CODIFYING WEB-BASED INQUIRY ACTIVITIES: PRELIMINARY INSTRUMENT DEVELOPMENT

Alec M. Bodzin, Ward Mitchell Cates, Veronica Vollmer
Lehigh University

Abstract

This study analyzed 313 Websites from The Eisenhower National Clearinghouse Digital Dozen award list (August 1998-October 2000). The study identified and analyzed those sites offering Web-based scientific inquiry. We analyzed a sample of 34 Web-based inquiry activities (WBIs) using a multi-pass unanimous consensus analysis of characteristics and classifications to identify how its activities reflect the key components of scientific inquiry as described in Inquiry and the National Science Education Standards (Olson & Loucks-Horsley, 2000). This paper describes the creation and refinement of the categorization system and instrument used for analyzing WBI activities.

According to the National Science Education Standards (1996), inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. The Standards note,

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p.23)

Recent science education reform initiatives (American Association for the Advancement of Science, 1993; NRC, 1996) emphasize using inquiry-based teaching for students to learn science. The term *inquiry* has different meanings to different people and has been described in a variety of ways over the years (see for example, DeBoer, 1991; Gunstone, Loughran, Berry, & Mulhall, 1999; Haury, 1993; Minstrell, 2000; Minstrell & van Zee, 2000). According to Duscell (1986), the roots of the inquiry approach to the teaching and learning of science are typically attributed to Schwab (1962). Schwab defined "teaching science as inquiry" as consisting of two separate parts in an "enquiring" curriculum: "teaching-learning by inquiry" and "science as inquiry.

Science-as-inquiry views science as more than a collection of facts and accommodates the tentative nature of science. That is, science-as-inquiry is conditional, a process by which theories are generated and facts are obtained. This contrasts with the view of science as a static body of knowledge that is always correct. As scientists engage in research, new ideas emerge, new perspectives are formed, new principles develop and are justified, and subject matter is refined or redefined.

Teaching/learning science by inquiry refers to the process by which learners acquire knowledge. This process of inquiry incorporates such scientific process skills as identifying problems, formulating hypotheses, designing experiments, collecting and interpreting data, and analyzing those data to formulate conclusions. Learners make inferences, provide possible explanations, evaluate accuracy, and identify possible sources of error. In doing so, inquiry learners often utilize learning strategies, such as problem-solving, evidence examination, scientific reasoning, and decision-making.

In the 1960's, the school science laboratory emerged as the place for students to do inquiry. Schwab described three levels of inquiry that can be used in student laboratory investigations: (1) The problem and methods are given to the students by the materials and students are asked to provide relationships they do not already know from their classroom studies. (2) The problem is given to the students, who must provide their own methods and solutions. (3) All phases of inquiry are left open to the student. Thus, inquiry may be presented to learners in different forms, ranging from highly structured material-centered activities to learner-centered, open-ended investigations. Variations in the openness of the inquiry are based, in part, upon the goals for learning outcomes and upon the material developers' perceptions of how students learn in the context of school environments.

DeBoer (1991) noted that many science curricular projects provide a hands-on framework emphasizing student inquiry. Research studies on the inquiry nature of science laboratory manuals reveal that many curricular laboratory materials are highly structured and provide step-by-step detailed instructions (Germann, Haskins, & Auls, 1996; Lumpe & Scharmann, 1991; Tamir & Lunetta, 1978, 1981). These "cookbook-style" laboratories usually ask students to manipulate materials, make observations and take measurements, record results, draw conclusions, make inferences and generalizations, and communicate and interpret results. Such laboratory manuals usually do not provide students with opportunities to pose their own questions to be investigated, design their own experimental procedures, or formulate new questions based on a prior investigation. These studies suggest that most text-based curricular materials were highly material-centered, providing large amounts of structure and guidance, but little opportunity for learner self-direction.

Inquiry in today's science classrooms can take a variety of forms, however. It may be highly structured, with teachers and/or materials that direct students towards known outcomes, or may take the form of open-ended investigations that are learner-centered. Current teaching and learning techniques that use inquiry include engaging students with authentic questions for local and global investigations (Crawford, 2000; Feldman, Konold, & Coulter, 2000), project-based science instruction (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Krajcik, Czerniak, & Berger, 1999), or role-playing debate simulations (Bodzin & Park, 1999). These techniques seek to engage students with meaningful questions about everyday experiences, emphasize using a method of investigation to evaluate some form of evidence critically, and engage learners in a social discourse to promote the knowledge-construction process. The proponents of such inquiry-based approaches argue that they provide learners with the opportunity to learn scientific practices by actually engaging in them.

Learning Science with the World Wide Web

While much of the discussion above has focused on classroom-based and laboratory-based inquiry, learning science in today's classroom does not have to be restricted to text-based curricular resources utilized solely under teacher guidance in the classroom. Owston (1997) contended that the World Wide Web is likely to bring new learning resources and opportunities into the classroom, providing teachers and students access to more resources and promoting improved learning. In fact, many such Web-based curricular resources for use in K-12 science classrooms have been described in the literature (see for example, Alloway et al., 1996; Beaujardiere et al., 1997; Berenfeld, 1994; Bodzin & Park, 1999; Cohen, 1997; Coulter & Walters, 1997; Feldman et al., 2000; Friedman, Baron, & Addison, 1996; Gordin, Gomez, Pea, & Fishman, 1996; Songer, 1996, 1998; Wallace & Kupperman, 1997).

There have been attempts to classify Web-based learning in general. These classification systems have focused on different models of instruction (Collins & Berge, 1995; Harasim, 1993), social aspects of Web-based interactions (Riel, 1993), cognitive features (Teles, 1993) and general factors to consider for evaluating Web-based instruction (Khan & Vega, 1997; Nichols, 1997; Ravitz, 1997). In an attempt to improve the design of science-related educational Websites, recently two teams of researchers formulated classification schemes for analyzing the properties of such Websites (Nachmias, Mioduser, Oren, & Lahav, 1999; Sarapuu & Adojaan, 1998).

Despite such Website analyses and proposed general classification schemes, it remains unclear to what extent the World Wide Web presently provides scientific inquiries for students. Further, it is unclear what form such inquiries take or how one should categorize Websites offering scientific inquiries.

Purpose of this Study

This study sought to begin the process of clarifying these key issues. It had as its goals: (a) to identify "exemplary" science inquiry Websites; (b) to analyze each Website and identify how its activities reflect the key components of scientific inquiry as described in Inquiry and the National Science Education Standards (Olson & Loucks-Horsley, 2000); and (c) to create and refine a categorization system and instrument for future analysis of such Websites.

Methodology

The research team consisted of three researchers, including a science education professor who is an experienced multimedia developer and evaluator of Web-based science education development projects, an educational technology professor and software developer with many years of experience in instructional design and the editor of a recent issue on the design of science software (*Educational Technology*, January/February 2001), and a master s level science education student teacher in a Technology-based Teacher Education Program who represents a likely user of the sampled WBIs.

We employed a variation of a content analysis approach for examining Web-based inquiry (WBI) science Websites. Content analysis is a research technique for making replicable and valid inferences from data to their context (Krippendorff, 1980). Such analysis does not necessarily describe the actual experiences learners will have, however, but rather the opportunities for learning the instructional materials offer (Tamir, 1985). Content analysis has been used in previous research studies to evaluate high school laboratory manuals to determine how well they promoted the basic and integrated science process skills that are involved in scientific inquiry (see for instance, Germann, Haskins & Auls, 1996; Lumpe & Scharmann, 1991; Tamir & Lunetta, 1978, 1981). These studies used inventory checklists that noted the presence or absence of a particular feature. One weakness of these inventories, however, is their failure to include descriptive information about how materials were presented to the learner.

