A Formative Evaluation Approach to Guide the Development of a Web-text Biology Curriculum

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Abstract:
We are currently conducting a formative evaluation study on a new basal biology curriculum for ninth and tenth grade students that integrates the World Wide Web with a short topic-oriented textbook. The curriculum is based on the National Science Education Standards and emphasizes an active, constructivist learning program that integrates interactive, Web-based instructional media. The new curriculum utilizes the interactivity of the World Wide Web, the storytelling abilities of a short textbook, and an inquiry-based program of "wet" labs and fieldwork. National Science Foundation funding supports the formative and summative evaluation of this curriculum. The evaluation program focuses on the effectiveness of integrating Web-based instruction into the biology curriculum, both in terms of helping students learn and helping teachers teach.
The major formative evaluation questions are:

- Do the materials address the important goals of biological science teaching and learning?
- Are inquiry and activity the basis of the learning experiences?
- Are the topics of the unit and the modes of instruction developmentally appropriate?
- How are teachers implementing the materials?

This paper presents our formative evaluation approach and describe how our initial findings have guided changes in the development of this biology curriculum.

Overview of the project

Biology: Exploring Life is a new kind of integrated high school biology program for 9th and 10th grade teachers and students. Exploring Life will consist of a short textbook, a set of exploratory lab and field activities, and an extensive World Wide Web site that will provide an interactive learning environment for all students and a source of daily support and collaboration for teachers. The integration of these components should enable all students to explore life actively instead of limiting them to passive exposure to content. This biology program should be adaptable to the unique needs of teachers and students by providing a broad range of resources that can be selectively integrated into the curriculum.

The main goal of the funded project is to guide the development of the Exploring Life biology program designed to improve high school biology students' understanding of fundamental biological concepts. The students' self-confidence and skill in scientific reasoning and inquiry and their ability to apply biological knowledge and the methods of science to important social issues, consistent with the National Science Education Standards, should also be enhanced.

The aim of the formative evaluation is to assess the materials in terms of their ease of use, pedagogy, program performance, and clarity and depth of content. The four major formative evaluation issues are,

1. Do the materials address the important goals of biological science teaching and learning?
2. Are inquiry and activity the basis of the learning experiences?
3. Are the topics of the unit and the modes of instruction developmentally appropriate?
4. How are teachers implementing the materials?

These evaluation issues were addressed in a series of data-collection measures. These included the AAAS criteria for evaluating the quality of instructional support instrument, feedback questionnaires, focus group questions, field observations, teacher journals, post implementation surveys, student reaction journals, teacher and student interviews with open-ended questions, and pre- and posttest content knowledge quizzes.

Forty-two high school biology teachers selected from a stratified sample of thirteen distinct geographical regions that included Alaska and Hawaii participated in the evaluation of the Exploring Life materials during the first year of the grant implementation period. The participants reviewed the Exploring Life Web-based and text materials in various stages of development at one of three evaluation workshops. Workshops were held in August 2000, October 2000, and March 2001. Feedback and recommendations resulting from the evaluation workshops were reported back to the development team.

A prototype cellular respiration chapter was developed prior to the August workshop. Feedback from the first evaluation workshop, the interface analysis reports, and initial pilot testing with classroom students resulted in the development of rapid prototypes of two new interfaces for Exploring Life. Rapid prototyping allows for rapid construction of different design approaches for the purpose of evaluating strengths and weaknesses of the instructional system interface before full-scale production. Participants in the October 2000 workshop evaluated both rapid prototypes. Participant feedback about the prototypes and the interface analysis reports led to adopting a new interface design for Exploring Life.

The cellular respiration and photosynthesis chapters were developed using the new interface design prior to the March 2001 evaluation workshop. An ecology chapter was developed in May 2001.

During the first year of the grant implementation period, eighteen participants pilot tested Exploring Life materials with 783 students. The evaluation team conducted five field observations. Each report was discussed with the development team and the recommendations made by the evaluation team have been acted upon. Throughout the first year of the project, close, almost daily contact has occurred among the evaluation team, the development team, and the teacher pilot testers.

Evaluation design

Throughout the development of Exploring Life, we have employed a user-centered design strategy that focuses simultaneously on interface issues, students and teachers' subjective experiences in using Web-based interactivities, and student learning outcomes. A concurrent integrative formative evaluation process was used to evaluate the Exploring Life program. The aim of the formative evaluation is to assess the materials in terms of their ease of use, pedagogy, program performance, and clarity and depth of content. Our mixed method approach combines experimental methods and qualitative approaches. An illuminative approach was used to discover how the program works by observing and measuring the teaching and learning process. Our aim was to discover which factors and issues are important for biology teachers in successfully implementing Exploring Life with their students and to convey this information to the developers of Exploring Life for their use in helping the program achieve its intended objectives. We proceeded through iterative cycles of design and evaluation.

