion #1: Inscriptions afforded in-depth discussions

Students in this study made explicit connections between their inscriptions, their evolving understandings, and their use of the modeling tool. For example, Heather and Jami constructed and examined multiple inscriptions (e.g., their graphs) of ozone concentrations that were based on varying amounts of Air Flow. During and as a result of these multiple iterations they engaged in discussions in which they wrestled with the connection between Air Flow and the formation of ground-level ozone. Through these discussions, the students could reason with their inscriptions and make evidence-based conclusions concerning the impact of the manipulated variable on ground level ozone formation. Similarly, Ann and Travis engaged in a prolonged discussion that was sparked by a previous iteration of constructing inscriptions using the ozone modeling tool. In this case, Ann and Travis went through multiple iterations of using the ozone modeler to construct inscriptions that they interpreted to represent the impact of these variables (temperature, sunshine, and airflow) on ground-level ozone concentrations. As a result, they were able to engage in discussions and construct arguments about the influence of the manipulated variables. It was through these discussions that their inscriptions played the role of mediator in that the students were able to point to and focus on the same features of the inscription when making their argument. During these instances the students diverse understanding of the impact of the manipulated variable could be made tangible and visible, because their inscription was a shared object that each student could refer too. This observation was consistent with Salomon's (1993) description of cognition as distributed among individuals, individuals and environments, and especially individuals and technologies.

It is important to note that some student groups superficially examined their inscriptions without critically examining and discussing the complexities embedded in them. In these instances, the student discussion was limited to simply process and goal oriented conversations in an effort quickly determine the "correct" answer. For example, when Mary and Ryan changed the temperature and examined the graph they simply noted that the ozone levels increased with increasing temperature, however these students did not investigate or discuss the trend in the graph over the three day period, nor did they investigate the ground-level ozone concentrations in relation to baseline levels. Therefore, at times, it was difficult for the students too look beyond the surface features of their inscriptions, instead taking them at face value rather than engaging in discussions about how and why a variable effects ground-level ozone concentrations.

<u>Assertion #2: The use of inscriptions is a complex process that differs among groups</u>

Each pair of students used the ozone modeler to construct and manipulate variables that influenced to the formation of the ground-level ozone in similar ways, but how students used the accompanying resources to facilitate their interpretations varied greatly from group to group. For example, Ann and Travis used the content resources and their inscriptions reflexively in that they used them to help interpret and construct meaning from the graphical inscriptions they constructed using the Ozone Modeler Tool. Ann and Travis, though using an iterative process among resources and the modeling tool, had difficulty in both interpreting the graphical display that the modeler produced and deciding how to systematically test the variables as they used the modeling tool. However, when they began to read the content resources, the arguments that they had put forth while examining their inscriptions began to evolve and change. They would then go back and forth between the modeler, the resources, while at the same time having rich discussions. It was this iterative process of constructing inscriptions, discussion, reflecting, then constructing additional inscriptions, and then discussion of these new inscriptions facilitated the development of rich conceptual talk among students.

There were also examples in which the students did not use their inscriptions and resources in combination with one another. That is, at times the students simply used the content resources as a isolated textbook that held the answers to the questions they were expected to answer as they worked through the curriculum unit. For instance, Renee and Jacob simply used the variables in the ozone modeling tool as their final solution concerning what variables influenced the formation of ground-level ozone. In a similar fashion Mary and Ryan used their initial constructed inscriptions as an exploration into a few variables that effected the formation of ground-level ozone, however, their investigation did not evolve further than simply using their inscriptions as an inquiry tool and the content resources as a source of information through which they could obtain answers to the questions being asked of them by the curriculum.

The conception of using tools and resources in concert with one another is contrary to many traditional forms of teaching and learning. For example, many students have grown accustomed to simply finding and memorizing information within very structured environments (ref). When students learn in this manner they frequently develop inert knowledge such as knowing the scientific terms, but not understanding their relationships to other scientific concepts and principles (Wallace, et al., 2000; Whitehead, 1929). Therefore, it is critical that students be supported in developing their understanding of how to proceed within the realm of science when the tools and driving questions serve as the central means through which inquiry is conducted and the resources are simply there to serve as a just-in-time resource. Once students develop such understandings, it is possible that they will engage in more meaningful discussions and feel more comfortable about developing their own hypotheses and opinions, rather than simply searching for the "correct" answer through trial and error or deferring to the nearest text-based resource or authority (i.e. the teacher). The challenge for the instructor is to facilitate a dynamic interplay among tool use and resource use.

