[From *Proceedings of ICLS 98: International Conference on the Learning Sciences, Atlanta, GA, December 1998*. Charlottesville, VA: AACE.]

Matching the Design of Activities to the Affordances of Software to Support Inquiry-Based Learning

Daniel C. Edelson
School of Education and Social Policy and Institute for the Learning Sciences
Northwestern University, 1890 Maple Avenue, Evanston, IL 60201, USA
d-edelson@nwu.edu

Abstract: Inquiry activities can play many roles in the learning process, including creating a motivation to learn and providing the opportunity to discover, explore, apply, and reflect upon new knowledge. In the Create-A-World Activity for the WorldWatcher scientific visualization environment, we have designed inquiry activities that play each of these roles. This paper presents the design of the Create-A-World Activity as a case of technology-supported inquiry learning

1. Introduction

Technology's potential to support new forms of inquiry-based learning has been widely touted by science education reformers and technology advocates. To achieve that potential, however, designers must have a model of inquiry-based learning to guide their design and an understanding of the ways that the affordances of technology can be matched to inquiry activities to foster and support that learning. This paper presents a model of inquiry-based learning to support the design of activities, and an illustrative case of activity design that was created using that model. The case is the Create-A-World Activity, which was designed to capitalize on the affordances of WorldWatcher, a geographic data visualization and analysis environment.

2. A Model of Learning from Inquiry

Research in cognitive science provides compelling evidence for the importance of the way knowledge is indexed and organized in a learner's memory in determining his or her ability to draw on it when it is relevant ([Schank 1982], [Kolodner 1993], [Greeno, Collins & Resnick 1997]). To be useful in the future, new knowledge must be connected appropriately to existing memory structures and organized in a way that supports its use. To develop these connections and organization requires a three-step process. The first step is the recognition by the learner of the need for new knowledge. This recognition occurs in situations when one is confronted with a limitation or gap in one's knowledge, such as those that Berlyne describes as curious [Berlyne 1966], Hiebert et al. describe as problematic [Hiebert, et al. 1996], and Schank describes as leading to expectation failures [Schank 1982]. There are two important effects of this recognition. The first is the creation of a desire to learn in order to address the limitation. The second is the creation of a context in memory for integrating new knowledge. The knowledge structures that are activated at the point that a learner recognizes a problematic situation can provide handles for connecting new knowledge.

The second step in the learning process is the acquisition of new knowledge. This step results in the construction of new knowledge structures in memory that can be linked to existing knowledge. The third step is refinement, in which knowledge is reinforced, re-organized, and connected to other knowledge in order to support its future use. While each of these steps is essential for developing robust understanding, they do not necessarily take place in an orderly, independent fashion in practice. Because understanding is never developed in discreet independent units, the same activity may trigger each of these steps for different pieces of knowledge simultaneously. For example, the acquisition of one concept may lead to the reorganization of some existing knowledge and the recognition of a need for new knowledge.

In the research described here, we have been exploring designs for inquiry-based learning activities that will lead to the connection and organization of knowledge to support its retrieval and application in the future. While inquiry activities can provide opportunities for students to learn about both the practices of science and science content, this paper focuses primarily on the learning of science content. We have built on the three-step model of learning described above by identifying roles that learning activities can play in facilitating each step. These are summarized in [Tab. 1].

Table 1: A 3-step model of inquiry-based learning, with activity design strategies.

Step	Strategy	Description
Motivate	**Create Demand**	Activities *create a demand* for knowledge by requiring that learners apply that knowledge to complete them successfully.
	Elicit Curiosity	Activities *elicit curiosity* by revealing a problematic gap or limitation in a learner's understanding.
Acquire	**Discover**	Activities that provide learners with direct experience with novel phenomena can enable them to *discover* new knowledge.
	Receive	Activities that provide learners with access to sources of knowledge through direct or indirect communication allow them to *receive* knowledge from others.
Refine	**Explore**	Activities that enable learners to investigate the implications of their knowledge and understand its limits support refinement and re-organization of knowledge through *exploration*.
	Apply	Activities that enable learners to use their knowledge in meaningful ways help to reinforce and reorganize understanding through *application*.
	Reflect	Activities that provide opportunities for learners to examine their knowledge provide the opportunity to refine that knowledge through *reflection*.

