Building Geoscience Vocabularies Using A Data Visualization Tool

(\textit{WorldWatcher})

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Abstract

Tools for visualizing data provide an opportunity for students to build useful understanding of geoscience vocabularies. Edelson’s (2001) Learning-for-Use framework serves an instructional model for designing an experience for students in which they can learn fundamental geoscience concepts. This paper presents results from an experiment on project-based learning with three cohorts (in subsequent semesters) of pre-service elementary teachers. The context for the experiment is a capstone science course for preservice elementary teachers. The project consists of six steps in which students must create a paleotemperature map of the Late Jurassic. Students make their decisions based on their constructed knowledge about factors that influence near-surface air temperature: latitude (axial tilt and curvature), topography and subsequent lapse rate, atmospheric effect, and surface cover (albedo). Analyses of reflection papers and classroom observations from each Step in the project indicate improvement in content knowledge for all cohorts. However, regarding the ability to perform complex analysis, which attributed to the expectations in Steps 5 and 6, only students in Cohort 3 performed better on predicting and defending their final temperature maps, which is attributed to their *useful* knowledge of geoscience vocabularies contained in the project.
Introduction

This paper provides insights into the use of WorldWatcher data visualization software to teach basic climate (temperature) concepts via an inquiry-based project. Pre-service elementary teachers were the subjects of an experiment in which two questions were addressed:

1. Can students understand the relationship(s) among two or more variables by analyzing data using WorldWatcher, a data visualization software?
2. Can students develop the capacity (i.e., useful vocabularies) to make predictions from the application of real data?

Pre-service elementary teachers enrolled in a capstone science course for Interdisciplinary Liberal Arts (IDLA) majors at the University of Northern Colorado (UNC) were the subjects in this experiment. This particular group of students was selected because of their significant deficiency in science education. When asked, nearly 80% of these students could not recall a moment in their k-12 education when science was “fun and exciting.” Approximately 95% of the students didn’t even recall doing science (beyond simple “phases of water”) in elementary. Essentially, we want these pre-service teachers to not only teach science in elementary, but to do so in a manner that persuades their students into pursuing science. A viscous cycle exists, where most elementary teachers are not only afraid to teach science, but have no general idea of what science is all about, and therefore, their students are discouraged with science.

This experiment attempted to gain insight into why pre-service elementary teachers were generally unable to “do science.” While students can easily define new geoscience vocabularies (regurgitated on weekly quizzes), they often struggle with using the new vocabularies in the context of “research” or “doing science.” Thus, if students are given the opportunity via an inquiry-based project, will they properly use their new vocabularies?
The context for the experiment is the course project, *Jurassic Jacuzzi*, where students use their knowledge about factors that effect temperature at the surface of the Earth to predict Earth’s surface temperature 150 million years ago.

Edelson (2001) provided a framework for the pedagogical design of inquiry-based, project activities used in the experiment. The *Learning-for-Use* (Lfu) framework consists of three components: motivate the learning objectives; build knowledge; and refine and apply the new knowledge. In contrast, the traditional model for undergraduate instruction is to spend most of the course on learning through lecture, with minimal motivation and almost no opportunities to apply the knowledge or build *useful* vocabularies. Unfortunately, the lecture method is comfortable for both the lecturer and the passive student. During lecture, the student faces no mental challenges and the instructor can simply convey information at her pre-determined pace. Even in most laboratory settings, the lab is contrived with known outcomes. Students know there is a “right answer” in lab and are merely trying to find the best method to replicate the answer. Thus, in both lecture and lab, the student does not have the opportunity to *use* their newly acquired vocabularies by applying them to new situations.

Data presentation and analysis software, such as *WorldWatcher*, provide an opportunity for students to use data in order to build geoscience vocabularies. If students are asked to make predictions, test their predictions, and refine their goals, then the students are presented with an opportunity to build their capacity for *useful vocabularies*.

**Design of the Experiment**

The IDLA major at UNC is required to take four science courses, three with laboratory components: Earth Science (lab), Physical Science (lab), and Biology (lab). The capstone course is a non-lab course titled, “Principles of Scientific Inquiry: Finding Order in Chaos” (SCI 465).
The course is designed to give students an experience with some of the major discoveries in the major disciplines. For instance, the Earth science focus is on plate tectonics and modeling of climate change.

The IDLA major must concentrate (18 semester credit hours) in one of nineteen disciplines. Majority of the IDLA majors in this experiment were concentrating in Speech Communications (Table 1). Of the ninety-seven students in this research, only 6% concentrate in science and 7% in math. All but seven students were female and five were sophomores, taking the course synchronously with at least one pre-requisite course.