Assertion 3: Students did not appreciate the complexity represented in the inscription

Students would frequently develop naïve interpretations of their inscriptions in the absence of conceptual discussion and reflection, frequently because they failed to conduct systematic tests of the effects of each variable in the Ozone Modeler Tool. For example, students often manipulated multiple variables during a single run of the modeler. This was most evident when Ann and Travis appeared to equate sunny days with warm days. At one point, they chose to increase both the amount of sunlight and the temperature as Ann stated “Ok, so our hypothesis is that the hotter it is the more ozone will produced. So the ozone levels will go up the sunnier it is.” While both temperature and sunlight do contribute to ground-level ozone proliferation, it is also possible to have a very sunny winter day on which ozone levels would not increase to the same extent as a summer day with a similar level of sunlight.

Other student groups also changed more than one variable at a time. Heather and Jami took a somewhat haphazard approach toward deciding what to change and by how much. At one point they considered changing three variables at once. Heather stated “Want to make it all sunny now? What do you think will happen? … I don’t know maybe we should change the air flow and the temperature first.” They decide to set air flow and temperature to their highest levels. This creates a unique situation because the effects of these variables are inversely related; as air flow increases ozone levels decrease, and as temperature increases ozone levels also increase.

An additional problem was the number of trials that students ran before making a conclusion about the effect of an environmental variable on ozone levels. Students commonly based their conclusions on a single test of the model. This was problematic both in terms of making grounded conclusions based on repeated trials and evidence, but the students also often failed to even establish a baseline set of readings for future comparison. For example, Ryan and Mary chose to examine the effect of increasing the temperature on ozone levels. The first time that they opened the Ozone Modeler Tool they increased the temperature to its highest level and ran the model. For some reason, they concluded that their ozone levels are “high” and that as you increase temperature ozone levels increase. As reported above, Mary stated “so our hypothesis is correct. The higher the temperature the higher the ozone concentrations.”

There are several potential reasons why the students did not typically test the effects of the environmental variables in a systematic manner. First, almost none of the groups examined the Ozone Modeler Tutorial that was available. Second, and most importantly, the instructor in this class did very little to support the students during their investigations. There was very little talk before or during time on the computer about how to use the modeling tool, how to systematically test the effects of variables, or how to discuss and interpret the graphical inscriptions. For example, with Renee and Jacob the instructor discussed how to use the ozone modeler without engaging the students in discussion of how to critically examine the impact of each variable on the formation of ground level ozone (i.e. examining one variable at a time and comparing their impact to the baseline graph and then begin to examine the relationships between variables). In facilitating such environments it is crucial that the instructor be aware that students typically will not systematically examine how to manipulate multiple variables or how to conduct their own research to assist them in interpreting their inscriptions.

IMPLICATIONS

While the use of inscriptions is pervasive in science courses and textbooks, students are expected to use, interpret and learn from the different types of inscriptions use different representations and language, than do scientists, and they use them in different ways (Roth, Bowen, & McGinn, 1999; Bowen, Roth, & McGinn, 1999). As was evident in this study, inscriptions can play a crucial role in supporting student discussion about complex scientific phenomena. However, there are a number of other variables such as the availability of content resources and technology that influence how students use inscriptions to construct their interpretations of scientific phenomena. To date, however, there have been few empirical studies that have examined how students use content resources and inscriptions within a technology rich environments to develop understandings of scientific concepts. Yet, as this study documents, students can flounder considerably without an appropriate level of support from the instructor and the learning environment about how to conduct a scientific test and how to interpret inscriptions such as graphs.