In the design of the Create-A-World activity for WorldWatcher, specific activities implement each of these strategies. In the sections that follow, I present the Create-A-World activity as a case of design, highlighting the ways that the activities take advantage of the affordances of the WorldWatcher environment to implement these strategies. Space limitations prevent an analysis of the enactment of the activity with students beyond a few informal observations and some examples of student work.

3. WorldWatcher and the Create-A-World Activity

WorldWatcher is a scientific visualization environment that displays gridded, geographic data using color to represent quantitative and categorical values. It was created following the principles of learner-centered design [Soloway, Guzdial & Hay 1994] with the goal of supporting inquiry-based learning in the earth and atmospheric sciences. WorldWatcher was inspired by the visualization tools used by scientific researchers and was designed to bring the benefits of visualization to learners [Gordin & Pea 1995]. It displays data in the form of interactive color maps that users can customize by adjusting the colorscheme, magnification, and spatial resolution [Fig. 1]. It also allows users to create new data by performing arithmetic operations on existing data or by entering data using an interface based on the common paint metaphor. WorldWatcher was originally designed to support global-scale investigations in earth and atmospheric sciences with a data library of 19 variables related to climate, physical geography, and human geography. With the addition of an open data architecture that allows the importation of arbitrary gridded data at any scale, its range has been greatly increased.

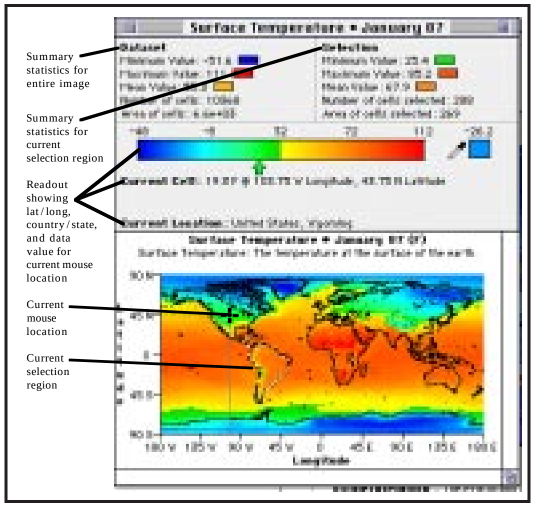

Figure 1: A WorldWatcher visualization window.

The Create-A-World Activity is a sequence of inquiry activities designed to teach advanced middle school and high school students about the interactions between physical geography and climate. Over the course of the activity, learners create their own fictitious worlds by inventing data describing their worlds' climate and geography. Learners are invited to invent any physical geography they want for their worlds, but they are asked to model the climate realistically based on scientific principles. In the course of the activity, students conduct an investigation of the earth's climate using WorldWatcher to develop an understanding of climate to apply to their invented worlds. The activity, as described below, takes approximately 10 hours. The activity has been piloted in two one-week workshops conducted at Northwestern University with the author serving as instructor. A total of fifteen ninth and tenth grade students participated in the pilots.

The stages of the Create-A-World activity are:

Stage 1. Introduction: Thinking about global temperature. Students are each given a blank map of the world and six crayons and asked to draw their best guess of the average July temperature all around the world in the month of July [Fig. 2]. They are told that this activity is intended to get them thinking about differences in temperature around the world. Students then participate in a group discussion of their maps, the knowledge they drew on in constructing them, and the questions that the activity raised.

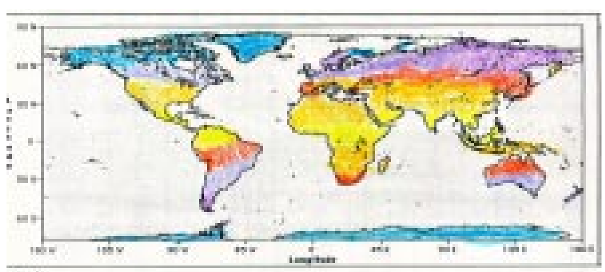

Figure 2: A student's hand-drawn map of July temperature.

Stage 2. Comparing their conjectures with "the real thing". Students are taught how to use the WorldWatcher paint tool to recreate their paper maps in the form of data visualizations. They are then taught how to access measured, global temperatures for July, and they engage in a series of activities in which they use WorldWatcher's visualization and analysis tools in the course of comparing their own maps to the measured temperature for July. By the conclusion of this 45-minute introductory activity, students have learned the basics of geographic visualization and data analysis using WorldWatcher.