Defining a Science Web-based Inquiry

Before establishing a conceptual framework for our content analysis, we operationally defined what we meant by "Web-based inquiry for learning science. We used as a foundation Schwab s "teaching/learning by inquiry." For this reason, we focused on the inquiry activities themselves, rather than on the broader Website. That is, we analyzed Web-based inquiry (WBI) activities, not Websites as a whole. We deemed the Website to be the host for offering the WBI, and only required that a Website include one WBI --among what might be many non-WBI activities and resources-- in order to be included.

A WBI science Website may offer a *full* inquiry or a *partial* inquiry. We defined a full inquiry as containing all five essential features of classroom inquiry described in *Inquiry and the National Science Education Standards* (Olson & Loucks-Horsley, 2000):

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
5. Learners communicate and justify their proposed explanations. (p.25)

We spent much time in extensive discussion of what constitutes an inquiry. As a result of those discussions, we made a number of decisions about the key properties we would require of science WBIs in this study.

We decided that an inquiry must exhibit the first three of Olson and Loucks-Horsley s features: A science WBI must contain a scientifically oriented question. These are questions that lend themselves to empirical investigation and lead to gathering and using data to develop explanations of scientific phenomena (Olson & Loucks-Horsley, p.24). Such questions might also pertain to moral, political, or ethical concerns pertaining to some aspect of science or that might have an impact on an environmental decision -- as advocated by the science-technology-society reform initiatives of the 1980s (Yager, 1996). We decided that the evidence used in a science WBI should be of the same type an actual scientist would use. For example, WBIs might contain links to rich databases of real-time scientific data, such as meteorological data that learners could use to examine trends in weather patterns. These existing Web-based instructional materials might be used in WBIs to seed learner inquiries. Web-based data might also be empirical data collection by a learner and then shared with others in an online database. Such data may be either learner-collected using a hands-on laboratory protocol supplied (or suggested) by the Website, or may be provided to the learner in the form of self-contained data sets. Learners may also collect data in real time or near-real time remotely for analysis.

We further decided that explanations in WBIs should be more than simple data analysis and reporting. Explanations may include task-oriented activities, such as locating the optimal placement of an observatory, figuring out the life expectancy of an animal using a simulation, or explaining observations (for instance the appearance of bread mold). We agreed that a WBI had to be student-directed. That is, it should be directed at the student and phrased in such a way that students would perceive it as directed at them. For this reason, we excluded Website activities directed at classroom teachers, such as teacher-centered organized lesson plans. Thus, in order to be included, the WBI must support student learning of a science concept or science content.

Identifying WBIs for the Study

Three hundred and thirteen Websites drawn from The Eisenhower National Clearinghouse (ENC) Digital Dozen award list from August 1998-October 2000 constituted our population. The ENC is a recognized science education organization whose mission includes identifying effective curriculum resources and disseminating useful information and products to improve K-12 mathematics and science teaching and learning. An ENC team selects 12 Websites every month that are judged to be exceptional in both technical and academic content and it honors those sites with its Digital Dozen award. A list of these Websites is available on the ENC Website (http://www.enc.org).

Each Website selected for our sample had to contain content in one or more recognized science discipline (biology, chemistry, physics, earth and space sciences). Websites meeting this criterion were classified as "science Websites." Websites that met this criterion were further analyzed for possible classification as WBI science Websites based on the Olsen and Loucks-Horsley (2000) criteria on inquiry. If a *science Website* contained at least one student-direct activity that exhibited at least the first three features of the Olsen and Loucks-Horsley criteria on inquiry, the Website was included in the sample.

Of the 313 Websites in the population, 209 Websites (66.8%) were classified as *science* Websites, while 94 Websites (30.0%) were classified as *non-science* Websites. One member of the research team was responsible for classifying each Website as being a *science* Website or a *non-science* Website. As a confirmation check, a second member of the research team reviewed a random sample of 10% of the Websites selected as *non-science* Websites to ensure that they did not contain content in one or more recognized science disciplines. Examples of *non-science* Websites include ones that contain content specific to the professional development of educators (such as *National Staff Development Council,* available online at: http://www.nsdc.org/) or mathematics content (such as *Japanese Math Challenge*, available online at: http://www.japanese-online.com/math/).

Of the 313 Websites, nine (2.9%) could not be accessed (two of these were no longer active/accessible), and one Website was listed twice. Although the Website *Boil, Boil, Toil and Trouble* is now part of the *CIESE Online Classroom Projects* Website, we decided to treat it as a separate site since it was self-contained, had been listed by ENC earlier than other CIESE activities, and had existed prior to the creation of the more formal Website. In addition, since the focus of our analysis was on WBIs, not Websites, this decision did not affect study findings.

Each of the 209 selected science Websites was reviewed by one member of the research team to see if it contained a WBI. Locating features of inquiry on a science Website was a very time-consuming process because it was often difficult to find a WBI. On average, each researcher spent 60 to 90 minutes navigating through a Website to locate a WBI. For example, a *CERES Project* WBI activity, *Investigating the Dynamic Martian Polar Caps* (http://btc.montana.edu/ceres/html/polarstudentact.htm) is buried three levels down in the Website. In order to locate this student-centered WBI, the researcher had to find http://btc.montana.edu/ceres/html/polar1.htm and click on a link titled "Materials and Technology Required." This section contained an additional link to an actual student-centered activity that met the criteria for a WBI.

It was difficult to ascertain if some science Websites actually contained features of inquiry. Each such questionable Websites was examined and discussed by all three researchers to determine if it contained a WBI. One such questionable Website was the *Conflict Yellowstone Wolves* (http://powayusd.sdcoe.k12.ca.us/mtr/ConflictYellowstoneWolf.htm). This Website appeared to offer a WBI. However, after much discussion about the data learners were to analyze on the Website, we concluded that this evidence was actually processed information. This processed information was predominantly informational summaries from news agencies and non-profit organizations. All three researchers agreed that the data available to the learner did not qualify as the type of evidence a scientist would use. Based on this interpretation, we agreed this Website did not contain a WBI activity.

Another questionable Website was *Carolina Coastal Science*. The key issue raised in our discussion was what counts as scientific data on this Website. The Shell Island Dilemma activity was reviewed. A section of the data available for students to review included a sequence of aerial photographs of a migrating inlet over a six-year period. The rate of the average distance change of the inlet position is documented at the bottom of these photographs. Additional data consisted of still images and an interactive panorama of the inlet from two different time periods. These digital images and interactive media allow learners to make visual observations. We agreed after extensive discussion that these data are the same type of evidence used by scientists who are investigating this problem.

After this first pass, 23 (11.0%) of the 209 science Websites appeared to contain science WBIs. As a confirmation check, a second member of the research team reviewed each of the 23 selected WBI science Websites and concurred that they appeared to meet the criteria for inquiry. The second researcher also reviewed a random sample of 20 Websites classified as not offering a WBI to ensure that these sites did not contain a science WBI as we defined it.

All three researchers analyzed the sample of 23 science WBI Websites in a multi-pass unanimous consensus analysis of characteristics and classifications. Each researcher was asked to judge the presence of a WBI on that site and classify the properties of that WBI using the current form of our evolving classification instrument. Then all three researchers met to go over each individual decision and classification. As the instrument evolved, all three researchers as a group revisited each site to confirm all decisions and classifications again (multi-pass). In all cases, the three researchers had to agree on all decisions and classifications before moving on to the next WBI (unanimous consensus).