Substantial research has been conducted concerning the role of external representations in individual problem solving, generally showing that the kind of external representation used to depict a problem may determine the ease with which the problem is solved (Kozma, et al., 2000). One person can ignore discrepancies between external inscriptions, but an individual working in a group must constantly refer back to the shared external inscriptions while coordinating activities with others. Thus it is conceivable that external representations have a greater effect on individual cognition in a social context than they do when working alone (Roth & McGinn, 1998). More generally, whether we are referring to a social context or not, we view computers as having the potential to scaffold understanding by distributing cognition (Salomon, 1993).

Computer-based inscriptions from a modeling tool within an electronic environment with a relatively limited amount of flexibility in terms of its output can create unique challenges for student learning. In this study, students changed the environmental conditions through the modeling software in order to run a simulation based on actual data. The output was a graph within a constrained electronic environment, rather than something that was generated by the students. As a result, interpretation of these inscriptions was mediated through the format and structure of the graphs in this environment rather than through the construction of the inscriptions themselves. For example, the graphical output displayed ozone levels only in parts per million over a three day period. In addition, the range of the outputted data dictated the range of the Y-axis. Therefore, if the highest peak on the graph was relatively low (0.05 ppm), then the Y axis may end at 0.08 ppm. Whereas if the highest peak was relatively high (0.19 ppm), then the Y axis may end at 0.22 ppm. There is a distinct possibility that the amount and quality of student dialogue may differ significantly between contexts in which students are examining computer-mediated inscriptions versus student-generated inscriptions in other contexts.

In sum, this study extends the growing research base (Harrison & Treagust, 2000; Jackson & Songer, 2000) that could inform instructional designers in the development of curriculum that supports students in producing inscriptions around which classroom dialogue can emerge. For example, when students are engaged in the process of externalizing their thinking in the terms of models, valuable conversations that support learning can unfold as they attempt to create meaning through and from their constructions (Roth, 1996). However, as this study shows there are numerous challenges and issues that science educators and instructional designers should be cognizant of when designing technology-rich learning environments that involve students using tools to construct inscriptions.

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Figure 1. Screen Shot of the Air Quality Project Level Home Page

