Learning-for-Use in Earth Science

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Abstract

The Learning-for-Use design framework provides guidance for curriculum designers based on principles from cognitive science research. The design framework offers design strategies for the three stages of learning that are necessary to acquire knowledge that will be accessible and usable in situation where it is useful. I briefly describe the Learning-for-Use design framework and Planetary Forecaster, a middle school Earth systems science unit that was developed based on the framework.

1. Learning for Use

In this paper, we are concerned with the design of learning activities that develop what we call *useful knowledge* Our primary motive is that address two significant challenges to teaching that are often overlooked in the design of learning activities: fostering engagement and ensuring that learners develop knowledge that they can access and apply when it is relevant. Regardless of the nature of the learning activities that students participate in, if they are not sufficiently and appropriately engaged, they will not attend to those activities in ways that will foster learning. Likewise, if students do not construct knowledge in a manner that supports subsequent re-use of that knowledge, it remains inert (Whitehead, 1929). To address these problems, we have developed the Learning-for-Use model and design framework based on contemporary research in cognitive science (Edelson, 2001). The Learning-for-Use model is a model of the learning process that describes how learners can develop useful knowledge. The Learning-for-Use design framework provides guidance to instructors and curriculum developers on how to design learning activities that foster engagement and useful understanding.

The Learning-for-Use model describes the learning process that results in useful knowledge. It builds on fundamental theories of learning with the express aim of supporting designers in the development of learning activities. The model is based on four principles that are shared by many contemporary theories of learning. The four principles are[1]:

1. Learning takes place through the construction and modification of knowledge structures.
2. Knowledge construction is a goal-directed process that is guided by a combination of conscious and unconscious understanding goals.
3. The circumstances in which knowledge is constructed and subsequently used determine its accessibility for future use.
4. Knowledge must be constructed in a form that supports use before it can be applied.

The Learning-for-Use model incorporates these four principles and their implications into a description of learning. The Learning-for-Use model characterizes the development of useful understanding as a three-step process consisting of (1) motivation, (2) knowledge construction, and (3) knowledge refinement.

Motivate: Experiencing the need for new knowledge[2]. The first step in learning for use is recognizing the need for new knowledge. The *motivate* step in the learning-for-use model creates a need for specific content understanding. In this context, *motivate* is being used in a very specific sense. It describes the motive to learn specific content or skills, not a general attitude or disposition to learn in the particular context. Understanding the usefulness of what they are learning for tasks that are meaningful to learners, provides a motivation for students to engage in learning activities and to construct understanding in a useful form.

Knowledge Construction: Building new knowledge structures. The second step in learning for use is the development of new understanding. This step results in the construction of new knowledge structures in memory that can be linked to existing knowledge. An individual constructs new knowledge as the result of experiences that enable him or her to add new concepts to memory, subdivide existing concepts, or make new connections between concepts. The "raw material" from which a learner constructs new knowledge can be firsthand experience, communication from others, or a combination of the two. This step in the Learning-for-Use model recognizes incremental knowledge construction as the fundamental process of learning.

Knowledge Refinement: Organizing and connecting knowledge structures. The third step in learning-for-use is refinement, which responds to the need for accessibility and applicability of knowledge. In the refinement step, knowledge is re-organized, connected to other knowledge, and reinforced in order to support its future retrieval and use. To be useful, declarative knowledge must be reorganized into a procedural form that

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[1] From (Edelson, 2001)

2 While the first step in the Learning-for-Use model is called *motivate*, this phase is only concerned with a small portion of what is normally thought of as *motivation* in education. In this context, I am using *motivate* to refer to a specific type of motivation—the motivation to acquire specific skills or knowledge within a setting in which the student is already reasonably engaged. Addressing the broader motivational challenges of engaging students in schooling are critical to, but beyond the scope of, the Learning-for-Use model.

supports the application of that knowledge (Anderson, 1983). Useful knowledge must also have connections to other knowledge structures that describe situations in which that knowledge applies (Chi, Peltovich, & Glaser, 1981; Glaser, 1992; Kolodner, 1993; Schank, 1982; Simon, 1980). Refinement of knowledge can also take the form of reinforcement, which increases the strength of connections to other knowledge structures through the traversal of those structures and increases the likelihood that those connections between knowledge structures will be found in the future.

While there is an inherent ordering among these three steps, the ordering does not preclude overlaps or cycles. For example, knowledge construction and revision may be interleaved, and knowledge construction or revision can create new motivation. Because of the incremental nature of knowledge construction, it can require several cycles through various combinations of the steps to develop an understanding of complex content. Even with this cyclical nature, the order of steps is important. To create the appropriate context for learning, motivation must precede construction, and to insure accessibility and applicability, refinement must follow construction.