Reduction of Sample

During the first round of analysis of the Websites, four Websites were dropped from the sample. One Website, *One Sky, Many Voices* (available online at http://www.onesky.umich.edu/), restricted the reviewers from accessing a majority of the Website content, preventing its analysis. A second Website*, Process of Science Activities* (available online at: http://heg-school.awl.com/bc/companion/cmr2e/activity/toc.htm), while appearing to have face validity as a WBI, neither had the learner collect data nor provided the learner with data to analyze. Instead, it asked learners to imagine they had collected data, showed a graph, and interpreted the results. For example, (http://heg-school.awl.com/bc/companion/cmr2e/activity/rf/results.htm) states:

> At this point, you go ahead and perform the test you designed earlier: you remove all epiphytes and soil from selected tree limbs, and then record their reappearance on a weekly basis. At the end of three months, you have all your data, which you have plotted on a graph.
> <Website displays graph here>
> Your results show an increase in the number of bromeliads as canopy soil accumulates. However, you are amazed to observe that some bromeliads appear even before any soil accumulates.
>
> Are these results consistent with your prediction?

All three researchers agreed that a third Website, *Space Food and Nutrition* (available online at http://spacelink.nasa.gov/products/Space.Food.and.Nutrition/), offered activities —many of which were teacher-directed-- from printed materials that were in no way enhanced for delivery on the Web. In fact, the very same materials were available from the site as a downloadable 1.9 MB PDF file. Similarly, a fourth Website, *EnergyNet* (available online at http://www.energynet.net) was also dropped from the sample after all three researchers agreed that its activities were teacher-directed and did not fit our definition of learner-centered inquiry. That inquiry was presented in a PowerPoint presentation to be downloaded by the classroom teacher for use in class.

The final sample consisted of 19 Websites that contained WBIs, a yield of 9.1% of the original 209 science Websites. Table 1 lists the 23 Websites, divided into those included in the sample and those excluded.

INSERT TABLE 1 ABOUT HERE

Instrument Evolution

We began our analysis using a conceptual framework present by Olson and Loucks-Horsley that describes five essential features of classroom inquiry and variations based on the extent to which activity is learner-directed or directed by the materials themselves. Initially, we adopted these descriptions verbatim to describe the differences across the design continuum for each feature of inquiry. Table 2 displays our initial instrument. L1 and L2 refer to levels of learner direction, while M1 and M2 refer to levels of direction provided by the materials on the Website. WBIs classified as M2 are more material-centered than those classified as M1. WBIs classified as L2 are more learner-centered than those classified as L1.

INSERT TABLE 2 ABOUT HERE

We field-tested the instrument, jointly using it to evaluate two WBI activities. A qualitative approach was used to analyze each activity, with each researcher carefully examining the WBI activity and locating specific content on the Website that aligned with a criterion for each essential feature of inquiry. The content was recorded in the appropriate box on the instrument. After each rater completed the instrument, all three researchers checked for agreement and negotiated differences until there was 100% agreement . We then went on to analyze a set of five Websites using our new shared understandings.

The instrument and underlying operational definitions were revised periodically throughout this process. We analyzed each WBI Website independently, with each researcher selecting a WBI activity to review on that Website. There was much variance in the number of WBI activities included on each Website. In some cases, the entire Website was one WBI activity (*Boil, Boil, Toil and Trouble*) while others had as many as twenty-eight activities (*Water on the Web*) from which to select. Some Websites contained many activities that were not inquiry. For example, *Athena* contained 59 separate activities, 10 of which were data-based. Therefore, it appears that approximately 17% of the Athena activities have features of inquiry. It should be noted that we did not look at all activities on each Website. Since each researcher independently selected a WBI activity from each Website, it was possible that two or three WBI activities could be selected from each Website. A total of 34 activities (WBIs) from the sample of 19 Websites were reviewed (one WBI from nine sites; two WBIs from five sites; and three WBIs from five sites).

As noted in the previous section, each selected WBI activity was discussed and negotiated with regard to placement on the instrument using a multi-pass unanimous consensus analysis of characteristics and classifications. This was not an easy process. It was difficult to locate specific examples of inquiry features on some Websites during discussions, even after the Website had been initially reviewed and discussed by the research team. It often took from one to two hours to discuss each WBI activity as a team and some WBIs were revisited eight to ten times over the three months of this initial study. Many of the troubles we encountered were related to inconsistent or difficult-to-use interfaces; on some sites, it was almost impossible for us to keep track of where we were and what we were doing (see Heller, 1990, and Marchionini, 1988).

First Revision

Prior to conducting the study, we knew of no instrument specifically designed to categorize WBIs. We expected that our instrument would be continuously modified as we conducted the multi-pass unanimous consensus analysis. The first modification to the instrument came after the first six Websites were reviewed. Specific wording in the *communicate* row of the L2 column was changed from "*Learners form reasonable and logical argument to communicate explanations*" to "*Learners form argument to communicate explanations*." We decided that the phrase "*reasonable and logical"* was a qualitative judgment and not a categorization description.

In addition, after reviewing the first six sites, we derived four column descriptors to guide classification decisions for each column. These descriptors represented our best first interpretations of what ratings in those columns represented philosophically. The four descriptors were,

L2: Highly spontaneous and independent.
L1: Independent but scaffolded.
M1: Some freedom to make choices.
M2: Highly controlled by design and materials.

The fourth row in the table, *Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding,* originally consisted of three columns in Olson and Loucks-Horsley. It was unclear how these criteria aligned with our four-column continuum, however. Initially, we centered the columns in the table. Then we expanded the three criteria to six as we saw different ways WBIs directed or prompted learners to consider alternative explanations for their findings. The hypertext nature of the Web appears to play an important role in how learners are prompted or directed to explore alternative explanations. Table 3 illustrates how we recategorized this feature of inquiry. Examples that demonstrate how we divided the cells in the *alternative explanations* row are presented below.

INSERT TABLE 3 ABOUT HERE

The presence or absence of hypertext links to alternative explanations separates the L side of the instrument from the M side of the instrument. WBIs that explicitly stated alternative explanations were classified as M2 in the *alternative explanations* row. For example, *KanCRN - How Does Your Cookie Crumble?* (available online at http://kancrn.kckps.k12.ks.us/cookie/index.cfm) presents questions that identify possible moderator variables (see Borg & Gall, p.619):

> Do most males like the same brand of cookie? Do most ten year olds like the same brand of cookie? Did most ten year old males choose the same "most important characteristic"?

M2 WBIs explicitly state specific connections to alternative explanations while M1 WBIs state or imply possible connections to alternative explanations. For example, *Water on the Web - Investigating Data Interpretation* (available online at http://wow.nrri.umn.edu/wow/student/data/inquiry.html) provides the following questions to assist learners in thinking about their results:

> Was data collected by RUSS possibly affected by external factors?
> Did you find any outliers? How can the outliers be explained?

L2 WBIs for *alternative explanations* use a “catalyst” to prompt learners to examine other resources and form links to explanations independently without guidance. Catalysts do not provide learners with hypertext links to sources of information with alternative explanations. Examples of catalysts include:

Can you come up with possible explanations for the few stray values that occur along the growth curve?
(From *Chickscope*
http://chickscope.beckman.uiuc.edu/explore/biological_imaging/)

Consider possible explanations for your experimental results.
(From *Water on the Web - Investigating Aquatic Respiration* -
http://wow.nrri.umn.edu/wow/student/aquatic/inquiry.html)

The presence of hypertext links separates the L2 column from the L1 column in the *alternative explanations* row. For instance, the *CERES Project- Mountainquest* (http://btc.montana.edu/ceres/html/mountainquest.htm) was classified in the L1 column. This WBI provides links to alternative explanations but does not refer to them. The learner must independently examine other resources containing alternative explanations embedded in team assignments. These links are not explicitly cited and the learner must independently decide to use this information.

<u>Second Revision</u>

After seven more sites were discussed and negotiated, a second major revision to the instrument occurred (see Table 4). Four of the five criteria of the essential features of inquiry were modified. The philosophical column descriptors were also modified to read:

L2: Learner-driven with much initiative and independence.
L1: Learner makes decisions, but with support and scaffolding, particularly with the process.
M1: Learner does much selecting from provided materials. Limited choices.