The SCI 465 course at UNC utilizes Gregory Derry’s Book, *What Science Is and How it Works* (1999) as thematic framework for teaching about inquiry in the context of science. For example, in discussing Wegener’s idea of Continental Drift, Derry describes the inquiry process as rich in methodical observation. Derry’s presentation of *how science works* illustrates several characteristics of *doing* science, such as the identification of patterns as explanation for repeatable observations for the basis of prediction. In the course, students are asked to explore the electromagnetic spectrum, atomic theory, Mendeleyev Periodic Table, and evolution and ecology in such a manner that follows *What Science Is and How it Works*.

This experiment consisted of a three cohorts (in consecutive semesters) of students completing in an inquiry-based project based on plate tectonic and climate concepts. The project activities utilized the Lfu framework outlined by Edelson (2001). The third cohort of students completed the project, but an additional activity on collecting temperature data was added.
Nature of the Student Experience

Jurassic Jacuzzi Project Overview

The Jurassic Jacuzzi project is based on “Planetary Forecaster,” developed by Edelson et al. (see the paper by Edelson et. al. in this volume). Jurassic Jacuzzi focuses on determining the global mean temperature of Earth during the late Jurassic, 150 million years ago. Students, working in team of two or three, predict paleotemperatures via the use of conceptual, data-based modeling in WorldWatcher. During the project, the instructor does not lecture on any of the concepts. Rather, students explore factors that effect temperature via activities, which are conducted in class. The instructor does occasional conduct discussions in class, particularly when a group discovers something significant. There are six steps to Jurassic Jacuzzi project.

Step One: Thinking about Temperature

Students were first asked to create a mean temperature dataset for July using WorldWatcher and compare their dataset with actual mean July temperature. (Edelson, 2001 describes the Thinking About Temperature activity in more detail.) The goal of this activity is to expose the student’s prior knowledge and subsequent gaps in knowledge. Achieving this goal proves to be extremely motivating to the students. Many of the students remarked that their knowledge about the spatial distribution of temperature was severely lacking. None of the students could explain the spatial and temporal distribution of temperature beyond “seasons” or “temperature is generally colder in the mountains.” The main vocabularies stressed during this activity were Kelvin temperature, spatial, temporal, and mean.

Step Two: Constructing Knowledge about Spatial and Temporal Distribution of Temperature

Students began Step Two with the examination of temperature datasets in order to refine their knowledge about spatial temperature variation. Students used WorldWatcher to explore the
role of curvature and axial tilt (Figure 1) and greenhouse gases in the atmosphere. The objective of Step Two is for students to understand that there are multiple factors influencing temperature. However, students are asked to ponder which factor(s) are most influential. Aside from the “Sun,” students recognized the atmosphere plays a major role (when compared to temperature without an atmosphere), as well as topography, and major biomes (tropics, desert, etc…). In addition to the atmospheric effect, students completed Step Two with the motivation to examine the effects of elevation and surface cover.

In Step Two, students were again provided opportunities to build their knowledge about certain vocabularies: spatial, temporal, atmospheric effect, topography, and biomes.

*Step Three: Constructing Knowledge about Temperature vs. Elevation*

Cohort 3 students began Step Three with collecting temperature profiles using Vernier Probes and Palm 550 Handhelds over two different surfaces on campus (snow and open grass or sidewalk). The purpose of this activity was to 1) provide students with a sense of where temperature data comes from and 2) show students that temperature varies with height. The previous two cohorts did not have any idea of where temperature came from or even what temperature is. When asked to “sketch a picture of temperature,” nearly 98% of the students in cohorts 1 and 2 drew a picture of a thermometer.

All students used data in WorldWatcher (Figure 2) to estimate the moist adiabatic lapse rate (approximately 6.0 K km⁻¹). Students used the synchronized mouse and selection tools in WorldWatcher to graph changes temperature with changes in elevation at 33.5 N latitude in the Himalayas. Students were asked to “define” their observations. Most students suggested, “air temperature cools with height” as their definition. The concept of lapse rate was then introduced via discussion.
When students revisited their mean July temperature maps created in Step 1, approximately half of the students did use the words “lapse rate” to describe their failure to account for cooler temperatures at higher elevations. Step Three introduced “lapse rate” and “variation” as new vocabularies, and continued building the students understanding of “mean.”

