The Status of Web-based Inquiry in Chemistry

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This study investigated 137 currently available chemistry-related Websites and identified 17 Web-based inquiry activities (WBIs) based on the criteria listed in *Web-Based Inquiry for Learning Science* (Bodzin & Cates, 2001). A multi-pass unanimous consensus analysis was used to examine how the 17 WBIs reflected the five essential inquiry characteristics described in *Inquiry and the National Science Education Standards* (National Research Council, 2000) and to classify them accordingly. Instructional and design features of chemistry-related WBIs are described.

Background

As a result of the Standards movement and increased Internet connectivity in schools, we appear to be on the cusp of a transformation in the way science is taught and learned in schools. Inquiry-based teaching and learning and technology integration are integral components of both the National Science Education Standards (*1*) and the Project 2061 Benchmarks (*2*) and the prevalence of Internet connections in public schools has risen from 35 percent in 1994 to 95 percent in 1999 (*3*). When schools have connectivity to the World Wide Web, they can do things they could not do before and the way science content is delivered in K–12 classrooms is one area in which new practices may now be possible. The Web is accessible worldwide, relatively easy to update, and adds new capabilities almost daily. With the simplification of Web-publishing software, almost anyone – a K-12 student, science educator, scientist, member of a special interest group, or even a for-profit commercial enterprise – can become a content provider for a science education site. Unfortunately, many of these content providers lack expertise, particularly pedagogical expertise. Despite the rich literature in teaching and an abundance of models in instructional design, many current sites do not take advantage of what we already know about instruction. Research-based principles and practices for designing Web-based inquiry activities (WBIs) for learning science can improve Web-delivered lessons and advance the use of the Web in teaching and learning science (*4*).

Design of the Study

The purpose of this study was to investigate (1) the prevalence of chemistry-related Websites currently available on the World Wide Web and (2) to determine their pedagogical and design characteristics. Websites were considered chemistry-related if they included subject matter traditionally covered in widely used introductory chemistry textbooks (*5, 6*). Each Website was reviewed in order to identify if it qualified as a Web-based inquiry (WBI) activity according to the six criteria listed in *Web-based Inquiry for Learning Science (WBI) Instrument Manual: Beta Version 2* (*7*):

1. A WBI must contain at least the first three essential features of classroom inquiry described in *Inquiry and the National Science Education Standards* (*8)*:
   - Learners are engaged by scientifically oriented questions that are stated explicitly or implied as a task.
   - Learners give priority to evidence, which allows them to draw conclusions and/or develop and evaluate explanations that address scientifically oriented questions.

- Learners draw conclusions and/or formulate explanations from evidence to address scientifically oriented questions.

2. The WBI should be phrased in such a way that learners would perceive it as directed at them. The majority of the wording used in the WBI should be directed at the learner ("you"), not at the teacher ("your students").

3. The WBI must support student learning of a science concept or science content. Science WBIs must fall into a recognized science discipline (biology, chemistry, physics, environmental sciences, astronomy, oceanography, and the like).

4. The WBI must be Web-based. A WBI is more than reformatted text from printed sheets placed on the Web, describing how an inquiry activity may be completed. Instead, it should be enhanced or customized to take advantage of the features of the Web to deliver instruction.

5. Evidence used in a WBI should be of the same type an actual scientist would use.

6. Conclusions and/or explanations in WBIs should be more than simple data analysis and reporting. They must involve reasoning.

Sampling

This study employed a two-stage sampling procedure. In the first stage we used *Science NetLinks* (*9*), the educational Website of the Association for the Advancement of Science (AAAS) as a source of potential chemistry WBIs. This site was selected for its alignment with the AAAS Project 2061 Benchmarks. Each Website listed on *Science Netlinks* has been reviewed by a board of editors. The site provides a section of "lessons" and reviewed "on-line resources" for grades 9-12 that is indexed by Benchmark topics. All of the Benchmark "lessons" were directed at teachers and not students, and therefore were eliminated on the basis of qualification rule 2. Of the 92 online potential resources examined, a pool of 59 chemistry-related Websites was produced by applying qualification rule 3 specifically to chemistry. Each of these sites was examined to see if it aligned with each of the WBI criteria listed above. The analysis yielded one chemistry-related WBI from this sample.