Stage 3. Laying out a planet. Students use the paint interface to create the topography for their worlds in the form of continent outlines and an elevation data set [Fig. 3]. In our pilot tests, we were interested to observe that some students chose to create worlds whose layouts are pictorial.

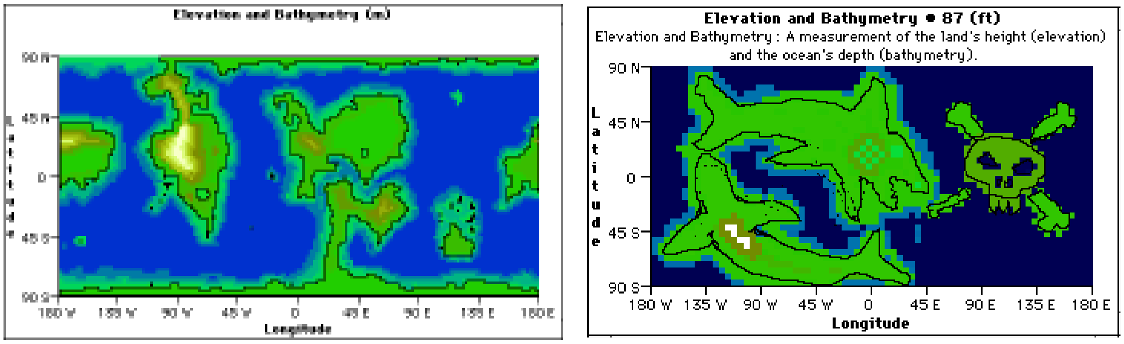

Figure 3: Elevation data for their new worlds created by two groups of students.

Stage 4. Investigating Earth. In order to create a temperature map for their own worlds, students conduct unstructured investigations of the earth to identify relationships between geography and temperature. Students use the tools and data in WorldWatcher to look for patterns that indicate relationships among variables. Following these investigations, they participate in a group discussion of the factors they identified. In the course of the discussion, the instructor challenges students to provide evidence for their theories and provides causal explanations for the relationships that they have identified, such as the impacts on temperature of incoming solar energy, surface and cloud reflectivity, atmospheric pressure, specific heat of land and water, and circulation in the oceans and atmosphere.

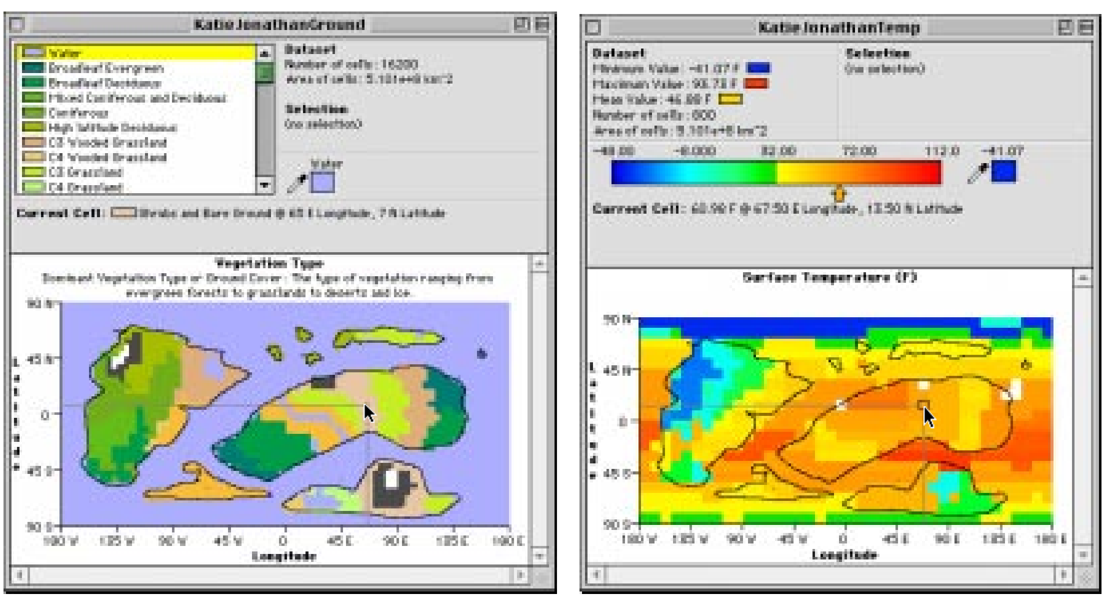

Figure 4: A ground cover (left) and temperature (right) visualization for an invented world.