M2: Materials-driven. Learner makes few choices and is given much direction.

INSERT TABLE 4 ABOUT HERE

As we began to get a broader picture of actual practices in WBIs and clarified our thinking through the consensus process, we established two rules for our classification system to help guide placement of WBIs into the cells of our instrument:

> Evidence Rule: If the learner collects data, it is classified as L1 or L2 on the e*vidence* row. If the WBI provides the learner with data, the WBI is classified as M1 or M2.
>
> Communication Rule: If instructions in the WBI about communication focus on presentation or need, the WBI is classified as L1 or L2 on the *communicate* row. If those instructions focus on content and/or layout, the WBI is classified as M1 or M2.

As we continued our multi-pass analysis, these rules and reformulated guiding column descriptors guided our decisions for continued modifications of the characteristics of individual cells and rows in the instrument. Distinctions in the *questions* and *communicate* rows became apparent at this time.

Whereas we had originally assumed that all questions would be explicitly stated as such, our analyses of multiple WBIs indicated that this was not the case. We concluded that scientifically oriented questions may be stated explicitly or may be implied as a task. For example, the activity, *Athena - Predicting the Weather* (http://www.athena.ivv.nasa.gov/curric/weather/hsweathr/index.html) used just such an implicit task:

> *Your task now is to make a forecast for the next several days and compare it with the real weather that occurs.*

This statement can be converted into a question to engage the learner. The implicit question in this WBI becomes, How does your forecast for the next few days' weather compare to the actual weather?

Another example, this time from the *Carolina Coastal Science - Shell Island Dilemma* activity (http://www.ncsu.edu/coast/shell/index.html):

> *In this inquiry simulation, your objective is to investigate the issues concerning the fate of the Shell Island Resort and then debate the future of this and other oceanfront structures threatened by coastal erosion*.

In this example, the implicit question becomes, What should be the future of this and other oceanside structures being threatened by coastal erosion?

Implicit questions may also be derived from WBIs that present a case to solve. For example, in *The Genetics Science Learning Center - The Farmer's Bones* activity (http://gslc.genetics.utah.edu/society/farmer/index.html) learners assume the role of an osteologist working in a forensics laboratory and are presented with skeletons whose cause of death must be identified. This case scenario engages learners with the implicit question, What do the skeletons tell you?

In contrast, explicit questions provide learners with specific questions to investigate. For instance, *The Natural History Museum. Interactive- Walking with Woodlice* activity (http://www.nhm.ac.uk/hosted_sites/woodlice/) provides the learner with specific questions to investigate:

> *What do I have to find out?*
> *We want you to help investigate these questions*
> *Where do woodlice live?*
> *How many different kinds of woodlice live near you?*
> *Which are the most widespread UK woodlice?*
> *Do different kinds of woodlice live in different place?*

In terms of learner-centered WBIs, a WBI in the L2 *question* row cell prompts learners to formulate their own questions or hypotheses to be tested. An example from the *Albatross Project* (http://www.wfu.edu/albatross/hawaii/ideas.htm) illustrates this:

> "*Are these hypotheses correct? If they are, keep 'em. If they're not, chuck 'em.*
> *You can think up lots of other hypotheses to test to advance albatross science! Do it! Also, check out the details below. You'll need to know them.*"

WBIs in the L1 cell of the *question* row suggest general areas or topics, or they help learners formulate their own questions. An example of an L1 WBI from the *question* row is,

> *In this lesson you will formulate and answer your own research question. Your question can be a water quality issue you have always wondered about, a class topic you wish to explore in greater detail, or an issue that has been in the news recently*.
> (From *WOW: Investigating Data Interpretation* http://wow.nrri.umn.edu/wow/student/data/inquiry.html).

As noted earlier, if communication in a WBI focused on presentation, the WBI was classified as L1 or L2 on the *communicate* row. If communication was focused on content, the WBI was classified as M1 or M2. WBIs in the L2 cell of the *communicate* row were very open-ended with regard to learners making decisions about techniques to use in presenting their results. These WBIs reminded the learner of the general purpose and need for communication, but did not provide specific guidance. One activity placed in this area included a science fair example that told learners to e-mail the results of their experiments to scientists. Another WBI from a *Chickscope* activity (http://chickscope.beckman.uiuc.edu/explore/biological_imaging/) stated:
Share your results, conclusions, and questions with other classrooms on the Web.

L1 placements in the *communicate* row addressed possible communication techniques but did not suggest specific content or layout to be used. For example, the

Bagheera G2-1 & G2-2 activity (http://www.bagheera.com/inthewild/class_activities.htm) stated:

Use these graphs as a visual in a written or oral presentation on species decline.

To distinguish between M1 and M2 WBIs in the *communicate* row, we decided that WBIs with clear specifications for the content and/or layout to communicate the explanations were reflective of the M2 cell, while WBIs that suggested possible content for the presentation represented the M1 cell. *The Athena - Predicting the Weather* activity (http://www.athena.ivv.nasa.gov/curric/weather/hsweathr/index.html) illustrated an M2 placement:

> *As a weather forecaster you must explain these maps to your viewing or reading audience. Write a weather report explaining your forecast sequence. Include forecasts for Chicago, Memphis, and Denver. Discuss changes in pressure, wind direction, wind speed, temperature, and sky condition.*

Subsequent Revisions

The instrument underwent two additional revisions as the final six Websites were negotiated and discussed. During the final pass on each WBI, the *evidence* row and the *explanations* row were finalized. Further distinctions were also made to the *questions* and *communicate* rows at this time. Table 5 displays the final version of the instrument. Examples that demonstrate how we redefined cells classifications in the *evidence* and *explanations* rows are presented below.

INSERT TABLE 5 ABOUT HERE

We derived a new rule for our classification system to help guide the placement of WBIs into the cells of the *evidence* row. This rule stated that if the learner collects data outside the Website, then the WBI is placed on the L side of the instrument. If the WBI provides the learner with data, the WBI is placed on the M side of the instrument. M1 and M2 WBIs are further distinguished by the amount of direction the WBI provides about how data should be analyzed.

WBIs are classified as L2 in the *evidence* row if the learner determines what constitutes evidence and develops procedures and protocols for gathering relevant data. The *Remote Access Online Real-Time Science Experiment-- Biological Clocks in Nature — Student Activity*(http://www.cbt.virginia.edu/Olh/middle/activ_m/nature.html) was an example:

> "*Design a method for recording what you are observing. Remember you can use any of your senses. For example, you may want to tape record the noises you hear*."

L1 WBIs in the *evidence* row directs learners to collect certain data, or only provides a portion of the needed data. Often the WBI provides protocols for data collection. For example, *Bagheera (CS2-8)* (http://www.bagheera.com/inthewild/class_activities.htm) provided only a portion of the needed data; in this case, only the field names for a database:

> *Design a database of the extinct species in this curriculum that includes the following categories of information:* ***species****;* ***scientific name****;* ***classification*** *(e.g., mammal, reptile, bird, amphibian);* ***location*** *(e.g., Brazilian rain forests);* ***habitat*** *(e.g., forest, ocean, grassland);* ***population decline over time causes of endangerment*** *(or causes of extinction, if extinct)*.

In a different L1 example in the *evidence* row, the *CERES Project-Mountainquest* WBI (http://btc.montana.edu/ceres/html/mountainquest.htm) directed learners go to an external Website to collect data. The data were repurposed for the inquiry; that is, they already existed on another Website for a different purpose.

The *explanations* row was the last row finalized on the instrument. The amount of direction the WBI provides the learner is the main determinant of whether an activity was placed on the L or M side of the instrument of this row. What distinguished M1 and M2 WBIs from one another was whether they were verification-type activities or not. If the activity calls for learners to perform analyses that inevitably lead to predetermined correct conclusions, it is classified as M2. If the learners are directed to make inferences and generalizations, the WBI is classified as M1.

