

# A Visuo-spatial Learning Ecosystem Enhances Adaptive Expertise with Preparation for Future Learning

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The progress of groups of minds in interaction with each other, or the properties of the interaction between individual minds and artifacts in the world, are frequently at the heart of intelligent human performance. (Hutchins, 1993)

## Abstract<sup>1</sup>

Education processes in our classrooms too often fail to engage children's interests, and instead come across as boring or irrelevant. Both of these challenges are harvested in an educational experiment that involves the largest dam removal project in US history. The driving question revolves around a shaping of learning experiences for children with the aid of an advanced graphing calculator in an informal environment. This study investigates how learning is triggered by an event that deeply engages learners, offering affordances that are typically missing from inert sequences of learning in everyday classrooms. We studied sixteen teenagers who undertook scientific investigations in STEM-related comprehension, in the watershed and drainage basin of the Elwha River System. This research project establishes a baseline that foreshadows a longitudinal study addressing the learning outcomes that occur (i) before, (ii) during, and (iii) after the dams come down. A mixed methods approach was used. Empirical data was collected in pre- and post-tests, that involved student exercises in STEM and social studies. Qualitative data were established in thick descriptive ethnographical record derived from extensive field notes and teacher and student documentation, and a network of educator roles as participant observers. Findings highlight three important considerations: (i) all participants showed a positive gain in knowledge, both in procedural and, more importantly, in conceptually connected knowledge; (ii) participants who had access to graphing calculators learned with understanding and appeared to be better able to draw inferences that connected inert knowledge with observed and grounded phenomena; and, (iii) low-achieving participants who had access to graphing calculators seemed to show the highest gains. Directions are proposed for future research that outlines how teachers, might effectively conceptualize, frame and develop learning environments around the advanced graphing calculator family of tools that foster collaboration and cultivate a preparation for future learning.

**Keywords:** learning sciences, informal learning, advanced graphical calculator, adaptive expertise, preparation for future learning, metacognition

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## Introduction

Research in the learning sciences has increasingly reframed learning not merely as cognitive, but also and importantly as social and participatory (LIFE, 2008; O'Mahony et al., 2007; Sawyer, 2006). Participation deeply links to engagement and motivation through the notion of belonging (Lave & Wenger, 1991)—students want to learn in order to belong, not only in order to know. As well as other components of a healthy learning ecology such as trust and safety, when students have a sense of belonging, they learn more, (Bransford, 2007; Lee, Smith, Perry, & Smylie, 1999). Participatory activities link the opportunity of belonging to a classroom activity with the opportunity to learn. In addition, and probably just as important, is the opportunity for students to become familiar with how they learn, to begin to know what processes and methods, what modalities and lenses assist them as they establish metacognitive skills and gain confidence in knowing how they know (Gawel & O'Mahony, 2008).

Furthermore, as the chasm between the disciplines of neuroscience and the science of learning is tentatively bridged, developmental molecular biologists and cognitive neuroscientists theorize that learning which includes deep understanding and transfer is connected to human species' primal needs for survival, procreation and protection (Medina, 2008; Varma, McCandliss, & Schwartz, 2008). According to Medina (2008) our brains were 'designed to solve problems related to surviving in an unstable outdoor setting and that we do so while we are in near-constant motion. In the area of mathematics and memorization, neuroscientists (Delazer et al., 2005) have used fmri to associate mental process and learning context, (something that learning scientists have long understood) and have established that indeed learning context is intricately

interwoven with learning outcomes. Cognitive neuroscientists (Cabeza & Nyberg, 2000) have identified the connection between the medial temporal lobe regions (which are typically activated in episodic memory retrieval with a left-sided dominance for verbal material and a right-sided dominance for visuo-spatial information) and further mapped the connection to mathematics learning that appears to employ the visuo-spatial components (inferior precuneus and anterior cingulate cortex) of the brain. They point out that brain activations found in mathematical studies suggest the use of spatial working-memory structures that store intermediate results during execution of algorithms in learning new arithmetic operations (Varma, McCandliss, & Schwartz, 2008). This is an important consideration since students in this study are introduced to graphing calculator devices that deliver multiple representations of algebraic and formulaic data with an immediacy and visibility that appears to engage the right-side dominance as mentioned.