Stage 5. Modeling climate for the new world. In the final phase of the activity students create the remaining data for their world making the assumption that their planet has the same incoming sunlight and tilt on its axis as earth. Students create ground cover and temperature visualization for their worlds [Fig. 4]. Creating data for their world generally requires that students return to the data for earth in order to quantify the principles uncovered in the previous phase. Once the worlds are completed, students present their worlds to each other and how they determined the temperatures in different areas.

4. Combining Activities and Affordances to Support Learning

The Create-A-World activities draw on the affordances of WorldWatcher in an integrated sequence that employs each of the strategies introduced in [Tab. 1]. In this section, I highlight the use of each strategy in the activities presented above and describe how WorldWatcher was designed to support these strategies.

Motivate: Create Demand. The overall structure of the Create-A-World Activity is designed to create a demand for knowledge. To successfully design their fictitious worlds, students must develop a functional understanding of the relationships between geography and climate. WorldWatcher supports the establishment of this demand through its interface for creating data. The ability to input data by hand is not a feature of the scientific visualization environments that WorldWatcher is modeled on, but was added as a bridge that would help bring learners into the more scientific practices of visualization [Edelson & Gordin 1998]. WorldWatcher uses familiar paint program metaphors for data creation. Learners use the colorscheme displayed on the window as a color palette and “draw” on visualizations using the conventional paintbrush and paintcan tools found in graphics programs.

Motivate: Elicit Curiosity. The introductory drawing activity is designed to elicit curiosity about variations in temperature. This activity is an example of an exercise in articulating prior conceptions. The articulation of prior conceptions has been described as a valuable technique for identifying potential misconceptions and for activating existing knowledge structures to which new knowledge can be connected [Hunt & Minstrell 1994]. The articulation of prior conceptions can also create curiosity by exposing gaps and limits in current knowledge, as in the temperature drawing activity. WorldWatcher support this activity through its data creation tools, as well. The ability to “draw” visualizations provides a mechanism for learners to express their initial beliefs about temperature. In the trials, learners reported that the drawing activity did, in fact, make them interested in looking at actual July temperatures.

Acquire: Discover. The Create-A-World Activity provides learners with the opportunity to discover scientific principles through their investigation of the earth’s climate. WorldWatcher has many tools designed to enable learners to identify relationships among variables. For example, the ability to change the spatial resolution of data enables learners to look for latitudinal and longitudinal trends [Fig. 5]. Similarly, the ability to magnify specific portions of visualizations and select areas with specific values enables learners to focus on areas of interest and to look for correlations among variables [Fig. 6]. Students in both pilots identified relationships between temperature and latitude, elevation, deserts, ice, and large bodies of water through examination of temperature, ground cover, and elevation data sets.

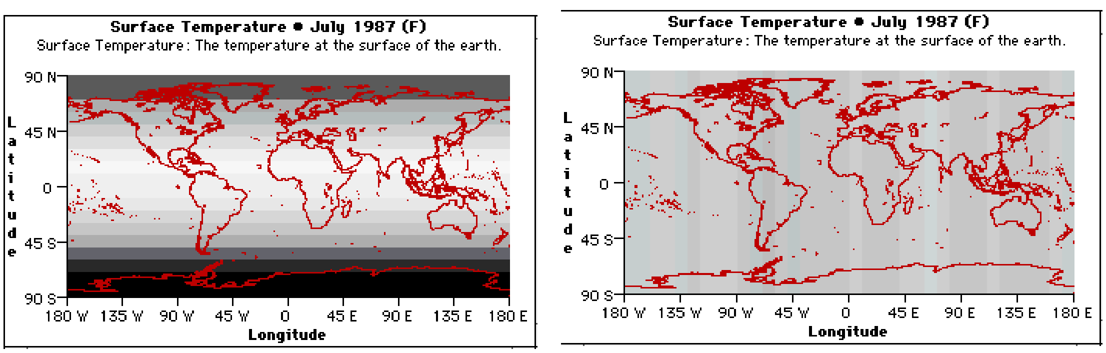

Figure 5: Visualizations with the spatial resolution adjusted to show the existence of a consistent latitudinal trend in surface temperature (left) and the absence of a longitudinal one (right).