WBIs are classified as L2 in the *explanations* row if the WBI prompts learners to analyze data and formulate their own conclusions. The following examples illustrate this:

> "*Can you think of anything that may explain your results?*"
> (From CIESE Online Classroom Projects - Down the Drain
> http://k12science.org/curriculum/drainproj/)
>
> "*Compare your graphs. Can you draw some conclusions?*"
> (From Bagheera (G2-1 & G2-2)
> http://www.bagheera.com/inthewild/class_activities.htm)
>
> *Consider possible explanations for your experimental results*.
> Water on the Web - Investigating Aquatic Respiration -
> http://wow.nrri.umn.edu/wow/student/aquatic/inquiry.html

WBIs are classified as L1 in the *explanations* row if they use metacognitive prompts to get learners to think about their thinking (see Costa, 1985; Glatthorn & Baron, 1985; Jones & Idol, 1990; Parker, 1991; Perkins, 1987; Resnick & Klopfer, 1989; Tishman, Perkins, & Jay, 1995). The following is an example from *Water on the Web -- Investigating Data Interpretation* (http://wow.nrri.umn.edu/wow/student/data/inquiry.html):

Sometimes, data are found that defy the observed pattern. These are known as data <u>*outliers*</u>*. Rather than dismiss them as unimportant, try to determine their cause. (e.g.: Is the probe working properly?) Sometimes outliers lead to new and interesting interpretations of the data. Were there any outliers in the data you collected? Be prepared to explain how you chose to handle outliers in your data analysis.*

INSERT TABLE 6 ABOUT HERE

Analysis and Findings

The placement of each activity on the final instrument is provided on Table 6 and can viewed online with hypertext links at: http://www.lehigh.edu/~amb4/papers/wbistudy1.html.

Each Website is labeled with a letter from A to S. Individual WBIs on a Website are indicated with numbers. So, S1 and S3 indicate two of three different WBIs categorized on the science Website labeled with the letter S.

Our initial data analysis of WBI activities illustrates a variety of design types for student learning. In 30 of the 34 reviewed WBI activities (88.2%), learners were provided with a specific stated (or implied) question or hypothesis to investigate. Two WBIs (5.9%), *Chickscop*e and *Water on the Web — Investigating Data Interpretation*, suggested topic areas or provided samples to help learners formulate their own questions. Two WBIs (5.9%), *The Albatross Project - Hawaii Study* and *Boil, Boil, Toil and Trouble*, offered learners lists of questions or hypotheses from which to select. As discussed below, one of these WBIs, *The Albatross Project - Hawaii Study,* was placed in two different cells in the *questions* row since it offered learners more than one pathway to pursue scientifically oriented questions. This WBI also prompted learners to formulate their own questions or hypotheses to be tested.

Inquiry-based Website activities structure how students give priority to evidence in diverse ways. In our sample, 12 WBIs (35.3%) provided learners with data and gave specific directions on how data were to be analyzed. Six WBIs (17.6%) provided data and asked learners to analyze them. Nineteen WBIs (55.9%) directed learners to collect certain data, while six WBIs (17.6%) allowed learners to determine what constitutes evidence and develop procedures for gathering data.

Seven WBIs (20.%) provided learners with multiple ways of using evidence and were placed in more than one cell in the *explanations* row. The *How Far Does Light Go? Debate* (http://www.kie.berkeley.edu/KIE/web/hf.html) provided different types of evidence at different stages of the activity. The learner was offered choices when using the *Survey Evidence* section. If the learner chooses to use the "evidence hints" provided by Mildred (the Help function), the WBI is classified as M2 since these hints instruct the learner about what to analyze. If the learner chooses not use the "evidence hints," the WBI is classified as M1 because the activity provides data and asks the learner to analyze a particular piece of evidence. This activity also contains a *Creating Evidence* section classified as L2 because the learner determines what constitutes evidence. Acceptable created evidence appeared to be subjective, observational, and anecdotal.

The Albatross Project - Hawaii Study (http://www.wfu.edu/albatross/hawaii/ideas.htm) offered learners three choices of evidence depending on which hypothesis was chosen. If the learner chose Hypothesis 1 or 2, the Website provided learners with data and told them how to analyze those data. If Hypothesis 3 was selected, however, learners were provided only a portion of the needed data (latitude and longitude coordinates that were sent to the learner via e-mail). The learner then had to obtain sea surface temperatures from a link provided in a separate area on the Website. If the learner elected to formulate a novel hypothesis, then he or she had to determine what constitutes evidence and develop procedures for gathering data.

Collaborative experiments represent a subsample of the WBIs we analyzed. They illustrate a twofold way to deal with evidence. First, the learner collects certain data and is provided with a protocol. These data are contributed to a collective database. Next, the WBI provides learners with cumulative data from remote geographical placements and instructs the learner in how to analyze the cumulative data. In each of these collaborative experiments, there is first a learner-centered component that is then followed by a materials-centered component. Examples of collaborative experiments include WBIs from the *CIESE Online Classroom Projects*, *KanCRN - Keeping an Eye on Ozone*, and *The Natural History Museum. Interactive- Walking with Woodlice*.

Twelve of 34 WBI activities (35.3%) were classified as full inquiries. Each of these contained all five essential features described by Olsen and Loucks-Horsley. Twenty-two WBIs (64.7%) were partial inquiries. Two WBIs (5.9%) contained partial inquiries consisting of essential features 1-4, seven WBIs (20.6%) contained partial inquiries consisting of essential features 1-3 and 5, and thirteen WBIs (38.2%) contained partial inquiries consisting only of essential features 1-3. In partial WBIs that contained four of the five essential features, it was more common for WBIs to require learners to communicate their explanations than to evaluate their explanations in light of possible alternative explanations.

Fourteen activities (41.2%) had learners evaluate their explanations in light of alternative explanations. Six of these (17.6%) used a "catalyst" to prompt learners to examine other resources and form links to explanations on their own. Such dialogue prompts encouraged a learner to go beyond the WBI activity and seek out additional knowledge in order to evaluate their explanations.

Nineteen activities (55.9%) had students communicate and justify their proposed explanations, although only a few sites permitted learners to share their conclusions on the Web. One of the sites that did permit sharing of conclusion on the Web, *KanCRN* provided a standard template for learners to communicate their results. When we examined previously submitted student reports, however, we found that learners seldom completed all areas of the report form and often did not articulate their data analysis or justify their conclusions. The *Chickscope*, *CIESE Online Classroom Project Activities*, and *The Natural History Museum Interactive--Walking with Woodlice* WBIs provided students with an area to post their conclusions for viewing by other learners participating in the projects. In the *Walking with Woodlice* WBI, most learners who submitted their conclusions did not, however, justify their conclusions.

Some Websites implied that they were providing authentic communication to learners, but in actuality did not deliver on that promise. For example, The *Remote Access Online Real-time Science Experiment* Website stated on the opening page that learners will "share conclusions with other scientists from all over the world." However, this did not appear to be the case. The Website implied communication by using terms such as *communicate, e-mail,* and *talk to* throughout the Website. Yet, students did not communicate conclusions or explanations on the Website and e-mail appeared to be used solely to ask scientists questions about the data itself.

Conclusions

Our data reveal a variety of activity structures on science education Websites. These included problem-based research scenarios, content presented in the form of storytelling, scientific procedures and explanations communicated through debates, and decision-making scenarios. Our data show that only a small percentage of science education Websites appear to be designed to facilitate student choice or provide opportunities for knowledge-building, social interaction, small group work, and higher-order thinking.

As a result of our examination of the 19 separate science ENC Digital Dozen Websites and detailed analysis of the 34 WBIs, we also drew five conclusions. We discuss each below.