2. The Learning-for-Use Design Framework

Based on this model of learning for use, we have developed the *Learning-for-Use Design Framework*. This framework provides guidelines for the design of activities that will contribute to the development of robust, useful understanding. The design framework articulates the requirements that a set of learning activities must meet to achieve particular learning objectives. The Learning-for-Use model poses the hypothesis that for each learning objective a designer must create activities that effectively achieve all three steps in the learning for use model.

The Learning-for-Use design framework describes different design strategies that meet the requirements of each step (Table 1). The different design strategies for each step can be treated as alternative or complementary ways to complete the steps. In the case of rich content, however, several learning activities at each step involving both of the processes for that step may be necessary.

Table 1: Overview of the Learning-for-Use Design Framework.

Step	Design Strategy	Student Experience
Motivate	Activities *create a demand* for knowledge when they require that learners apply that knowledge to complete them successfully.	Perceive need for understanding
	Activities can *elicit curiosity* by revealing a problematic gap or limitation in a learner's understanding.	Experience curiosity
Construct	Activities that provide learners with *direct experience* of novel phenomena can enable them to *observe* relationships that they encode in new knowledge structures.	Experience or observe phenomena
	Activities in which learners receive direct or indirect *communication* from others allow them to build new knowledge structures based on that communication.	Hear, view, or read about phenomena
Refine	Activities that enable learners to *apply* their knowledge in meaningful ways help to reinforce and reorganize understanding so that it is useful.	Apply understanding
	Activities that provide opportunities for learners to retrospectively *reflect* upon their knowledge and experiences retrospectively, provide the opportunity to reorganize and reindex their knowledge.	Reflect upon experiences or understanding

Although it was designed to describe learning in general, when applied to inquiry-based science learning, the Learning-for-Use design framework represents a variant of the Learning Cycle (Abraham, 1998; Karplus & Thier, 1967; Lawson, 1995; Renner & Stafford, 1972). While they are similar in many ways, the two frameworks were developed with different goals. The Learning Cycle was developed as way to bring the process of learning from inquiry that scientists engage in to students. The Learning-for-Use design framework has been developed to highlight the need for motivation based on usefulness and the need to develop knowledge that is organized to support access and application (the *motivate* and *refine* phases in the framework), because they are too often overlooked.

3. Planetary Forecaster[3]

Planetary Forecaster is a middle school curriculum unit for Earth systems science that we have developed using the Learning-for-Use design framework. It combines computer-supported investigations of geospatial data with hands-on laboratory activities in which students observe and measure the phenomena under study. The Planetary

[3] Planetary Forecaster is a revised version of the Create-A-World activity, which is described in greater detail in Edelson (2001)

Forecaster curriculum unit is the product of an ongoing iterative development effort that involves teachers both directly as members of design teams and indirectly as implementers who are observed or provide feedback. The curriculum has been through three revision cycles based on three cycles of classroom implementation.

3.1 Unit Scope and Sequence

The content goal for the unit is for students to understand how physical geography influences temperature at a climatic timescale. The premise of the curriculum unit is that students have been asked by a fictional space agency to identify the portions of a newly discovered planet that are habitable given information about the planet's topography, water cover, and the tilt of its axis. For simplicity, the planet has the same atmospheric make-up as Earth, is orbiting around a star with the same intensity as the sun, and has an orbit with the same radius as Earth's. This mission is designed to create a demand for understanding of the curriculum's target content.

There are four major relationships that students must understand to complete the task. They are:

Curvature—The effect of a planet's curved surface on the intensity of the solar radiation received at each point. Temperatures decreases toward the poles because of the planet's curvature. Where the plane of the ecliptic cuts through Earth, sunlight hits the surface at a ninety-degree angle; as you move toward the poles, the angle at which sunlight hits the Earth decreases, which in turn increases the amount of surface area covered by the same quantity of light and decreases the intensity of the light in any unit area. This decreased intensity has a smaller heating effect.

Tilt—The effect of the tilt of a planet's axis of rotation on temperatures at different times of year. Because the Earth is tilted on an axis, the angle at which the sunlight hits the Earth's surface at each latitude changes on a seasonal cycle. Between the March and September equinoxes, the location of the most direct sunlight is north of the equator (northern hemisphere spring and summer), and between September and March, the location of the most direct sunlight is south of the equator (southern hemisphere spring and summer).

Land/Water heat capacity—The effect of surface cover (land vs. water) on the temperatures at different locations. Water takes longer than land to heat/release heat. This causes temperature differences between water and land depending on the time of year. Generally, air over water is cooler than over land in summer and warmer in winter.