In this study, several elements of the theoretical frameworks above are synthesized to design a learning environment that utilizes some of the best practices of each. In the first place, the study takes place in the outdoors, in a landscape of critical historical and geographical importance to the students and their families. Secondly, the students are dealing with real-time data collection in a real life situation, a derivative of meaningful local issues. The design included an investigation of how collaborative interactions around advanced graphing calculator equipment influenced STEM learning outcomes. Differences in pre- and post-tests for 16, sixteen-year-old, math and science students were analyzed utilizing quantitative and qualitative methods. Subjects were randomly assigned to groups in which field-investigative activities were undertaken in the outdoors over a two-day period with either traditional pen and pencil methods or (in

the case of the treatment group) with the use of graphing calculators. Activities were spread over two days of investigative data collection in the Elwha drainage basin that stretched from the upper lake to the coastal strip (see: Fig. 1 Map of Elwha River System) in which students explored various attributes of the natural environment in relation to rivers and oceans. The field activities consisted of students, in groups of four or five, collaborating in a beach exercise in which data was collected on a coastal transect in order to define a beach profile, (either constructive or destructive), analyzed to understand the resultant topography and, in particular, the artifacts that contributed to the evolutionary processes.

## **Background**

The hinterland of the Elwha River in Washington State is currently being transformed, directly impacting the geographical, ecological and cultural environments of thousands of families, including schoolchildren, who live in the area. The great majority of the Elwha watershed lies within Olympic National Park and has undergone very little alteration since white settlers arrived over one hundred years ago. According to some environmental scientists (Allaway, 2004; Freilich, 2008), this pristine environment is an ideal prospect for a large ecological experiment, where the only significant disturbance for most of a natural watershed has been the absence of anadromous fish, up to now and it will be post-dam when the fish can return.<sup>2</sup> There is much to be gained from understanding ecosystem processes by tracking the ecosystem responses to this renewal.

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<sup>2</sup> Olympic Peninsula waters have historically supported abundant and diverse fish populations, notably salmon and other anadromous fish such as steelhead. All five species of Pacific salmon (chinook, coho, sockeye, pink, and chum) have been widespread. Resident freshwater fish include cutthroat, rainbow, and introduced Eastern brook trout, as well as other species.

Environmental and specialty marine and forest scientist are excited about the prospect of finding answers to many big questions, such as the role of marine-derived nutrients in salmon ecosystems, feeding and nutrition (trophic) web responses, processes of succession, and the influences of sediment and woody debris regimes on floodplain geomorphology (Allaway, 2004). Further, the information gained on important management issues such as modes of salmon and habitat restoration and the effects of dam removal will be immensely valuable and widely applicable to ecologists and environmental scientists as well as to teachers and students.

This study, the *Elwha Dam Removal Learning Sciences Study*, takes advantage of an unparalleled opportunity presented by the impending removal of two dams that have had major impact for many decades on the people and terrain of the local environment within the river hinterland. The two Elwha dams have, for over 90 years, blocked anadromous fish from all but the lower five miles of what was once a major producer of numerous stocks of Pacific salmon species. From a learning sciences perspective this study investigates an informal learning environment in the outdoors using technological tools i.e., advanced graphing calculators, innovative assessment techniques, and designed instructional methodologies. This study involves learners and teachers in the natural environment. It is part of a comprehensive long-term research program that is ongoing in the natural ecological systems of the Elwha River watershed. It is a study of the interactions of natural with human systems in the region, and is linked to an array of educational outcomes—not least of which is the importance of using advanced graphing calculator technologies in an outdoor educational arena.