*Step Four: Influence of Surface Cover on Temperature*

In Step Four, students again used *WorldWatcher* to identify patterns that described the relationship of surface cover and temperature. One objective of Step 4 was for students to learn about *data control*. In this case, students learned to control the factor of incoming solar radiation by looking for changes along constant latitude (to avoid temporal and spatial changes due to curvature, tilt, and day of year).

A second objective in Step Four was to provide experience in making predictions based on data. For some Biomes (tundra, for example), the relationship between temperature and the major surface cover was unclear and inconsistent spatially. For others (dry, warm desert and tropical humid, for example), the relationship was more clearly defined. Students had to judge the weight of influence each surface cover has on temperature. Students were asked to compare the annual mean temperature of the biome as compared to the global mean. For example, when selecting major northern deserts, the mean temperature for the selection is 293 K as compared to the global mean of 288 K. Students were asked to decide on the two most influential biomes. Most students chose dry, warm deserts and tropical humid biomes. “Data control,” “data-based predictions,” and “weighing factors” were new vocabularies in Step 4. By the end of Step 4, students had a firm understanding and use of the vocabulary word “mean.”
Step Five: Applying Large Scale Plate Tectonics to Create Topographic Map

Students were introduced to plate tectonics by first visualizing the distribution of earthquakes using the Discover Our Earth (http://atlas.geo.cornell.edu/education/) interactive data mapping software developed at Cornell University. The motivation was simple; “How long does it take before a global earthquake pattern emerges?” Students were amazed that in less than four months, most of the plate boundaries were mapped by earthquake activity.

Next, students mapped earthquakes, elevation and bathymetry datasets using WorldWatcher to describe patterns in topography (mountain ranges) and bathymetry (trenches) associated with earthquakes and volcanoes (Figures 3a and 3b).

Students then applied their knowledge about plate tectonics to determine the breakup of Pangaea and resulting topography. Students used visualizations from the PALEOMAP project and the Ocean Drilling Stratigraphic Network’s plate tectonic reconstruction model to estimate the location of continents and mountains on Earth 150 million years ago.

The actual elevations of late Jurassic mountains are unknown. Therefore, students estimated the mean mountain elevation as 3000m, using WorldWatcher as a model for exploring data about current mountain elevations. Young volcanoes due to late Jurassic divergence were not considered in determining topography. The remaining non-mountainous elevation was estimated as 500m, resulting in a topography dataset for the late Jurassic (Figure 4).

The expectation was students would have the skills to estimate values, based on mean values obtained from analysis of elevation and bathymetry. For example, students already could use the selection tool in WorldWatcher to determine the mean of a selected biome (from Step 4). When surveyed, students indicated that they did not know the direction of thinking to take in determining how high to map paleomountains. Some students simply mapped all mountains as
5000m (upper end of current mountain heights). Only 8% of the student actually determined how high to map paleomountains based on the mean value of current mountains.

Students could define the word “mean” as an average for numbers. Students also could use the selection tool in WorldWatcher without any problems. Students could even read the statistic, “mean,” from the WorldWatcher visualization window. However, very few students could use “mean” as a basis for predicting the heights of paleomountains.

**Step Six: Applying Knowledge about Temperature to Create Temperature Map**

The final phase of the project required students to combine their knowledge about temperature variation with latitude, elevation, atmospheric effect, and surface cover in order to estimate a mean global temperature for their 150 million year old Earth (Figure 5). The order in which they developed their final temperature map is described by

- First constructing a base temperature map by converting absorbed energy at the Earth’s surface. Students assumed no topography (land mass at uniform 1m) and no change in the solar constant in the past 150 million years;
- Second, constructing a temperature map with current atmospheric effect;
- Third, constructing a temperature map based on their elevation map (Figure 4) using knowledge about moist adiabatic lapse rate.

Next, students conducted a comparison of their estimated mean global temperature with 6 – 7 K temperature increase estimated by Royer *et. al.* (2001). Based on the comparison, students were asked to

- Conclude and their temperature maps were wrong and why, or
- Conclude Royer *et. al.* were wrong and why, or
• Make corrections to their temperature map and defend decisions by systematically adjusting elevation estimates and/or atmospheric effect (due to increased CO2 levels) in order to achieve a mean global temperature that is approximately 6K warmer than today.

A graduate student periodically conducted observations (Cohort 1 only), using a modified version of the Horizon Research Inc. Classroom Observation protocol, developed for the National Science Foundation's Local Systemic Change program. Students in all cohorts were also interviewed throughout the project and asked to write reflection essays in order to understand the type of decisions they were making. Data from post activity interviews and analysis of project summaries were also collected.