A battery of methods and instruments was used in the Year 1 evaluation. These included:

1. *Content knowledge assessments*. The assessments were constructed by the Exploring Life developers with considerable input from members of the evaluation team. The quizzes were given to 9th and 10th grade biology students before and after using an Exploring Life chapter. Each question usually corresponds to a distinct learning objective. For consistent marking, these quizzes are multiple choice.
2. *AAAS Criteria for evaluating instructional support.* This evaluation instrument examines how well the instructional materials are likely to help students learn the important ideas and skills in the widely accepted Benchmarks for Science Literacy and in the National Science Education Standards. Biology teacher participants completed this after each evaluation workshop.
3. *Usability analysis*. We focused on determining whether or not the interfaces were consistent and easy to use (user evaluation) and determining whether or not the program performed as specified (functional evaluation).
    a. *Evaluation workshops*. Biology teachers were given Web-based and text materials to review prior to an evaluation workshop. In each evaluation workshop, biology teachers were observed as they worked through the Web-based materials for 1.5 hours. Each biology teacher participated in a focus group session after he or she worked through the materials.
    b. *Site-based field observations*. Evaluation team members visited a sample of classrooms as an observer, gathering open-ended observations. Six classrooms of students were observed using the Exploring Life materials in different developmental stages.
    c. *Expert Analysis*. An instructional design expert reviewed the materials and provided analyses and recommendations at different developmental stages of the Web-based materials.
4. *Attitude measures.* Biology teacher participants completed a post-implementation survey consisting of Likert-type and open-ended questions. These participants also

submitted a journal that used open-ended questions. These instruments were designed to address our four main formative evaluation questions:

- Do the materials address the important goals of biological science teaching and learning?
- Are inquiry and activity the basis of the learning experiences?
- Are the topics of the unit and the modes of instruction developmentally appropriate?
- How are teachers implementing the materials?

5. *Interviews with students.* Semi-structured interviews with a sample of students were conducted to initiate discussion about their perception of learning with Exploring Life. The students' comments acted as prompts for each other.
6. *Student response journals*. A sample of students were asked to write a student reaction paper about their experience using the Exploring Life materials.
7. *Interviews with teachers*. Structured phone interviews were conducted with each Exploring Life teacher participant from the first two workshops who were unable implement the materials with their classroom students.
8. *Computer experience questionnaire*. This instrument asks about past and current computer and Internet training, usage, skills, and confidence about computers and Web-based learning.

AAAS Criteria for evaluating instructional support

Table 1 displays the results of the AAAS Criteria for Evaluating the Quality of Instructional Support instrument. The main findings on the effectiveness of the Exploring Life program were based on teacher-participant responses (n=43) to the AAAS Criteria for Evaluating the Quality of Instructional Support Instrument. They include:

Strengths:

- The material does a good job in conveying an overall sense of purpose and direction that is understandable and motivating to students.
- The material conveys the purpose of each lesson.
- The material involves students in a logical or strategic sequence of activities.
- The material provides a sufficient number and variety of phenomena, observable events in nature that can make a scientific idea real to students.
- The materials include activities that provide firsthand experiences with phenomena when practical and a vicarious sense of the phenomena when not practical. The experiences that are not firsthand (for example, text, pictures, animations, interactivities) provide students with a vicarious sense of the phenomena.
- The materials introduce technical terms in conjunction with an experience with the idea or with a process. Terms are introduced as needed to facilitate thinking and

promote effective communication. The material is effective in linking technical terms to relevant experiences rather than just having students learn definitions of terms.

- The materials include accurate and comprehensible representations of scientific ideas. The interactivities provide a sufficient number and variety of representations that are explicitly linked to the presented concept and comprehensible to the students.
- The materials provide a sufficient number of tasks in a variety of contexts, including everyday contexts. Furthermore, novel tasks are included.
- Many of the online concept areas encourage students not only to express but also to clarify, justify, and represent their ideas. The Web-based materials include text that directly provides students with immediate feedback regarding their ideas.
- The material includes specific and relevant tasks and/or questions for the experience or reading. There are examples throughout the material that use questions or tasks that have helpful characteristics. Examples include: framing important issues, helping students relate their experiences with phenomena to presented scientific ideas, helping students make connections between their own ideas and the phenomena observed, and helping students make connections between their own ideas and the presented scientific ideas.
- The current Exploring Life material includes assessment items that require application of ideas and avoids allowing students a trivial way out, such as using a formula or repeating a memorized term without understanding. Some assessment items that appear in the "applying the concepts" section of the text include both familiar and novel tasks.
- Exploring Life does contain materials that appear able to help teachers create a classroom environment that welcomes student curiosity, rewards creativity, encourages a spirit of healthy questioning, and avoids dogmatism. These materials include the CalorieQuest, the Wisconsin Fastplants lab, and the Explore It! activity.
- The material avoids stereotypes or language that might be offensive to a particular group.
- The material does suggest alternative formats for students to express their ideas during instruction and assessment. This is evident where students report their laboratory results in the form of mini-posters or are provided suggestions to give a report or to create a PowerPoint presentation.