In the second stage of sampling we returned to the 59 Websites found in *Science NetLinks* for links to additional chemistry-related Websites to broaden the pool from which we might obtain WBIs. Another 78 sites contained links to additional chemistry-related Websites that ultimately resulted in the inclusion of 137 sites with the potential to contain WBIs.

Of the 137 sites examined, the vast majority provided only science content information (75.9%) and failed to meet WBI qualification rule 1 (minimum of first three essential features). Fifteen sites contained activities for students such as experiments, games, and projects (10.9%) and twelve sites (8.8%) were directed at the teacher, not the learner. Only six sites (4.4 %) included activities that qualified as WBIs. Figure 1 illustrates the distribution of sites by type, and Table 1 lists these sites. Only three of these sites contained multiple inquiry activities, yielding a total of 17 WBIs in the sample (Table 2). For ease in later reference, we have labeled each Website with a letter from A to F. Individual WBIs on a Website are indicated with numbers. So, B1 and B3 indicate two of three different WBIs categorized on the chemistry-related Website labeled with the letter B. An examination of the content in the WBIs shows that the subject matter is limited to a minute fraction of possible chemistry topics and concepts. Of the 17 WBI activities, 14 involve aspects of water chemistry. Of the remaining three, one (B3) teaches the concepts of heat, temperature, specific heat, and energy transfer. Another (D) is a study of influences on boiling point, and the last (E) includes concepts in chemical bonding.

Table 1: Chemistry Websites that qualified as Web-based Inquiries

Code	Website	URL
A	Water on the Web	http://wow.nrri.umn.edu
B	WISE	http://wise.berkeley.edu
C	Center for Innovative Learning Technologies	http://www.cilt.org
D	Boil, Boil, Toil and Trouble	http://k12science.stevens-tech.edu/curriculum/boilproj/
E	Chemistry Webquest	http://nths.newtrier.k12.il.us/academics/faculty/gressel/mendelevwebquest
F	Supplying Our Water Needs	http://www-ed.fnal.gov/trc/projects/hs_proj.html

Table 2: Website activities that qualified as Web-based Inquiries

Code	Confirmed BWIs	URL
A1	Studying the Chemistry of Oxygen Solubility	http://nrri.umn.edu/wow/student/oxygen/study.html
A2	Studying Conductivity	http://nrri.umn.edu/wow/student/conduct/study.html
A3	Studying Diel Temperature Variation in Lakes	http://nrri.umn.edu/wow/student/diel/study.html
A4	Studying the Effect of pH on Aquatic Organisms	http://nrri.umn.edu/wow/student/pH/study.html
A5	Investigating Diel Temperature Variation in Lakes	http://nrri.umn.edu/wow/student/diel/inquiry.html
A6	Investigating Conductivity	http://nrri.umn.edu/wow/student/conductivity/inquiry.html
A7	Investigating the Effects of pH on Aquatic Organisms	http://nrri.edu/wow/student/pH/inquiry.html
A8	Investigating the Chemistry of Oxygen Solubility	http://nrri.edu/wow/student/oxygen/inquiry.html
A9	Investigating Increases in Conductivity - Are Culverts the Culprits?	http://nrri.edu/wow/student/inconduct/inquiry.html
B1	Water Quality - Drink or Swim?	http://wise.berkeley.edu/teacher/projects/projectInfo.php?id=1101
B2	Water Quality - Pine Creek	http://wise.berkeley.edu/student/topFrame.php?projectID=216
B3	Thermodynamics - Probing Your Surroundings	http://wise.berkeley.edu/student/topFrame.php?projectID=1434
C1	Alameda Creek	http://wise.berkeley.edu/WISE/demos/alameda
C2	Strawberry Creek	http://wise.berkeley.edu/WISE/demos/strawberry
D	Boil, Boil, Toil and Trouble	http://k12science.stevens-tech.edu/curriculum/boilproj/
E	Chemistry Webquest	http://nths.newtrier.k12.il.us/academics/faculty/gressel/mendelevwebquest
F	Supplying Our Water Needs	http://www-ed.fnal.gov/trc/projects/hs_proj.html