At the start of the last century (circa 1911) white settlers made their way through the corridor of the Elwha drainage basin. They were immediately struck with the richness of the local environment, in particular the widespread abundance of old growth forest. Furthermore, they were not unaware of the profuse, untamed power of the river and remarked with pecuniary interest the natural canyons that offered easy opportunities for dams. Manifest destiny was intentional in their quest for progress and power. They installed, over the next decade, a pair of dams that became the chief source of power for operating sawmills in the newly-formed seaport town of Port Angeles (see: fig. 1 Map of Elwha River System). Since that time both the economic and ecological climate has shifted such that it now has become uneconomic to operate and maintain these dams. Consequently it has become *de facto* acceptable to remove both dams, and to hand the affected land back to people that were displaced since the early years of the last century—members of extant tribal communities—Elwha and Clallam nations.

A major learning outcome for the study derives from the topographical and geomorphological structure of the river basin: could learners make connections between their immediate observations in the landscape and the underlying causes and effects that stem from simple historical and contemporary episodes in earth science and climate? The following information is pertinent to understanding the historical backdrop.



Fig. 1 Map of Elwha River System

The Elwha River watershed is the largest drainage area on the Olympic Peninsula and because the Olympic Mountains are made up mostly of relatively soft sedimentary rock, they erode very easily—a fact that leads to extensive silting. The two dams blocked the free flow of the river. As a result, over the next hundred years more than eighteen-million cubic yards of sediment has built up in the reservoirs (Randle, Young, Melena, &

Ouellette, 1996). To understand the extent of this volume of sediment it helps to visualize a string of dump trucks, each filled compactly with Elwha River sediment, lined up bumper-to-bumper and stretching three times across the United States from New York to Seattle. This has very obvious implications for the near-coastal region adjoining the river estuary. A massive amount of sediment sits in the reservoirs that, if the dams were not in place, would have been transported (by the river) to the coast. Consequently, it is highly likely that the lack of this sediment-flow to the coast over the last one hundred years has resulted in erosion of beaches around and near the Elwha River mouth (Casey, 2006). This topographical condition has implications for the students who have the opportunity to make first-hand observations and deductions in the vicinity as a result of this learning intervention. We hypothesize that students at first will not “see” the massive sedimentary deposit at the head of the lake (where the river enters the lake), even when they are looking directly at it (and standing up to their ankles in it, and smelling and touching bits of it). The massive extent of this sediment is not where they expect it to be. There is evidence that supports the thesis that their preconceived ideas will be difficult to overcome (Vosniadou & Brewer, 1992), and that, like most people, they will assume that the sediment is deposited at the other end of the lake, right up against the wall of the dam.

In the next number of years both dams in this natural ecosystem are projected to be removed—an engineering feat of colossal magnitude. This event has numerous outstanding opportunities and implications for learners in STEM, social studies and engineering. The lakes will be drained and the emergent land will be restored to the local first nation peoples—the Clallam and Elwha—allowing the rivers to naturally restock with indigenous species of salmon, the forest to reestablish itself, and the natural habitat to be

restored. The entire project comprises the largest dam removal occasion in the history of the United States. The current research team's long-term plan for this event revolves around a longitudinal research strategy that includes both students and teachers, and First Nations people in an ongoing study that unfolds the landscape associated with the dam removal--'before, during, and after'.

## **Research Questions**

Several strategic driving questions revolve around ideas of teaching and learning from situations that emerge during the dam-removal project and the impact, if any, for the learners and teachers. As noted earlier there are ample opportunities to witness STEM subjects in the wild, during this project. Technology plays a large part in the outcome. Specifically, what effect will the introduction of advanced graphical calculators into the learning ecosystem have on students' abilities to comprehend and deeply understand advanced concepts in math and science associated with the removal of dams from their local community? Furthermore, what effect will a designed learning environment (in which the students are situated in real questions that have direct bearing on their personal and family way of life) have on their capacity to connect inert knowledge and make meaning that is deep and cohesive? Finally, does experiential investigative activities- that happen in the outdoors in which discovery learning is solidly rooted in real-world concepts and practices and mediated through formative assessment routines, advance the way students perceive their own learning?