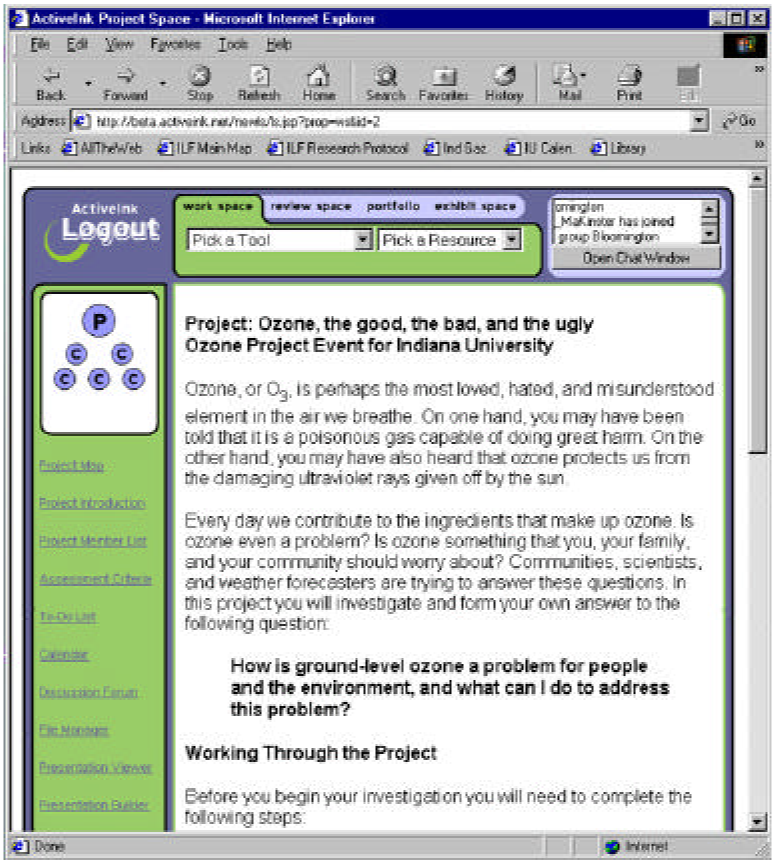

Figure 2. Screen Shot of the Air Quality Project Map

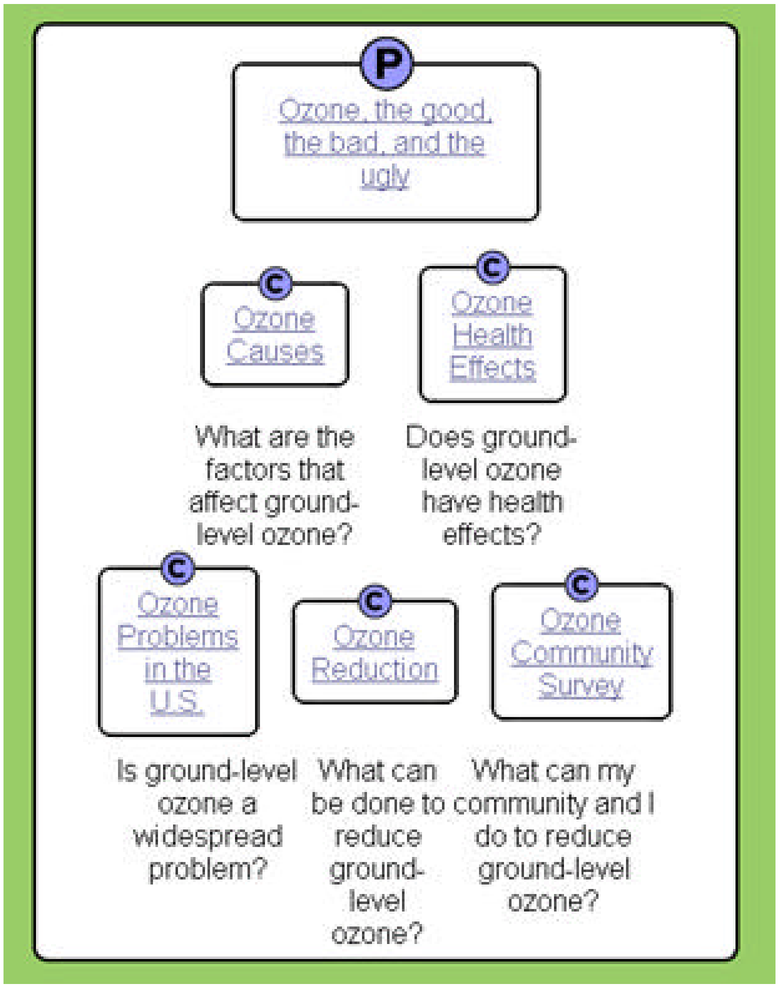

Figure 3: Screen Shot of the Ozone Modeler Tool

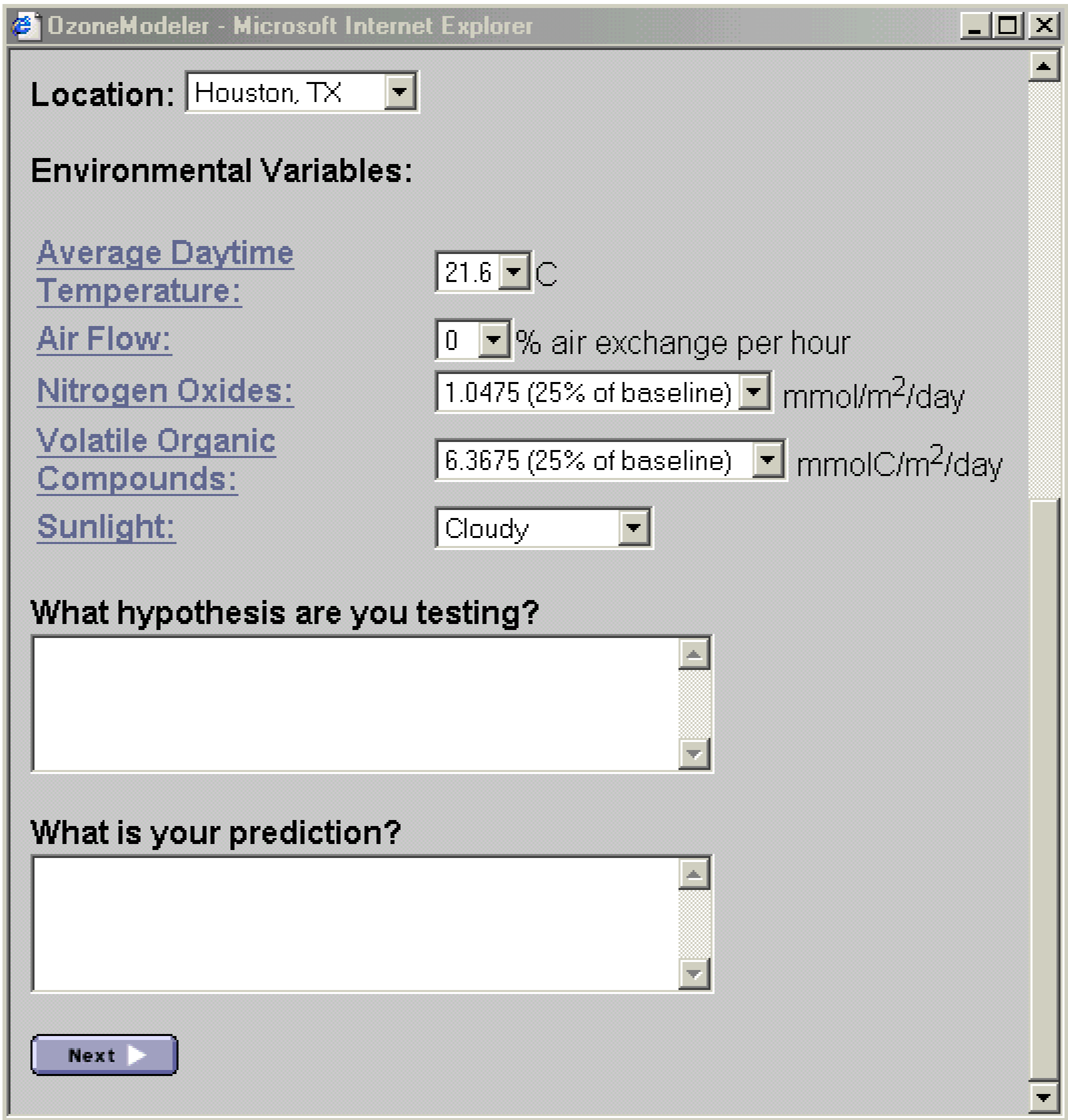