Analysis

Each coded WBI was analyzed using the WBI instrument (*7*). The instrument classifies WBIs for learning science along a continuum from learner-directed to materials-directed. Learner-directed activities call for much learner involvement in making decisions about how to complete the inquiry and accommodate a diversity of learner approaches and actions. Materials-directed inquiries tend to be very specific about what learners should do in order to complete the inquiry and often lead the learner towards expected conclusions and explanations.

Classification of WBIs was accomplished using a multi-pass unanimous consensus approach: Two researchers independently examined each WBI and classified its properties using the instrument. Next, these researchers revisited each site together (multi-pass) to confirm all decisions and classifications. In all cases, both researchers had to agree on all decisions and classifications (unanimous consensus) before moving on to the next WBI.

Figure 1: Classification of the WBIs on the instrument

Website Name: **ALL - SUMMARY** Website URL: ______

Specific Activity Name: ______ Specific Activity (Root) URL: ______

	Learner Directed		Materials Directed	
Essential Feature of Inquiry	**L2: Learner-driven with much initiative and independence.**	**L1: Decisions to make, but support & scaffolding, particularly with process.**	**M1: Much selecting from provided materials. Limited choices.**	**M2: Materials-driven. Few choices and much direction given.**
Learners are engaged by scientifically oriented **QUESTIONS.**	Prompts learner to formulate own question or hypothesis to be tested.	**Suggests topic areas or provides samples to help learner formulate own question or hypothesis.** **F**	Offers learner lists of questions or hypotheses from which to select.	Provides learner with specific stated (or implied) question/hypothesis to be investigated. **A1 A2 A3 A4 A5 A6 A7 A8 A9 B1 B2 B3 C1 C2 D E**
Learners give priority to **EVIDENCE,** which allows them to draw conclusions and/or 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). **F**	Directs learner to collect certain data, or only provides portion of needed data. Often provides protocols for data collection. **A2* A4* A6* A7* A9 B3* C1* C2* D***	Provides data and asks learner to analyze. **A2(* A5 A6* A7* A8 C1* C2* D* E**	Provides data and gives specific direction on how data to be analyzed. **A1 A3 A4* B1 B2 B3***
Learners formulate **CONCLUSIONS** and/or **EXPLANATIONS** from evidence to address scientifically oriented questions.	Prompts learner to analyze evidence (often in the form of data) and formulate own conclusions/explanations. **F**	Prompts learner to think about how evidence leads to conclusions/explanations, but does not cite specific evidence. **A7**	Directs learner attention (often through questions) to specific pieces of evidence (often in the form of data) to draw conclusions and/or formulate explanations. **C1 C2**	Directs learner attention (often through questions) to specific pieces of evidence (often in the form of data) to lead learner to predetermined correct conclusion/explanation (verification). **A1 A2 A3 A* A5 A6 A8 A9 B1 B2 B3 D E**
Learners evaluate their conclusions and/or explanations in light of ALTERNATIVE CONCLUSIONS/ EXPLANATIONS, particularly those reflecting scientific understanding.	[shaded] Prompts learner to examine other resources and make connections to conclusions and/or explanations independently ("Catalyst").	Provides hypertext links but does not refer to them. Learner independently examines other resources and make connections to conclusions and/or explanations. **A1 A2 A3 A4 A6 A7 A8 A9 D E** Directs learner to hypertext links related to areas and sources of scientific knowledge. **B1 B2 C1 F**	Identifies areas and sources of scientific knowledge that could be useful, but does not provide hypertext links. Suggests or implies possible connections, but does not provide hypertext links. **B3 C2**	Explicitly states specific connections, but does not provide hypertext links. [shaded]
Learners **COMMUNICATE** and justify their proposed conclusions and/or explanations.	Reminds learner of general purpose of communication and/or need for communication, but gives no specific guidance. **A8**	Talks about how to improve communication, but does not suggest content or layout. **A6* A9 F**	Suggests possible content to include and/or layout that might be used. **A5 A6* A7 D E**	Specifies content to be included and/or layout to be used. **A1 A4 B1 B2 B3 C1 C2**

NOTE: *Site categorized in more than one cell as a result of having multiple sections.