Topography—The effect of surface elevation on the temperatures at different locations. Temperatures decrease as elevation increases. This results from air pressure decreasing as elevation increases.

Understanding these relationships requires an understanding of fundamental scientific concepts that are commonly found in national, state, and local standards documents, such as the Earth-sun relationship, radiative energy transfer, conservation of energy, heat and temperature, specific heat, and the ideal gas law.

The curriculum is divided into seven sections that take from 1-5 class periods each:

1. Setting the stage. In this section, students conduct an exercise in articulating prior conceptions in which they draw color maps showing their current conceptions of

global temperatures. They then compare their maps with actual data from Earth and formulate initial hypotheses about the factors that influence temperature.

2. Getting the task. Students learn about their mission of identifying habitable regions on a newly discovered planet, *Planet X*. They do an exploration of habitable regions on Earth. (For the purposes of this unit, habitable is defined as having minimum temperatures above 25F and maximum temperatures below 80F.) Students are assigned to investigate the four factors listed above (shape, tilt, surface cover, and elevation), to investigate for their influence on temperature. They are told that they will receive data about the shape, tilt, surface cover, and topography of Planet X that will help them to develop a map predicting the distribution of temperature on Planet X.
3. Investigating shape. Students investigate the effect of angle of incidence of solar energy on surface temperature through hands-on labs and explorations of global incoming solar energy data for Earth. They create an initial temperature map for Planet X that shows variation of temperature with latitude.
4. Investigating tilt. Students investigate the effect of a tilted axis of rotation on temperature at different times of year, through explorations of incoming solar energy data for Earth. They observe how the bands of incoming solar energy shift with seasons. They modify their temperature map for Planet X to account for seasonal differences.
5. Investigating surface cover. Students investigate the effect of land versus water on temperatures through hands-on labs looking at specific heat of water and soil and explorations of global surface temperature data for Earth. They modify their temperature map for Planet X to account for differences in temperature over land and water.
6. Investigating elevation. Students investigate the effect of elevation on temperature through explorations of global surface temperature data for Earth. They modify their temperature map for Planet X to account for differences in temperature at different elevations.
7. Final Recommendations. Students identify habitable areas by looking at maximum and minimum temperature values in their temperature maps for Planet X. They present their findings and their recommendations for colonization.

The curriculum materials place a special emphasis on forming and revising hypotheses and includes journaling activities that ask students to record their hypotheses together with evidence and rationales. Teachers have the option of using a computer-based inquiry-support tool called the Progress Portfolio (Loh et al., 2001), which gives students a place to store visual records of their work and provides prompts students to structure students' journaling. At each stage of the curriculum, students are asked to describe the factors that they believe affect temperature, how they affect temperature (i.e., the direction of the effect), and why (i.e, the underlying causes). They are also asked to provide any evidence they might have for these hypotheses and any open questions. They first record their hypotheses about the factors that affect temperature during the initial "setting the stage activity". During the portions of the unit where they investigate individual factors, they record their initial hypothesis about how each factor affects temperature before they do their investigations, and then they record their revised understanding following the investigation. It is this revised description of the relationship between a particular factor and temperature that they use when they construct their temperature maps for Planet X.

3.2 Planetary Forecaster as an Example of Learning-for-Use

Planetary Forecaster incorporates all six design strategies in the Learning-for-Use design framework to achieve all three steps of learning.

Motivate. The curriculum *creates a demand for understanding* through the mission of determining habitable areas on Planet X. This mission requires that they model temperatures for Planet X based on the provided data about the planet, which in turn demands that students understand the relationships between physical geography and temperature that comprise the content learning objectives for the unit. It also *elicits curiosity* through the stage-setting activities which ask students to articulate there prior conceptions and confront them with the limitations of their understanding. After trying to create temperature maps for Earth off the tops of their heads, students become curious about what the actual temperature patterns are and why they are that way.

Construct. Students learn about the relationships between physical geography and temperature through a combination of hands-on labs, computer-based investigations of Earth science data, readings, lectures, and discussions. The hands-on labs provide them with direct, concrete *experiences* with the phenomena and relationships they are learning about. The computer-based investigations provide them with *observations* of these same relationships at a scale that they cannot experience directly. The readings, lectures, and discussions help to *communicate* information about the phenomena and relationships from which they can construct understanding.

Refine. The process of constructing temperature maps for Planet X gives students the opportunity to *apply* their understanding of the relationships between physical geography and temperature as they are developing it. Classroom discussions and the journaling activities where students record their hypotheses encourage students to *reflect* upon their developing understanding.

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