Philosophy Guides Design.

The philosophy of a WBI designer appears to drive how that site approaches inquiry. In fact, in making some of the more difficult decisions about which cell in a row was most appropriate, we often relied on the four column descriptors to help us. After reviewing 16 Websites, we were able to predict fairly quickly a site s learning philosophy, depending on how learners interacted with data. The level of guidance provided also appeared to reflect what the designer believed about how students should learn inquiry. For instance, some WBIs evinced a highly controlled and specified philosophy in which learners followed specific instructions in each of the stages of inquiry. This philosophy was reflected in a large number of M2 classifications for the WBI. In contrast, other WBIs exhibited a much more learner-center philosophy with much freedom and independence. This was reflected in a large number of L1 and L2 classifications for the WBI.

Many materials-centered WBIs were highly structured and provided learners with step-by-step detailed instructions and procedures to follow. For example, 58.0% of WBIs that classed into the M2 *evidence* row also classes into the M2 *explanations* row. The process of inquiry in materials-centered activities was almost always highly controlled by the design of the materials. In fact, 23.5% of the WBIs in this study were "cookbook" investigations, with the learner following clearly stated procedures to verify predetermined correct conclusions.

In contrast, some WBIs clearly had a more learner-centered approach, often with an emphasis on supporting learner decision making. For example, some WBIs enabled learners to choose multiple pathways to perform their inquiry. Most often, these WBIs directed learners to collect data outside of the Website. In some cases, learners were provided with scaffolding that made their inquiry path more materials-driven. In the *How Far Does Light Go? Debate*, for instance, learners had access to an area with an avatar that provided suggestions to help guide them to think about the main idea they should keep in mind as they looked at each piece of evidence presented. Often, the avatar highlighted critical features of a concept the learner was to understand.

Many of the WBIs used some form of scaffolding. Some sites provided cognitive prompts to the learner, such as writing predictions, giving reasons, and elaborating on answers. WBIs, such as those on *KanCRN*, sequenced the inquiry process into step-by-step sub-tasks to help learners complete one sub-task at a time.

Too Much Help Can Defeat the Purpose of Inquiry.

While the intent of hints and immediate feedback is to support learner inquiries, if learners choose such support prior to completing the inquiry or before giving thought to what they have found, the inquiry process may be "short-circuited." That is, the activity may cease to be inquiry.

In the *Population Growth and Balance* WBI, learners designed and ran experiments using a Web-based modeled simulation. It appeared that the intention of the WBI was to engage learners actively in designing experiments. However, *hint boxes* were placed throughout. In some cases, the hint boxes provided scaffolding for the learner to help solve the problem. This scaffolding transformed the nature of this WBI from learner-centered to material-centered. For example, in Experiment 6, learners were presented with a hypothesis and instructed to design an experiment to test the hypothesis (Figure 1). With the *Theory box* closed, the design of the activity was learner-centered; learners were directed to collect certain data and were prompted to analyze the data to formulate a conclusion. However, if the learner decided to open the *Theory box*, the learner was provided with specific instructions regarding how to solve the problem and the inquiry was ended (Figure 2). If a learner went through this WBI with all *hint boxes* open, the activity became a verification activity with no requirement that the learner draw conclusions or formulate explanations, and the inquiry was effectively short-circuited. In another WBI (*Fun With Fomites*), if learners accessed the immediate feedback links on the Website, not only were they told how to interpret the data, but they were also provided with reasoning to formulate an explanation. Clearly, an activity in which the learner no longer has any major responsibilities for data analysis or reasoning is no longer inquiry.

Poor Interface Design Can Damage an Inquiry.

Some observed Websites had usability and interface design problems: Site navigation was poor and links not visually obvious. In some cases, the home page of a Website did not contain a clearly labeled table of contents, nor was a site map always provided for larger Websites. Similarly, some navigation button labels were confusing and links not clearly and accurately described. Not only was it not easy to figure out where to go on some Websites to find needed information, but when one located that information, it was sometimes difficult to browse through it. On some Websites, it took many, many clicks to get the desired information.

We would be remiss if we did not concede that interface problems may also have prevented us from finding a WBI on a site we rated as not having one. While we regret if this occurred, we would argue that any site on which three highly motivated researchers devoting between three and five hours of concerted effort are unable to locate a single WBI is a site unlikely to garner many learners. Such learners seldom have either the time or the effort to devote to ferreting out a WBI.

There is a rich literature on interface design --and on design for the Web-- that might help eliminate these problems. Designers of science Websites would be well-advised to consult such literature (see for example, Bickford, 1997; Cates, 1992; Cooper, 1995; Galitz, 1996; Head, 1999; Mandel, 1997; Microsoft, 1995; Schneiderman, 1998; Schwier & Misanchuk, 1993; Siegel, 1996).

Misaddressed Messages Can Confuse WBI Users.

It was unclear on some Websites to whom the instruction was directed. For example, the *Boil, Boil, Toil and Trouble* Website had wording on certain pages that was directed to both students and teachers, despite having separate sections designated as *Student Area* and *Teacher Area*. On some pages this WBI appeared to have a split personality. That is, in one paragraph, it would speak apparently directly to the student (You should), while in the next it would appear to address the teacher (Have your students). This caused some confusion for us in analyzing and classifying these activities and it likely would cause some confusion in learners coming to the site to complete a WBI.

WBIs Can Offer Authentic and Collaborative Learning Experiences.

Some WBIs offer classroom students opportunities to participate in authentic learning experiences outside traditional school settings. These experiences involve learners in investigating real-world questions using scientific process and inquiry skills that are used by actual scientists. Learners gather data, such as population counts or observable weather phenomena, and contribute these data to shared databases that learners and scientists can use later to answer other research questions. Some of the WBIs in the present study would likely leave learners feeling that they had done real science and were part of the larger scientific community, not merely students completing assignments. This is a large part of authentic learning.

WBIs may include distributed learning environments that offer significant potential for students to engage in a collaborative inquiry as a learning community where data and ideas are shared. Internet science projects can engage students in scientific questions that are not yet solved by scientists (Berenfeld, 1994; Cohen, 1997; Feldman et al., 2000; Friedman et al., 1996). In these projects, students gather data and contribute their findings to a larger database. Students make interpretations of the data and share their conclusions with other students and scientists using Web-based tools. Students can engage in detailed discussions about their scientific findings not only with their peers, but also with experts. Scientists can provide scaffolding to help students think critically about the data they collect and offer alternative explanations to pursue.

While not all WBIs took advantage of these capabilities, their presence in a few suggests one way in which WBIs might fulfill Owston s suggestion that the Web could expand science education beyond traditional classrooms. WBI designers may wish to look for ways to provide opportunities for learners to investigate real-world problems that incorporate distributed data-based activities. Furthermore, these activities can be designed to encourage collaboration across distributed classrooms and learner communities.

Snapshot in Time

Unlike text-based instructional materials, Websites have the ability to be altered quickly. As an example, when we first visited The *CIESE Online Classroom Projects -- Sun Times: Global Sun Temperature Project* (http://k12science.org/curriculum/tempproj/index.html), it was an archive of a past project. When we revisited the site later in our study, it was actively collecting data again.

In looking at our results and categorizations, readers will wish to recognize that the WBIs described here may be enhanced from partial to full inquiries after our assessments. Similarly, they may be modified to be more or less learner-centered later. Lastly, just as WBIs may be modified subsequently, some of the sites that were classed as not containing WBIs in this study may later add WBIs. Unfortunately, it is also possible that some of the WBIs cited here may also be modified in ways that make them cease to be inquiries.

Future Research

This study produced a snapshot of some very large and extensive science Websites, and we noted that not all WBIs on a given Website are the same. In our next study, we will attempt to obtain a more detailed picture of the types of WBIs that are found on larger science Websites. Furthermore, this study investigated only one population of exemplary science Websites, those that were included on the ENC's Digital Dozen lists. In future we plan to replicate this study with different populations of sites. Based on our findings, we hope to derive a series of principles and practices for designing WBIs to inform science education Web developers.