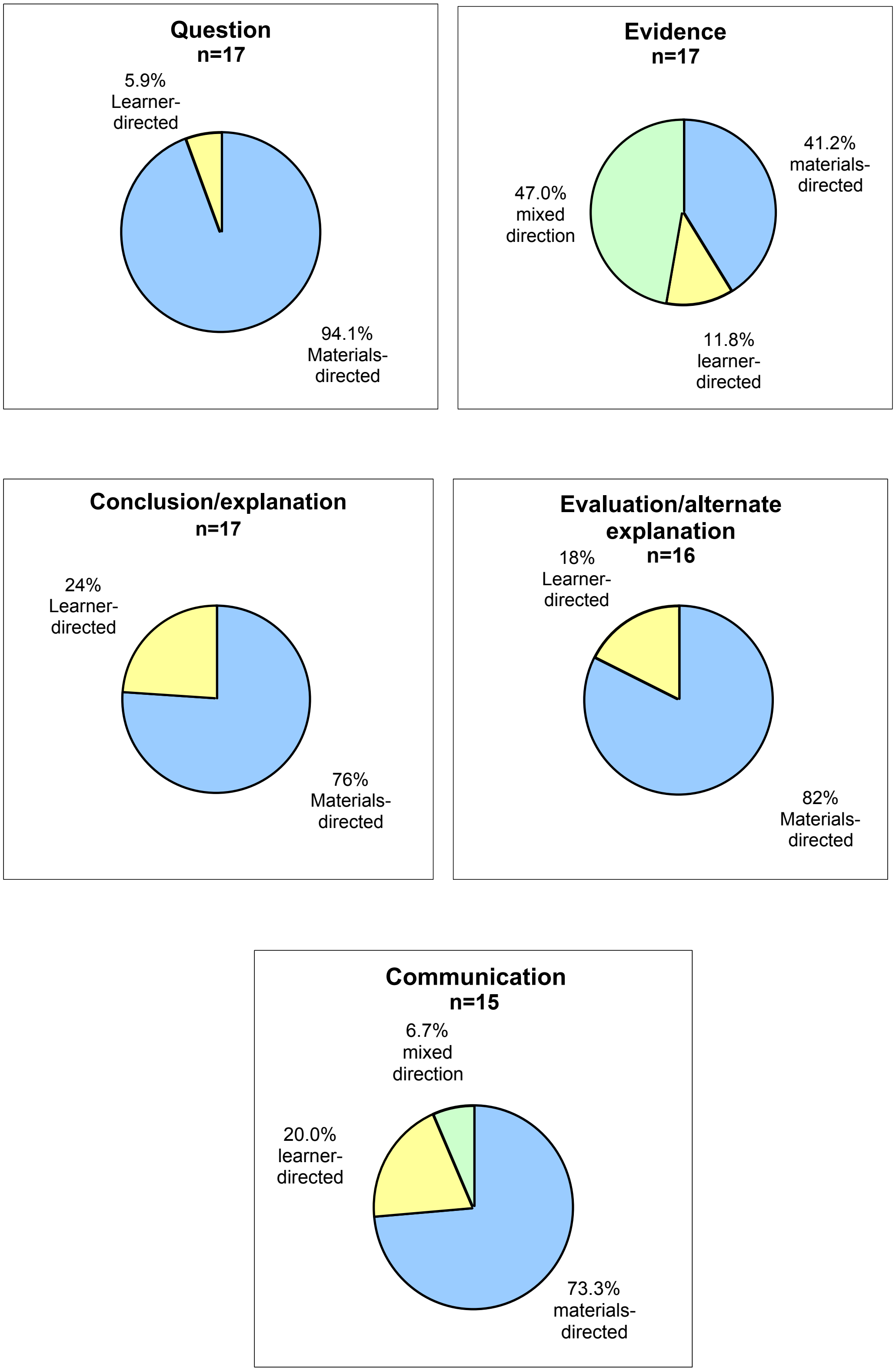
Results and Findings

The placement of the17 coded WBI activities is shown in Figure 1. Fourteen (82.3%) of the WBI activities were classified as full inquiries containing all five essential elements as described in *Inquiry and the National Science Education Standards*. Three WBIs were classified as partial inquiries (at least the first three essential features): two (11.8%) lacked communication and justification, and one (5.9%) failed to address alternative conclusions/explanations.

Figure 2 shows a summary of the learner-directed/materials-directed qualities of the WBI placements on each of the five essential features of inquiry. Materials-directed questions (94.1%) predominated in the WBIs. Only one WBI (5.9%) did not provide the learner with a question to be investigated. This activity furnished the general topic of investigation and instructed the learners to identify a problem relating to it. Although most of the WBIs included prescriptive questions, some activities were learner-directed in terms of other essential features of inquiry.

Collecting evidence was materials-directed in seven WBIs (41.2%) with the learner provided with data to analyze. In two inquiries (11.8%) collecting evidence was learner-directed since the learner was involved in data collection. Eight WBIs exhibited what we term the "dual nature of evidence." That is, they provided data in some sections, but directed learners to collect data in others.

Figure 2: Percentage of learner/materials directedness in WBI sample



Six (25.3%) WBIs then provided specific directions for analyzing those data, while nine (52.9%) asked learners to analyze them but did not provide specific directions on how to do so. Ten WBIs (58.8%) were learner-directed: one WBI (5.9%) allowed the learner to determine what constitutes evidence and develop methods to gather relevant data, while nine (52.9%) directed the learner to collect certain data and usually included protocols for that collection.