Acquire: Receive. The discussion that follows the students’ investigations of Earth provides an important opportunity for the instructor to provide the learners with additional information to support their discoveries. (It also provides an opportunity for reflection described below). The sequencing of this communication in the overall activity is a critical element of the design. It takes place once the motivation has been established and immediately follows an activity designed to facilitate discovery. The information conveyed by the instructor in this discussion is intended to fill the gaps and create connections in the knowledge constructed through discovery through direct communication. For example, learners in both pilot tests observed that the temperature over large bodies of water is cooler than land during the summer, but the data do not provide them with any way to develop a causal understanding of this observation. In the course of the discussion, the instructor explained the influence of specific heat and circulation on the temperatures of these bodies of water. In other designs, this information could have been conveyed through reading and library research activities.

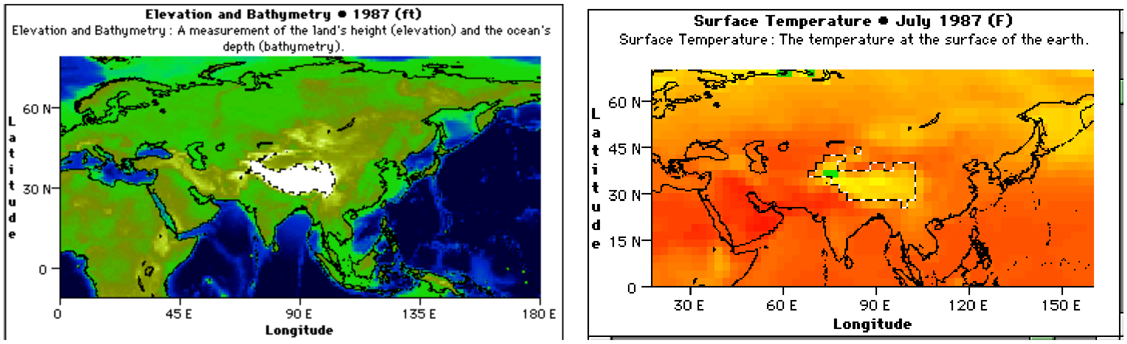

Figure 6: Magnified images showing the area above 10,000 feet selected on elevation (left) and temperature (right) visualizations.

Refine: Explore. In exploration, learners investigate the implications of their knowledge. This can lead to the refinement of knowledge through the identification of its limits and exceptions, and to the elaboration of knowledge through either specification or generalization. In inquiry, learners explore the implications of their knowledge by looking for evidence that supports or contradicts it. This requires that they formulate and evaluate predictions based on their current knowledge. In the Create-A-World Activity, exploration of knowledge takes place during the investigation of earth and the creation of a temperature map for the new world. WorldWatcher supports exploration through a number of visualization and analysis operations. The selection feature illustrated in [Fig. 6] is one of the operations that support the verification of knowledge. WorldWatcher enables the user to select all of the areas in a visualization that have a certain range of values, such as all the deserts in a ground cover data set. So, for example, if the learner has a prediction that all deserts are warmer than their surrounding areas, he or she can verify this prediction by selecting all desert areas and then inspecting their temperature data to see if the correlation holds. Other features in WorldWatcher support the specification and elaboration of knowledge by allowing learners to identify quantitative values for qualitative relationships. For example, in both trials, learners identified an inverse relationship between elevation and temperature. Some of them used the analysis tools in WorldWatcher to sample the average temperature at several ranges of elevation and compute the value that scientists call lapse rate.