The answer to these questions is the perfect invitation to invoke a process of documenting the dams removal and the effects of this on the people and the environment. Those participating in documenting the process would become better caretakers of their

local environment (and in doing so better understand the implications for the planet), for the schoolchildren would observe and participate in a meaningful way, documenting their experience in this feat of engineering and the social and environmental implementations that result and hold enormous weight, depth and gravity for the nation.

## **Conceptual Framework**

Preparing students for future learning is a critical and an enduring challenge in educational research for the twenty-first century (Bransford, 2007). Recent research from the learning sciences e.g. *How People Learn*, (NRC, 2000) *How Students Learn* (Bransford, Darling-Hammond, & LePage, 2005) and *Preparing Teachers for a Changing World* (Bransford, Darling-Hammond, & LePage, 2005) make visible many of the pertinent and overriding elements of learning that are associated with creating learning ecosystems that advance a pupil's preparation for future learning. In this vein, the Elwha dam removal learning sciences study team established and extended learning design procedures developed as a result of working with K-12 educators (Vye et al., 1999), the VaNTH Center for Bio-engineering Technologies (Harris, Bransford, & Brophy, 2002); community colleges (Center for Regional Economic Competitiveness, 2007) and other groups, (The Boeing Company, 2007).

Many students are able to solve problems by applying previously learned (e.g., schematized) skills and knowledge in new settings. This is largely true for most of us. If we encounter a problem that seems similar to previously solved problems, we are much more efficient at solving it (Anderson & Pearson, 1984; NRC, 2000). Yet since students must function in a rapidly changing world, they must learn to navigate every day in situations that reside at the edges of existing knowledge. They must have technical

knowledge in addition to an ability to think and reason and solve problems as they innovate and communicate. This kind of expertise is critical for survival in today's fast-paced, complex and technological world. Researchers have identified two kinds of experts: routine experts and adaptive experts (Hatano & Inagaki, 1986). Routine experts are efficient and technically proficient. Though this type of expertise is necessary for everyday survival (we are familiar with the competent driver who can change gears and talk at the same time), routine experts may fail to adapt when situations change or new types of problems present themselves (Hatano & Osuro, 2003). Adaptive experts are the kinds of learners fill the order for a fast-changing technologically complex world: - individuals who are prepared for future learning; are proficient at dealing with unexpected and novel situations as they arise; are willing to take risks and often find themselves outside of their comfort zones where they demonstrate a flexibility and eagerness to learn from new situations and all people (Bransford, Brown, & Cocking, 2000; Hatano & Greeno, 1999).

Technology has become more or less ubiquitous for the majority of students in the US today and many schools are beginning to integrate their learning and teaching models with technological tools that equal or rival those that the students are familiar with at home and at play. There is ample evidence in the literature concerning the effectiveness of technologically intentioned teaching and learning models and since many new technologies are interactive (Greenfield & Cocking, 1996), many educational researchers have shown that it is now possible to create environments in which students can learn by doing, receive feedback, and continually refine their understanding and build new knowledge (Scardamalia & Bereiter, 1993). Furthermore, assessment and learning can be

intimately linked in technology-rich learning environments. To take advantage of this richness we designed student assessment to be particularly formative so that it would facilitate nuances of a technological approach that presented the student with real-time, visuo-spatial feedback from multi-representational graphs and tables. In this vein, the Elwha dam removal learning study has, as a central aspect of the research, included an advanced graphing calculator that delivers these visuo-spatial representations of live data in real-time to the student participants. The question remains whether the students who make use of these devices are in a better position to draw inferences, stitch what educational psychologists refer to as inert and often disconnected scraps of knowledge together in a cohesive colloidal mass so that they make relevant meaning of the observations within the geomorphological framework (Bransford & Schwartz, 2008; Whitehead, 1929).