Figure 4: Graphical output of ozone modeler with the default variables

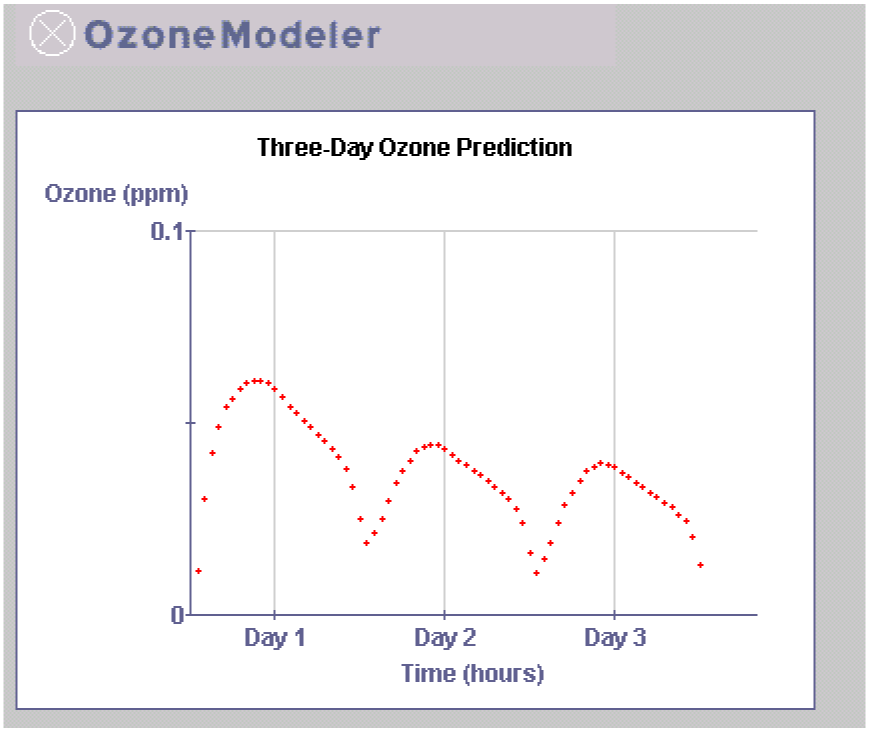

Figure 5: Graphical output of ozone modeler with the weather variable set to sunny