In a majority of the WBIs, formulating conclusions/explanations was materials-directed: thirteen (76.4%) led the learners to verify a predetermined correct conclusion; two (11.8%) allowed the learners to use the data provided to draw conclusions and /or formulate explanations. One of these prompted the learners to think about how evidence leads to conclusions/explanations and the other one prompted the learners to analyze evidence and formulate their own conclusions or explanations.

Sixteen (94.1%) WBIs had learners evaluate their conclusions and/or explanations in light of alternative conclusions/explanations. Fourteen of these were distinctly learner-directed in asking learners to evaluate their conclusions and explanations in light of alternative conclusions/explanations. Ten of the 16 WBIs provided hypertext links but did not refer to them, allowing learners to independently examine other resources, and four directed learners to related hypertext links. (A hypertext link consists of underlined text on which a learner clicks and is taken either to an area within a Website that provides related information or to an external Website that provides such information.) Another two of the 16 WBIs explicitly stated specific connections to the conclusion or explanation drawn, but did not provide hypertext links

Fifteen (88.2%) WBIs had learners communicate and justify their proposed conclusions/explanations. Materials-directed communication predominated among the examined WBIs. Seven of the 15 specified the content and/or layout to be used, while another five suggested possible content or layout. Of the remaining four activities, three discussed how to improve communication without suggesting content or layout and one reminded the learners of the general purpose and/or need for communication, but provided no specific guidance.

The one WBI that began with a learner-centered question was classified as learner-directed in four of five other essential features. This WBI did not meet the criteria for *communication,* however, because the learner was not given the opportunity to communicate his or her findings to an "audience" other than a classroom teacher.