Weaknesses:

- Currently, the Exploring Life chapter materials do not specify prerequisite knowledge (prior knowledge or understanding that learners need to be able to learn new content or concepts) or skills that are necessary to meet the benchmark(s) for learning. The materials in Chapter 8 do contain links to content presented in Chapter 7.
- The Exploring Life chapter materials do not alert teachers to commonly held student ideas (some of which are troublesome and some helpful).

- The current Exploring Life Teacher Resource materials do not demonstrate/model or include suggestions for teachers on how to demonstrate/model skills or how to use the knowledge that is presented in the chapter.
- The material does not include specific suggestions to help teachers provide explicit feedback or include suggestions on how to diagnose student errors, give explanations about how these errors may be corrected, or how to further develop students' ideas.
- The material does not appear to provide students a way of expressing initial ideas about the content and concepts presented in the material. Furthermore, the material does not engage (or provide specific suggestions for teachers to engage) students in monitoring how their ideas have changed periodically in the unit.
- The materials do not contain a variety of alternative assessment items. Additional types of assessment could be included in the development of the materials including open-ended questions, essays, and lab practicals. Rubrics could be developed to score these assessment items.
- The material does not provide specific suggestions to teachers about how to use the information from the embedded assessments to make instructional decisions about what ideas need to be addressed by further activities.
- The material currently does not suggest how to probe beyond students' initial responses to clarify and further understand student answers.

The results from the above section will be used to help guide further design and development of teacher support materials.

Table 1. Results of the AAAS Criteria for Evaluating Instructional Support Instrument. [Rating scale: Excellent (3), Good (2.5-2.9), Satisfactory (2.0-2.4), Fair (1.5-1.9), Poor (0-1.4)]

Criteria for evaluating the quality of instructional support		Prototype (n=28)		New interface (n=15)	
		Mean	sd	Mean	sd
I.1	Conveying unit purpose	2.45	0.85	2.67	0.49
I.2	Conveying lesson purpose	2.43	0.50	2.67	0.62
I.3	Justifying activity sequence	2.71	0.46	2.80	0.41
II.1	Attending to prerequisite knowledge and skills	1.41	1.31	1.93	0.96
II.2	Alerting teacher to commonly held student ideas	1.29	1.24	2.27	1.03
II.3	Assisting teacher in identifying own students' ideas	2.04	0.94	1.67	1.11
II.4	Addressing commonly held ideas	2.11	0.88	2.20	0.86
III.1	Providing variety of phenomena	2.85	0.36	2.67	0.82
III.2	Providing vivid experiences	2.81	0.40	2.47	0.83
IV.1	Introducing terms meaningfully	2.81	0.40	2.60	0.63
IV.2	Representing ideas effectively	2.83	0.37	2.67	0.49
IV.3	Demonstrating use of knowledge	1.62	1.30	2.13	0.99
IV.4	Providing practice	2.77	0.43	2.67	0.49
V.1	Encouraging students to explain their ideas	2.27	0.83	2.47	0.52
V.2	Guiding student interpretation and reasoning	2.42	0.79	2.73	0.59
V.3	Encouraging students to think about what they've learned	2.00	1.10	2.07	0.96
VI.1	Aligning assessment to goals	2.21	1.02	2.33	0.90
VI.2	Testing for understanding	2.46	0.83	2.53	0.92
VI.3	Using assessment to inform instruction	1.91	1.08	1.73	1.03

Evidence of the effectiveness of the efforts

Significant product improvements have been made in the design of the instructional materials since the original prototype chapter. Table 2 summarizes the changes made to the prototype chapter of Exploring Life as a result of the NSF evaluation feedback. The resulting modifications were used in the development of additional media for succeeding chapter development.

A comparison of the original prototype with the current version of Exploring Life reveals many differences in the design of the materials with the intent of enhancing student learning.

During the first evaluation workshop, novice computer user participants had difficulty navigating within the prototype Website. This was especially evident with activities that contained hypertext links to Websites located outside of the Exploring Life host server (for example, CalorieQuest and Explore). Participants experienced high frustration levels using these activities. They had difficulty navigating back and forth between two browser windows, and, in many cases, had difficulty locating their second browser window. A few participants lost data by inadvertently closing their browser windows. Interface recommendations to the development team led to a new interface for these activities. Participants using the new interface in the third evaluation workshop did not experience navigational difficulties as in the previous workshops with the prototype chapter. Furthermore, students using the new interface did not have problems navigating within the new Website. The redesign of the Exploring Life Website interface appears to have solved the navigation problems that occurred with the prototype.