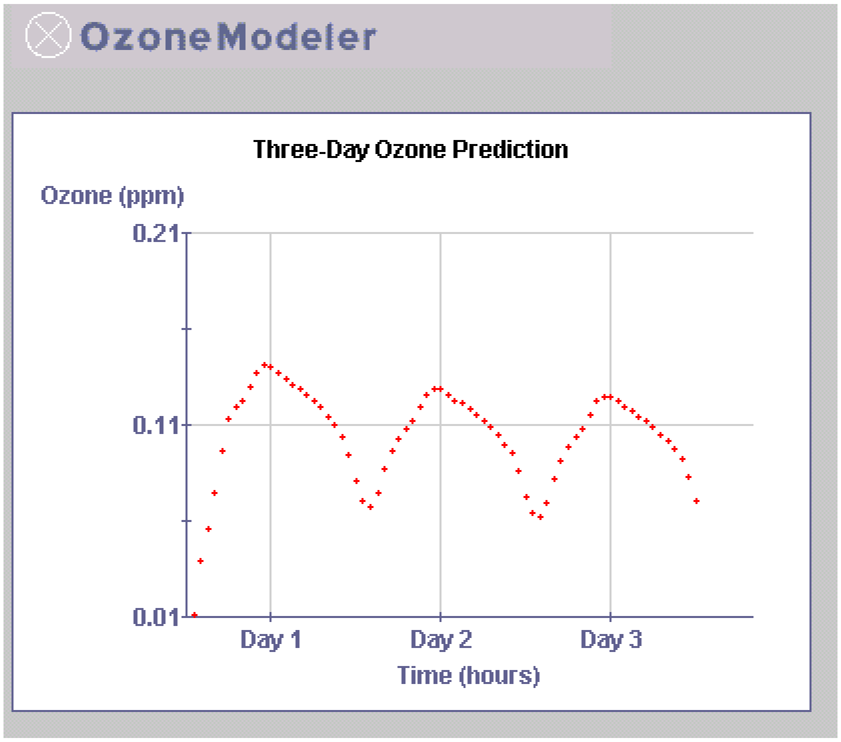

Figure 6: The relationships between the inscriptions, student interpretations, and the ozone modeler where discussions and content resources serve as mediators.

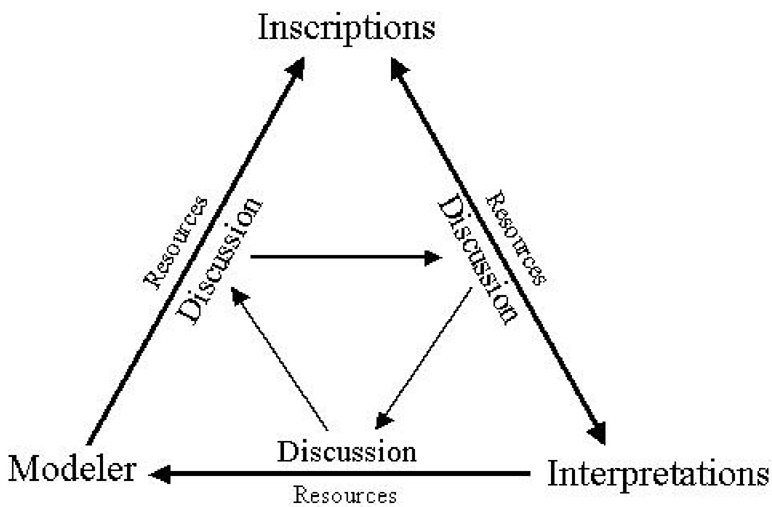

Figure 7: How technology can change the relationships between inscriptions, student interpretations and ozone modeler.