Discussion

Classroom Observations, Reflection Essays, and Interviews

Students in all cohorts were able to easily grasp knowledge about the mechanics of using WorldWatcher, such as zooming and selecting subsets of data. Students also were able to interpret graphical data. For example, in Figure 2 students wrote the line as “a straight line and therefore temperature gets colder as elevation gets higher.” However, despite the ability to “read the graph,” students in the post-test failed to recognize the line for what it represented: lapse rate. Student reflection essays offer some insight into the problem. Students could explain what the graph illustrates (straight line), but they could not defend why they were graphing the temperature with elevation data. Making connection between the mechanics of working with data and why was found to be a constant frustration for students.

The problem is a student’s lack of vocabulary related to the graphical display of data. As simple as it sounds, students in a pre-test prior to the project start did not use the words axis, linear, increase, and decrease when explaining graphical data. In addition, when looking at
temperature variation with latitude (an early exercise in Step 1), many students had difficulty in equating the negative numbers on the x-axis with south latitude (Figure 1).

By Step 5, however, many of the students were beginning to use vocabularies in analyzing datasets. For instance, students were comfortable with determining the mean temperature of a biome and articulating what the mean value represented, in the context of the minimum and maximum values. Interestingly, though, students in cohorts 1 and 2 were completely unable to explain why some of their temperature values were unrealistic (e.g., 80 K for Antarctica). In post project interviews, the students posed two interesting questions to the instructor: “What is Temperature?” and “What are Ridges?”

What is Temperature?

Despite a lengthy project on working with factors that influence temperature, students in Cohorts 1 and 2 did not know what temperature meant or even where temperature data originates. Some students thought the visualization of temperature data represented the tangible surface of the Earth, such as a hot parking lot or a cold snow surface. The students did not know that the temperature data was an estimate of the air temperature near the ground based on multiple sources (stations, buoys, satellites, etc…). Second, students did not know that annual global mean temperature meant the annual, day and night, average of all the grid cells in the dataset. Most instructors (including the lead author on this paper) would have simply never addressed this issue, as the assumption is made that students know the accurate definition of temperature. Yet, it is very clear that the students lack of understanding of temperature lead to their inability to conduct the necessary reasoning to make defendable temperature maps. As a result of this insight, a new activity on collecting near surface temperature was introduced in
Step 3 for Cohort 3. Students in Cohort 3 proceeded through the project the experience of collecting temperature data and knowing Earth is the source of the data.

What are Ridges?

When graphing the Mid-Atlantic Ridge (Figures 3a and 3b), most students were surprised to discover the ridge topography. On the pre-test activity, students explained that divergent boundaries created canyons. Interviews with students revealed the misconception as divergence leading to the separation of plates and subsequent void or “Grand Canyon.”

Due to the visual representation of student-selected data, however, the misconception about topography along plate boundaries is then graphically dismissed. This is evident when students are asked to speculate the topography on convergent boundaries (students then think about the mechanics of convergence) and confirm their speculation by using WorldWatcher to create a line graph of topography data across a convergence boundary.

Pushing Their Inquiry Skills: Decisions Regarding the Final Temperature Map

Determining a method for conducting an investigation to understand why the global mean temperature maps were ~6K less than Royer et. al. (2001) proved to be very difficult for students. The instructor provided no guidance on how to conduct the comparison or even how to interpret the results. Most students simply concluded that their global mean temperature is similar to today’s 286 K (Figure 5), but could not offer an explanation as to why the estimated mean temperature did not agree with Royer, et. al. (2001). Students previously examined the influence of greenhouse gases on temperature by comparing Earth’s temperature without an atmosphere to temperature with an atmosphere. Despite the conclusion from Royer et. al. (2001) that the late Jurassic had 3 to 5 times more CO₂, 80 % of the students in Cohort 1 (40% in Cohort 3, a major
improvement) failed to investigate the influence on temperature due to increased greenhouse gases (Figure 6). Why?

**Student Deficiencies**

Some students indicated that any errors in calculating temperatures must be in their choice of mathematical operator (i.e., add instead of subtract) in using a mathematical operation in *WorldWatcher* or that *WorldWatcher* had a programming error. The questions are: *why were the students wrong in this thinking? Why were they unable to determine the cause of their error?*

Further evaluation of student responses in interviews and analysis of student project summaries lead to the discovery of three major deficiencies on the part of the students. First, students were uncertain about the *estimation of data*. Students failed to constitute the boundaries of what data was “real.” Students were unable to determine if their estimates of temperature were “correct.” Students continually sought reassurance from the instructor regarding their predicted temperatures.