We believe it is important to investigate different contextual factors in WBIs to see how inquiries are presented to learners. Similarly, we need to find out how science teachers use WBIs in classroom environments and to learn which factors determine the types of WBIs science teachers use in their classroom. Ours is an extensive research effort calling for multiple studies over many years and we would welcome collaboration with others interested in this research.

Table 1. Science Websites classified as WBIs

Confirmed as Offering WBIs	
Athena	http://www.athena.ivv.nasa.gov/index.html
Bagheera	http://www.bagheera.com/
Boil, Boil, Toil and Trouble	http://k12science.stevens-tech.edu/curriculum/boilproj/
Carolina Coastal Science	http://www.ncsu.edu/coast/
CERES Project	http://btc.montana.edu/ceres/
Chickscope	http://chickscope.beckman.uiuc.edu/
CIESE Online Classroom Projects	http://k12science.org/currichome.html
Find Out Why	http://www.nsf.gov/od/lpa/events/fow/start.htm
Genesis	http://www.genesismission.org/
Genetic Science Learning Center	http://gslc.genetics.utah.edu/
KanCRN	http://kancrn.org/
MicrobeWorld	http://www.microbeworld.org/
Population Growth and Balance	http://www.arcytech.org/java/population/
Remote Access Online Real-time Science Experiment	http://www.cbt.virginia.edu/Olh/exp.html
The Albatross Project	http://www.wfu.edu/albatross/
The Biology Project	http://www.biology.arizona.edu/
The How far does Light Go? Debate	http://www.kie.berkeley.edu/KIE/web/hf.html
The Natural History Museum. Interactive.	http://www.nhm.ac.uk/interactive.html/
Water on the Web	http://wow.nrri.umn.edu/wow/index.html
Confirmed as Not Offering WBIs	
EnergyNet community web	http://www.energynet.net/
One Sky, Many Voices	http://www.onesky.umich.edu
Process of science activities	http://heg-school.awl.com/bc/companion/cmr2e/activity/toc.htm
Space food and nutrition	http://spacelink.nasa.gov/products/Space.Food.and.Nutrition/

Table 2. Essential features of classroom inquiry and their variations from Olson and Loucks-Horsley (2000) p. 29

	Learner Directed		Materials Directed	
Essential Feature of Inquiry	L2	L1	M1	M2
Learners are engaged by scientifically oriented questions.	Learners pose a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other sources.
Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.	Learner determines what constitute evidence and collects it	Learner directed to collect certain data.	Learner given data and asked to analyze	Learner given data and told how to analyze
Learners formulate **explanations** from evidence to address scientifically oriented questions.	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
Learners evaluate their explanations in light of **alternative explanations**, particularly those reflecting scientific understanding.	Learner independently examines other resources and forms the links to explanations	Learners directed toward areas and sources of scientific knowledge	Learner given possible connections	
Learners **communicate** and justify their proposed explanations.	Learners form reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

Table 3. Modifications to *"learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding"* criteria.

L2		L1		M1		M2	
	Prompts learner to examine other resources and form links to explanations independently ("Catalyst").	Provides links but does not refer to them. Learner independently examines other resources and forms links to explanations	Directs learner to links related to areas and sources of scientific knowledge.	Identifies areas and sources of scientific knowledge that could be useful, but does not provide links.	States or implies possible connections, but does not provide links	Explicitly states specific connections, but does not provide links.	

Table 4. Modified essential features of Web-based inquiry for learning science and their variations.

	Learner Directed		Materials Directed	
Essential Feature of Inquiry	L2	L1	M1	M2
Learners are engaged by scientifically oriented **questions**.	Prompts learner to formulate own question or hypothesis to be tested.	Supports learner in process of formulating question or hypothesis. May suggest general areas or topics.	Offers learner lists of questions or hypotheses from which to select.	Provides learner with specific stated (or implied) question/hypothesis to be investigated.
Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.	Learner determines what constitutes evidence and develops procedures and protocols for gathering relevant data.	Directs learners to collect certain data, or only provides portion of needed data. Usually provides protocols for data collection.	Provides data and asks learners to analyze.	Provides data and gives specific direction on how data is to be analyzed.
Learners formulate **explanations** from evidence to address scientifically oriented questions.	Prompts learner to analyze data and formulate conclusions, but does not provide specific guidance.	Directs learner to type of evidence that might be useful, but does not cite specific evidence.	Cites specific evidence and asks learner to think about how this evidence leads to explanation.	Specifically directs learner in making inferences and forming generalizations.
Learners **communicate** and justify their proposed explanations.	Reminds learner of general purpose and need, but gives no specific guidance	Addresses possible communication techniques but not content.	Suggests possible content for presentation.	Provides clear specifications for layout and/or content.
	Learner-driven with much initiative and independence.	Learner makes decisions, but with support and scaffolding, particularly with the process.	Learner does much selecting from provided materials. Limited choices.	Materials-driven. Learner makes few choices and is given much direction.

Table 5. Final Instrument.

<table>
<tr><th></th><th colspan="4">Learner Directed</th><th colspan="4">Materials Directed</th></tr>
<tr><th>Essential Feature of Inquiry</th><th colspan="2">L2</th><th colspan="2">L1</th><th colspan="2">M1</th><th colspan="2">M2</th></tr>
<tr><td>Learners are engaged by scientifically oriented questions.</td><td colspan="2">Prompts learner to formulate own question or hypothesis to be tested.</td><td colspan="2">Suggests topic areas or provides samples to help learner formulate own question or hypothesis.</td><td colspan="2">Offers learner lists of questions or hypotheses from which to select.</td><td colspan="2">Provides learner with specific stated (or implied) question/hypothesis to be investigated.</td></tr>
<tr><td>Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.</td><td colspan="2">Learner determines what constitutes evidence and develops procedures and protocols for gathering relevant data (as appropriate).</td><td colspan="2">Directs learner to collect certain data, or only provides portion of needed data. Often provides protocols for data collection.</td><td colspan="2">Provides data and asks learner to analyze</td><td colspan="2">Provides data and gives specific direction on how data to be analyzed.</td></tr>
<tr><td>Learners formulate explanations from evidence to address scientifically oriented questions.</td><td colspan="2">Prompts learner to analyze data and formulate own conclusions.</td><td colspan="2">Prompts learner to think about how evidence leads to conclusions, but does not cite specific evidence.</td><td colspan="2">Directs learner attention (often through questions) to specific pieces of data to make inferences or form generalizations.</td><td colspan="2">Directs learner attention (often through questions) to specific pieces of data to lead learner to predetermined correct conclusion (verification).</td></tr>
<tr><td>Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.</td><td></td><td>Prompts learner to examine other resources and form links to explanations independently (Catalyst).</td><td>Provides links but does not refer to them. Learner independently examines other resources and forms links to explanations</td><td>Directs learner to links related to areas and sources of scientific knowledge.</td><td>Identifies areas and sources of scientific knowledge that could be useful, but does not provide links.</td><td>States or implies possible connections, but does not provide links</td><td>Explicitly states specific connections, but does not provide links.</td><td></td></tr>
<tr><td>Learners communicate and justify their proposed explanations.</td><td colspan="2">Reminds learner of general purpose and need, but gives no specific guidance.</td><td colspan="2">Talks about how to improve communication, but does not suggest content or layout.</td><td colspan="2">Suggests possible content to include and/or layout that might be used.</td><td colspan="2">Specifies content to be included and/or layout to be used.</td></tr>
<tr><td></td><td colspan="2">Learner-driven with much initiative and independence.</td><td colspan="2">Learner makes decisions, but with support and scaffolding, particularly with the process.</td><td colspan="2">Learner does much selecting from provided materials. Limited choices.</td><td colspan="2">Materials-driven. Learner makes few choices and is given much direction.</td></tr>
</table>

Table 6. WBIs placed on instrument.