Student access to the Exploring Life materials is fast. Students log on to their computers and are able to enter a specific *Concept* in less than a minute.

Table 2: Exploring Life Product Improvements as a Result of NSF Formative Evaluation.

Instance Prior to Feedback	Evaluation Feedback	Resulting Product Change
The prototype chapter did not have adequate "teacher resources" available to assist teachers in using Exploring Life with their students.	1. The evaluation team made recommendations for the "teacher resources" section based on the results from the AAAS criteria for evaluating the quality of instructional support instrument, workshop surveys and focus group responses. 2. Pre- and posttest content assessments revealed students' misconceptions.	1. Current Website contains a revised "teacher resources" section that includes alternative assessment ideas, suggestions for teaching in different computer settings, troubleshooting suggestions, tips for teaching each concept, hypertext links to additional content information, and examples of student data. 2. A "teaching for conceptual change" section of the teacher resources is currently under development.
User interface issues: 1. The concept backbone structure. 2. Showing the relationship between labs/explores and their parent concepts. 3. Color scheme 4. Confusion over how to page forward within an activity and the function of the breadcrumb (navigation trail) feature. 5. Difficulty finding and reading instructions for the activities.	1. Teachers had trouble understanding how each Website component related to the entire site. User interface recommendations made. 2. Teachers expressed confusion over the different types of activities and how they all fit together. User interface recommendations made. 3. Teachers expressed concern that the screen looked too "bland." Color scheme recommendations made. 4. After completing an activity, students and teachers had trouble figuring out how to page forward. Many did not understand the page stepper and most did not use the breadcrumb (navigation trail) feature. User interface recommendations made. 5. Learners would scan the text for specific instructions, not bothering to read carefully. User interface recommendations made.	See new user interface on the Website: 1. New concept backbone as it appears on the chapter table of contents and on each activity page. 2. New concept backbone. 3. New color scheme. 4. Page stepper was revised for greater clarity and put in its own frame so it became enduring no matter where the user was located in the activity. The breadcrumb (navigation trail) was increased in size and colored blue to make it more obvious to the user. 5. Developers added a blue instruction box to each activity to house specific interactive instructions. The type size was increased for ease of reading.
Chapter 7 Cellular Respiration Pre-/Posttest Question #5: All work requires a source of _____.	A few student scores on this test question decreased from pre- to posttest. Students selected "ATP" from the answer choices, erroneously concluding that all work required ATP. This was most likely due to the chapter's strong focus on ATP.	Authors revised Chapter 7 to make clear that ATP was one source of energy. See Concept 7.2, page 4, ***Food Stores Chemical Energy***.
Chapter 7, Concept 7.4 Electrons fall from food to oxygen during cell respiration. Online activity: ***The Snowboarder***	The keyboard controls were difficult to use and the snowboarder analogy wasn't a perfect one for the concept. Some student confusion.	Media team scrapped the activity. A new 7.4 interactivity was developed that more accurately presented the concept without using keyboard controls.

Animations played through from beginning to end at the click of a "start" button.	Teachers and students expressed the need for more user control. Their concern came in the form of "speed control." Recommendations made to increase the user's control over the animations by segmenting animations into smaller components.	While developers could not offer varying speeds to play the QuickTime animations, they did adapt the standard QuickTime controller at the bottom of the animation window to show a content progress bar. This enabled the user to access relevant segments of a complex (or long) animation quickly when they wanted to replay it. See Concept 7.1 activity (***Bear in the Apple Tree***). Chapter 8 animations were developed with this revised format.
Animations were populated with teenagers to give the product a "high school" feel and a more personal, human touch.	Teachers pointed out that the animations looked too "young" and reminded us that teenagers think of themselves as older than they are. The inclusion of these younger-looking teens might make the material less interesting and attractive to them.	The developers removed the original characters, replacing them with photos for context-setting scenes. These contained adults or animals in areas where organisms needed to be animated.
Chapter 7, Concept 7.5 Cellular respiration converts food energy to ATP energy. A pinball animation showing the basic mechanisms of Glycolysis, Krebs Cycle, and Electron Transport	Teachers and students expressed the need for more user control. Participants' concern took the form of "this activity is too long, there's too much going on for the student to absorb everything."	The developers segmented the animation. Summaries of steps were provided to break the animation into manageable chunks and to slow it down. See Concept 7.5
Students and teachers noted they were frequently confused over the purpose of some activities, particularly the longer, multi-part interactivities.	The evaluation team suggested that each activity should contain a goal statement to make its purpose clearer to the learner. Furthermore, expected outcomes of the activity should be explicitly distinguished.	Goal statements were added to each concept activity. See any activity on the current version of the site.

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