The second deficiency is in *evaluating causality*. Indeed students did recognize changes in *value* of the numbers while conducting “trial and error” experimentation with data. However, students were generally unable to use content vocabularies to explain *why* changes occurred (i.e., the lapse rate problem). Students offered simple explanations, such as “I subtracted [this amount],” rather than “an increase in elevation is correlated with a decrease in temperature due to the lapse rate.”

A third deficiency is in *quantitative reasoning*. When interviewed, students indicated one reason they may not have calculated a percent increase in the atmospheric effect with their temperature data is that they did not understand the impact of a “3 percent increase” (Figure 6).
Again, students knew *mechanically* how to do the calculation in *WorldWatcher*, they just didn’t know *when to apply the skill*.

Each of these deficiencies presents a “teaching moment” for the instructor. The key is recognizing the need to build new vocabularies and provide students with the opportunity to apply the vocabularies. In the scope of this research project, only Cohort 3 benefited from teaching moments. As a result, students in Cohort 3 indicated in post-interviews that were more comfortable in the decisions made during Steps 5 and 6. Indeed, more students (60% vs. 20% for Cohorts 1 and 2) were successful in defending their decisions about why the global mean temperature was 6K warmer during the Late Jurassic. Inadvertently, some students (5%) in Cohort 3 actually *doubled* temperatures due to the *doubling* of CO₂. Analysis of reflection essays was inconclusive as to why students did not recognize this error.

**Summary**

Classroom observations, analysis of student reflection papers, and analysis of student project summaries revealed that the occurrence (in writing) of both content and science process vocabularies increased as the course project progressed. However, students struggled with the understanding of the vocabularies, often resulting in their non- or mis-*use*. Intervention of an activity where students collected near surface temperature data, focused on the meaning of *temperature* and improved the students understanding of *temperature* for completing their final temperature map. Continued pedagogical intervention on additional content and science process vocabularies is necessary, albeit time consuming.

Analyses of reflection papers from each Step in the project indicate improvement in content knowledge for all cohorts. However, regarding the ability to perform complex analysis, which attributed to the expectations in Steps 5 and 6, students in Cohort 3 performed better on
predicting and defending their final temperature maps. Exact reasons for this are speculative.

The temperature data collection activity introduced in Cohort 3 certainly could have helped, but further research is needed to identify key interventions during class by the instructor, which collectively may have a greater impact on student success of using geoscience vocabularies. In addition, further research is needed to determine the longitudinal impact of the course project on the students’ ability to use geoscience vocabularies in the proper context.

Acknowledgment

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References


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The Ocean Drilling Stratigraphic Network [http://www.odsn.de/odsn/](http://www.odsn.de/odsn/)


WorldWatcher Software. [http://www.worldwatcher.org](http://www.worldwatcher.org)
### Tables and Figures

<table>
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<tr>
<th>IDLA Concentration</th>
<th>Percentage (n=97)</th>
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**Table 1.** Distribution of IDLA concentrations for students in all Cohorts.
Figure 1. Temperature versus latitude for January 1982 created using *WorldWatcher’s* line plot tool.
Figure 2. Temperature change with elevation based on synchronized selection of elevation data (Figure 1) and average climatic temperature data. This graph was used to estimate the moist adiabatic lapse rate (~6 K km\(^{-1}\)).
**Figures 3a.** Selection of data along the Mid-Atlantic Ridge used in generating a topographic profile (Figure 3b).
Figure 3b. Topographic profile across the Mid-Atlantic Ridge created using WorldWatcher’s Line Plot tool.
Figure 4. Estimated continent and mountain locations derived from the PALEOMAP project (http://www.scotese.com/) and the Ocean Drilling Stratigraphic Network (http://www.odsn.de/odsn/). White regions represent the approximate locations of mountains.
Figure 5. Annual mean temperature of the late Jurassic as determined from variation in latitude, moist adiabatic lapse rate, and location of deserts. The mean temperature of the dataset is 285K, compared to 286K today.
Figure 6. The resulting temperature dataset estimated by a 3% atmospheric effect and subsequent increase in global mean temperature due to a doubling of CO$_2$, based on paleo-CO$_2$ estimates (Royer, et. al, 2001).