Feedback loops, and especially timely feedback loops, in themselves are vital to a healthy learning ecology (Bransford & Schwartz, 2008). There also is tractable evidence in the literature that teachers' questions used to deepen students' higher-order thinking, in addition to timely feedback loops, allow significant learning gains to occur (Dillon & Wittrock, 1984; Redfield & Rousseau, 1981; Samson, Strykowski, Weinstein, & Walberg, 1987). We hypothesize further, that visuo-spatial feedback delivered in real-time, and *in situ*, through the various screens of the advanced graphing calculator, will enable the student to grasp the meaning of difficult mathematical concepts, and connect the meaning to concrete phenomena in his/her immediate field of activity.

Finally, higher achievement levels are reported in classrooms where students are involved in checking their own understanding of concepts and assessment data are used

to inform and adjust instruction (Black & William, 1998; Fuchs & Fuchs, 1986). The technologically advanced calculator device when coupled with teachers' questions that are used to deepen the students' higher-order thinking will significantly improve understanding. We looked carefully at the implications of Roschelle's work with students' kinesthetic experience and learning. He and his colleagues did some exploratory work in controlled experiments (e.g., MathWorlds, SimCalc) in this field around mathematics understanding and transfer. They found that kinesthetic explorations directly involved bodily understanding and connected directly to familiar experiences (Roschelle & Kaput, 1996). Given that our participants were working in small collaborative groups, conducting controlled experiments in the outdoors, making calculations and inputting raw data via hand-held kinesthetic devices we were deeply interested in Roschelle's findings involving students' kinesthetic experience. His findings were in relation to learning about functions in a unit that emphasized (a) representing problems in multiple formats, (b) anchoring learning in a meaningful thematic context, and (c) problem-solving processes in cooperative groups. Results showed that treatment students were more successful in representing and solving a function word problem and were better at problem representation tasks such as translating word problems into tables and graphs than were comparison students. Similar results were found for students who spoke English as a second language (Brenner et al., 1997).

## **Subjects**

Having interviewed a number of likely candidates we eventually settled for a local high school that was nestled nicely in the lower valley adjacent to the shoreline and below both dams. Participants for this educational intervention consisted of a

math/science class of teenage students from Joyce High School, WA. (N=16). Joyce High is at the south end of the River Elwha drainage basin adjacent to the shoreline and below both dams.

The research team, in collaboration with the science and math teacher at Joyce High School and the teaching members from the Olympic Park Institute (OPI), decided upon a syllabus, which eventually became the basis for the educational intervention and research study. The project took place during a two-day field trip to the Elwha River valley in which students undertook first-hand experiential discovery learning along various portions of the channel.

A constituent of Yosemite National Institute, OPI is an outdoor experiential / residential and day center situated in the heart of the Olympic Peninsula, in Washington State. Ideally located in close proximity to the Elwha drainage system, we chose to capitalize on existing facilities and local knowledge in order to carry out this research project. Through an arrangement with OPI, we were able to gain access to math and science students from a local school, Joyce High School. These math and science students were the recipients of the instruction and intervention associated with the advanced graphing calculator software and hardware. The staff at OPI, being familiar with local topography and access issues helped identify and select suitable sections of the coast and river that we subsequently used in the research endeavor.

All participants and their parents were asked to sign consent forms in which they received detail knowledge of the proposed research activities. All parents and students signed and returned the consent forms. All participants took part in a pre-test activity in which an affective survey was used to capture relevant demographic information that

would help interpret some of the situated findings later on. A pre-test was also used to illuminate students' prior knowledge in relation to math, science and issues that dealt specifically with the Elwha drainage basin, its history and its current politics.

Based on earlier assessments derived from classroom teachers' scores and state and national tests, the students were categorized as low, medium, or high achievers. This prior assessment was related to STEM learning in science, math, English, and technology.