	Learner Directed		Materials Directed	
Essential Feature of Inquiry	**L2**	**L1**	**M1**	**M2**
Learners are engaged by scientifically oriented questions.	Prompts learner to formulate own question or hypothesis to be tested. ***O1**	Suggests topic areas or provides samples to help learner formulate own question or hypothesis. F1, S3	Offers learner lists of questions or hypotheses from which to select.	Provides learner with specific stated (or implied) question/hypothesis to be investigated. A1, B1, B2, D1, D2, E1, E2, E3, G1, G2, G3, H1, H2, H3, I1, J1, K1, K2, L1, L2, M1, N1, N2, P1, P2, P3, Q1, R1, S1, S2
Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.	Learner determines what constitutes evidence and develops procedures and protocols for gathering relevant data (as appropriate). N2, *O1, *Q1, S1, S2, S3	Directs learner to collect certain data, or only provides portion of needed data. Often provides protocols for data collection. A1, B2, *C1, E2, E3, F1, *G2, *G3, H1, H2, H3, I1, *K1, K2, L1, L2, M1, *O1, *R1	Provides data and asks learner to analyze D1, D2, *G2, *K1, *Q1, *R1	Provides data and gives specific direction on how data to be analyzed. B1, *C1, E1, G1, **G3, J1, N1, *O1, P1, P2, P3, *Q1**
Learners formulate explanations from evidence to address scientifically oriented questions.	Prompts learner to analyze data and formulate own conclusions. B1, B2, E2, E3, F1, G2, M1, N2, *O1, S1	Prompts learner to think about how evidence leads to conclusions, but does not cite specific evidence. *Q1, S2, S3	Directs learner attention (often through questions) to specific pieces of data to make inferences or form generalizations. A1, D1, D2, H2, K1, K2, N1, *O1, *Q1, R1	Directs learner attention (often through questions) to specific pieces of data to lead learner to predetermined correct conclusion (verification). C1, E1, G1, G3, H1, H3, I1, J1, L1, L2, P1, P2, P3

Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.		Prompts learner to examine other resources and form links to explanations independently (Catalyst). C1, F1, G2, G3, K1, S1	Provides links but does not refer to them. Learner independently examines other resources and forms links to explanations A1, E2, Q1	Directs learner to links related to areas and sources of scientific knowledge. D1, D2	Identifies areas and sources of scientific knowledge that could be useful, but does not provide links.	States or implies possible connections, but does not provide links S3	Explicitly states specific connections, but does not provide links. K2, N1	
Learners communicate and justify their proposed explanations.	Reminds learner of general purpose and need, but gives no specific guidance. E2, F1, N2, R1		Talks about how to improve communication, but does not suggest content or layout. B1, G2, Q1		Suggests possible content to include and/or layout that might be used. E3		Specifies content to be included and/or layout to be used. A1, C1, D1, G1, G3, I1, K1, K2, S1, S2, S3	
	Learner-driven with much initiative and independence.		Learner makes decisions, but with support and scaffolding, particularly with the process.		Learner does much selecting from provided materials. Limited choices.		Materials-driven. Learner makes few choices and is given much direction.	

Figure 1. Learner-centered design.

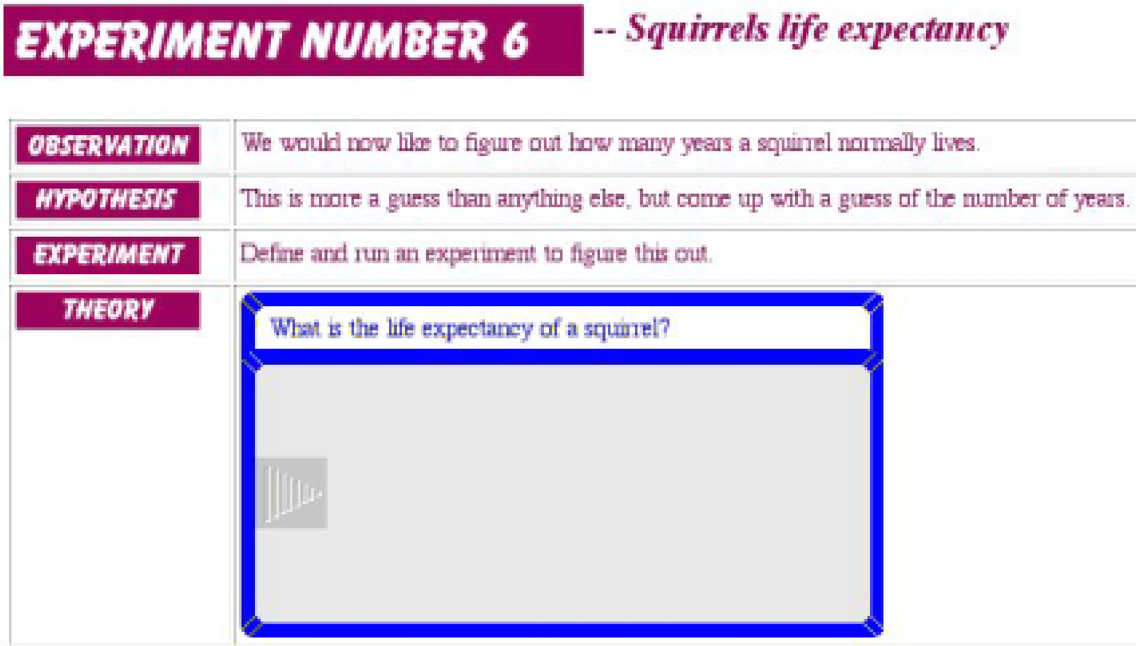
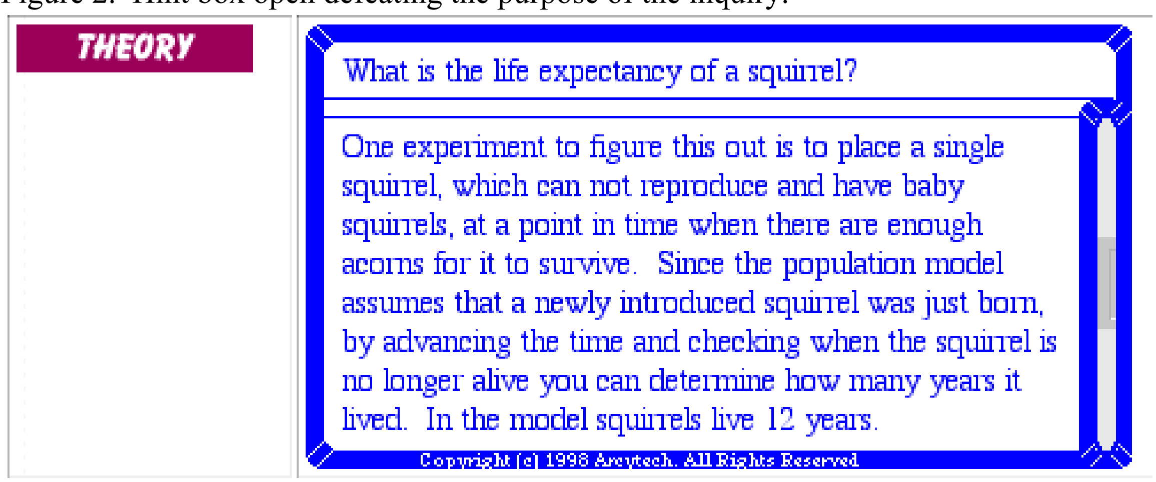


Figure 2. Hint box open defeating the purpose of the inquiry.



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