Refine: Apply. The application of knowledge is a critical stage in the refinement of understanding because it forces a learner to organize his or her knowledge in a way that will support its use. The Create-A-World Activity provides learners with the opportunity to apply their knowledge in the creation of their fictitious world. In order to create a temperature profile for their new worlds, the learners must apply the principles that they learned through the investigation of earth and ensuing discussion. This application task requires that learners be able to operationalize their understanding of climate, because they must be able to generate specific temperature values. The task challenges them to refine their understanding because it requires them to apply several principles at once. For example, selecting a temperature value for a coastal desert may require a learner to take into account its latitude, its proximity to the ocean, its high surface reflectivity, high specific heat, and low elevation. Once again, the data creation capabilities of WorldWatcher provide the mechanism that makes this knowledge application task possible.

Refine: Reflect. The Create-A-World activity design includes three discussions that provide learners with the opportunity to refine their understanding through reflection. They each follow knowledge articulation, discovery, and application tasks. The first is the discussion that follows the introductory temperature drawing activity, in which learners reflect on the strategies they used in constructing their temperature maps, the knowledge that they drew on, and the questions that the activity raised. The second is the discussion following the investigation of earth temperature, in which the learners review their observations, defend them with data, and speculate on their causes. The third is the final discussion, in which they present the worlds that they have created and explain how they determined the temperatures for them. In each case, the discussion contributes to knowledge refinement by asking learners to examine their actions and their observations in order to explain and justify them to others.

5. Open Issues

Any design for a set of learning activities can be viewed as the expression of a theory of learning. The design of the software and activities described here embody a theory of technology-supported inquiry learning. To the extent that this design has been implemented successfully in a workshop setting, there is evidence to support the theory. These early experiences indicate that the overall structure of the Create-A-World activity motivates inquiry, that WorldWatcher supports the investigation and creation of data that the activity requires, and that the individual activities in the sequence provide opportunities for learners to acquire and refine knowledge. Exploring the theory more carefully calls for a great deal more experience in implementing and evaluating the design. The issues that still remain to be addressed include: the conditions that are necessary for the successful implementation of the design; the nature of individual differences in motivation and approaches to the activities, and their impacts on learning; and the lasting impact of the activities on learners' beliefs, attitudes, and understandings of science content and science practice. These issues can only be addressed through implementation on a larger scale in[redacted]cational settings.

References

[Berlyne 1966] Berlyne, D. E. (1966). Curiosity and exploration. Sci[redacted]

[Edelson & Gordin 1998] Edelson, D. C., & Gordin, D. (1998). Visu[redacted] framework for adapting scientists' tools. Computers and Geosciences, 24(7), [redacted]

[Gordin & Pea 1995] Gordin, D. N., & Pea, R. D. (1995). Prospects for Scientific Visualization as an Educational Technology. Journal of the Learning Sciences, 4(3), 249-279.

[Greeno, Collins, & Resnick 1997] Greeno, J. G., Collins, A., & Resnick, L. B. (1997). Cognition and Learning. In D. Berliner & R. Calfee (Eds.), Handbook of Educational Psychology, .

[Hiebert, et al. 1996] Hiebert, J., Carpenter, T. P., Fennema, E., Fuson, K., Human, P., Murray, H., Olivier, A., & Wearne, D. (1996). Problem Solving as a Basis for Reform in Curriculum and Instruction: The Case of Mathematics. Educational Researcher, 25(4), 12-21.

[Hunt & Minstrell 1994] Hunt, E., & Minstrell, J. (1994). A cognitive approach to the teaching of physics. In K. McGilly (Ed.), Classroom Lessons: Integrating Cognitive Theory and Classroom Practice, (pp. 51-74). Cambridge, MA: MIT Press.

[Kolodner 1993] Kolodner, J. L. (1993). Case-based reasoning. San Mateo, CA: Morgan Kaufmann.

[Schank 1982] Schank, R. C. (1982). Dynamic Memory. Cambridge: Cambridge University Press.

[Soloway, Guzdial & Hay 1994] Soloway, E., Guzdial, M., & Hay, K. E. (1994). Learner-centered design: The challenge for HCI in the 21st century. Interactions, 1(2), 36-47.

Acknowledgments

This research was supported by the National Science Foundation program in Advanced Applications of Technology under grant number RED-9453715. The WorldWatcher design team includes Douglas Gordin, Brian Clark, Matthew Brown, and Duane Griffin. WorldWatcher was implemented by Brian Clark. Ben Loh, Ryan Kowalczyk, and Maya Wallace assisted with the Create-A-World workshops and their analysis. WorldWatcher is available at http://www.worldwatcher.nwu.edu/.