## **Methods**

The learning intervention took place during a two-day field trip to the Elwha River valley in which students undertook first-hand experiential discovery learning in various portions of the valley (upper, middle, and lower). All participants received instruction in processes and carried out measurements at the site of the upper dam and all students participated in hands-on activities involving a beach transect. Both groups examined the effect of wave-action on the formation of beaches, including processes like long-shore drift, deposition and distribution of sediment. The control group collected data and measured samples using traditional tools, which included pencil and paper.

Another unit of instruction entailed a visit to the lower course of the Elwha river, site of the Glines Canyon dam. Here, observations were undertaken in relation to the dam construction and the build-up of sediment in the lake. Below both dams, the river enters the Strait of Juan de Fuca and connects with a coastal landscape. The objective of the study unit was two fold: (i) a look-and-see approach so that the subjects experience features of the lower course of the river system, and (ii) verification of facts in the field so that subjects could authenticate abstract theories that they have encountered in the

classroom and in previous study sessions related to the work of rivers in the lower course, i.e. deposition, as opposed to erosion and transportation. A key feature to the conceptual learning involved a comprehension of the fact that a ‘lower course’ feature, i.e., deposition, can occur in other areas of the watershed particularly where the river is forced to slow down or stop, e.g., a dam. A further learning objective involved a deep understanding of the systemic interaction between riverine and estuarine process that connected the Elwha and the foreshore in the strait.

Students were randomly assigned to bus A or bus B. On the first day bus A went up stream to the Glines Canyon Dam, where students carried out observations and measurements in an area of the drainage basin that is associated with the overriding work of the river at this point—deposition. The following day, bus A went to the foreshore where the students carried out a transect stretching from the far-edge of the beach to the waterline. In so doing, they described in a mathematical representation a typical beach profile—either constructive or destructive. Bus B participants did the same work in reverse order. All students, while on the buses—going to and from the various data gathering locations (roughly 30 minutes from their school)—were asked to complete a one-page worksheet that depicted a lake, a river and a dam. They were asked to use crayons (supplied) to identify with colors, and mark using an appropriate key, the river, the dam and an area where silt and sediment would be prone to accumulate.



Fig. 3 First-Hand Data Collection in the Outdoors using Advanced Graphical Calculators

All processes were carefully explained to the participants before the project began and all participants received written instructions for themselves and their parents; only students whose parents signed the release forms were included in the study as per requirements of the University of Washington Internal Review Board. (For more information on these release forms, please see: Appendix i and ii below).

	A (...)	B (...)	C (...)	D (...)	E	F s...	G	H
4	1	3	18	45	55	128	$\Sigma x^2$	16
5	1	4	20	65	75	256	$s_x : \dots$	64
6	1	5	12	77	87	32	$\sigma_x : \dots$	64
7	1	6	8	85	95	90	n	
8	1	7	18	103	113	128	MinX	
9	1	8	10	113	123	8	$Q_1 X$	

*E9 | =d9+10*

Fig. 4 Example of Data Input in Document feature of Advanced Graphical Calculator

All students were asked to establish a secret code so that their anonymity was assured. The secret code was the only marker on their assignments and other paper or written dispatches that transacted during the study. All data was collected by the research team and carefully kept under lock-and-key at the University of Washington for the duration of the project.

At the beginning of the project, each participant completed a demographic survey and a 23-question pretest (see: Appendix iii). The demographic survey consisted of a questionnaire and survey eliciting background knowledge that helped shed light on the individuals participating in the study. The pre-test likewise was an attempt to establish and make visible prior knowledge relating to key areas of math, science and language comprehension that offered deeper insights into the composition of the participant cohort. In addition, we had access to school and state results for the 16 participants and were able

to verify with their classroom teacher that they were represented as low, medium or high achiever as a result of previous testing.