The majority of the sampled WBIs (82.3%) originated from three Websites containing multiple WBIs. We examined these for common design features that characterized each site. The *Center for Innovative Learning Technologies (CILT)* WBIs were full inquiries. They generally delivered instruction using a common template. Each included materials-directed questions, conclusions, and called for communication. In addition, each exhibited the dual nature of evidence identified earlier (provision plus collection) and asked learners to consider alternative conclusions/explanations. The three *WISE* WBIs were also full inquiries. Their design pattern was similar to that of *CILT* WBIs. This was expected since the two host Websites were related (The *CILT* Website described *WISE* as one of their SYNERGY projects) and both projects are housed at the University of California at Berkeley. In the nine *Water on the Web* WBIs, learners were provided with questions. Each alternative conclusion/explanation was learner-directed, but only some of these guided learners to hypertext links. There was one major area of commonality among the *Water on the Web* WBIs. All but one WBI had the learner investigate a predetermined conclusion. In contrast, the learners' use of evidence and the method of communication varied across the continuum from material-directed to learner-directed. Seven of the nine were full inquiries and the other two lacked only the communication component.

Discussion

Three findings of the present study suggest that there is room for much growth in Chemistry WBIs: First, we found few Chemistry WBIs. Second, the few Chemistry WBIs we found were limited in scope and content coverage. Third, we found many valuable chemical information Websites that, in addition to those suggested by other authors (*10*), might provide strong source materials for Chemistry WBIs.

The design of WBIs differs markedly from that of most other science sites found on the World Wide Web. A WBI is designed to be a scientific investigation in which the learner engages. It has a large measure of self-sufficiency, calling on teachers to play a less direct role than many do in traditional teaching settings. The various non-WBI science sites are all valuable resources, however. Informational sites provide useful facts and figures for students, teachers, and scientists. Sites for teachers usually contain ideas for lesson plans and learning activities for classroom use. And many student sites present entertaining experiments, projects, and games that make science fun.

The small number of chemistry WBIs we found may reflect the difficulty that teachers have in designing and implementing inquiry approaches (*8*). Such change is difficult. As noted above, teachers' and students' roles differ from the ones they have traditionally played. Few teachers have extensive training in helping students acquire scientific inquiry, regardless of the specific science discipline, teachers may fear a loss of control in more learner-directed approaches, and students have little experience in constructing scientific questions (*8*). Of the Chemistry WBIs in our sample, the feature that emerged as the most learner-directed was the one in which students have the most experience: collecting data as evidence, as they do in traditional laboratory exercises. This suggests that the WBIs we examined may constitute a bridge between present practices and some of the more constructivist, learner-centered approaches now being espoused in the literature (*13, 14, 15*).

The relative consistency among WBI activities on a single Website confirmed the findings of earlier studies that the philosophy of the WBI designer appears to drive the design (*4, 11*). For example, the single activity that contained a learner-centered question was entirely learner-directed, suggesting that the designer's philosophy was based on the belief that students require little guidance in completing such inquiries. Similarly – but conversely -- the majority of WBIs that began with materials-directed questions usually then called for materials-directed conclusions/explanations and often contained traditional "cookbook" investigations. This prescriptive approach appears to indicate the designer's philosophical belief in the need to teach specific concepts in a directed way.

All but two WBIs focused on water quality as their content. One that did not dealt with heat and temperature, while the other addressed chemical bonding. The fact that water quality is more concrete than either of these other concepts may account for its predominance. Water quality also crosses the disciplines of biology, chemistry, and ecology, so its study is useful in multiple settings.

One could easily be disheartened by the limited number of Chemistry WBIs we found and the relative simplicity of some of the inquiries offered. But, the Web is a rapidly changing place; tomorrow may be different. What we depict here is what exists today. Thus, our findings constitute a historical and development baseline for future investigation of Web-based scientific inquiry in Chemistry. They should allow us to look back later and see how things have changed. At the same time, the findings here suggest that the *Web-based Inquiry for Learning Science* instrument (*12*) may provide developers with a blueprint for how to develop WBIs that more nearly reflect pedagogical and philosophical beliefs about how scientific inquiry should be done.

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