Members of the research team who were knowledgeable in techniques of ethnographic data collection, spent at least two days in the company of the students—while they were engaged in doing their classroom preparation and data capture, field assignments and classroom exposition. Each researcher played a key role as participant observer, and was careful not to interfere with or influence the work at hand. Field notes were typed up and added to the materials in the final data collection pertaining to this research project. Interviews with the students were impromptu and organic. There were many opportunistic occasions for discussions and observations regarding the dams and the coastline. Each day there was at least 30 minutes of travel time in a bus, at least a ten-minute hike across the beach to and from the site of the transect, and at least a ten-minute hike to and from the dam viewing points and sample sediment site. Many students brought their cameras and individuals, in posing and taking pictures, had much fun. The group with the Advanced Graphical Calculators spent time exploring the interface and usability on the bus to and from the beach.

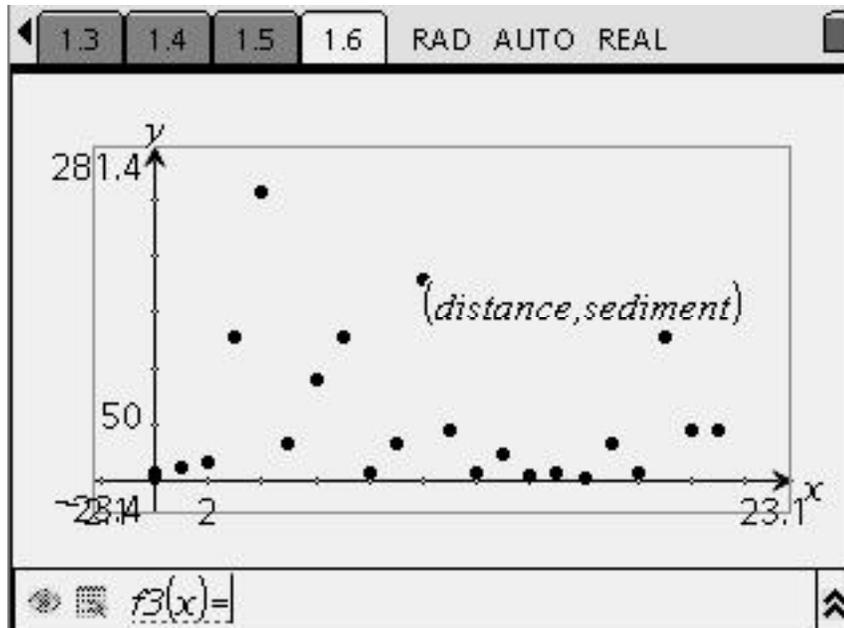


Fig. 5 Example of Data Representation using Advanced Graphical Calculator

Students were asked to self-report about progress with data collection, observations and representations at the end of each day. The results of their pre-tests were made available to each individual and they were allowed read over their previous answers and in light of new information or breakthrough thinking were given the opportunity to make additions or edits.

Subjects were asked to describe what they saw, as they walked the shore, collected artifacts and took measurements and observations. Then they were asked to synthesize their findings into a presentation, with written, verbal and mathematically descriptive worksheets to illustrate their thoughts and ideas. The weather cooperated and the students, while chilly, did not get rained on. There were essentially two groups—the baseline control group and the treatment or experimental group. The students in the treatment group received training in and used, during their data observation and gathering

phase, advanced graphical calculators. The training consisted of a two-hour in-class activity before the bus trip to the beach. This training was in two parts. First, participants were allowed time to explore the calculators on their own or in groups, to familiarize themselves with the screens and essentially to simply play around, dive in, get overwhelmed or figure it out. This exploration is in line with theoretical assumptions relating to pedagogy associated with a “time for telling” that enables generative thinking and problem solving and leads also to preparation for future learning (Schwartz & Bransford, 1998). After an appropriate amount of time (roughly twenty-minutes), they were given expert, hands-on instruction on how to navigate, input, save, and output data, including how to change and exchange data. They were introduced to the ‘document’ module, which was prepared specially and designed specifically for capturing data relevant to the beach profiles. With the help of timely training, that cohort of students (who were assigned calculators) were then able to use the instrument in the capturing of their data during the beach transect.

The participants of the control group, carried out similar work with traditional tools, i.e., pencil and paper on an identical transect (see: Fig 3 Example of Traditional Pen & Paper Profile). We theorized that the use of pencil and paper with a clipboard would not impact the students negatively since they were used to carrying out class project by this means. However, we did observe that the students who did not receive the training on the advanced graphing calculator were interested in finding out about them. After the experiment all students were given opportunities to work with the calculators and to explore the document screen where the data was collected.

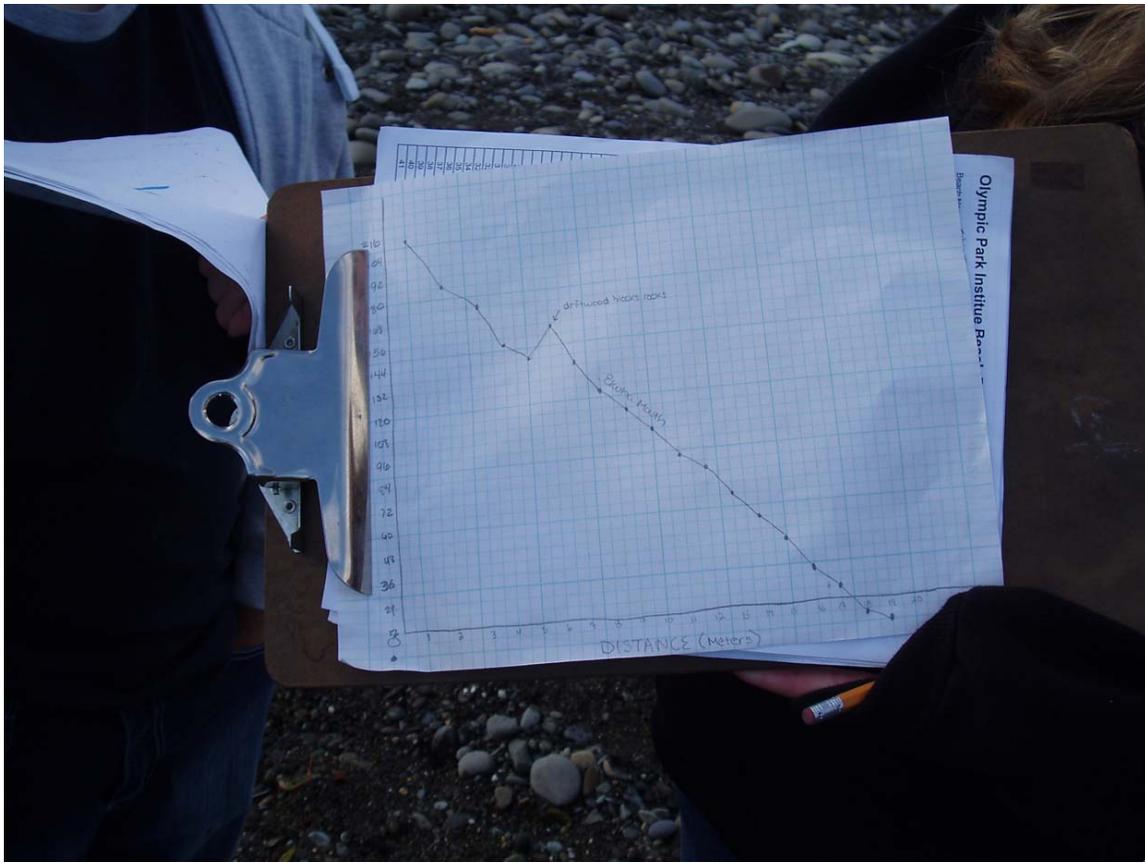


Fig. 3 Example of Traditional Pen & Paper Profile

Both transects were a few meters apart and, apart from individual differences in the size, distribution, and perhaps type of pebble or rock, were virtually indistinguishable. All students were asked to represent their fresh data in a mathematical representation that described the nature of the beach—constructive or destructive, based on their observations (see: fig 4 Example of Beach Transect using Calculator Screen).

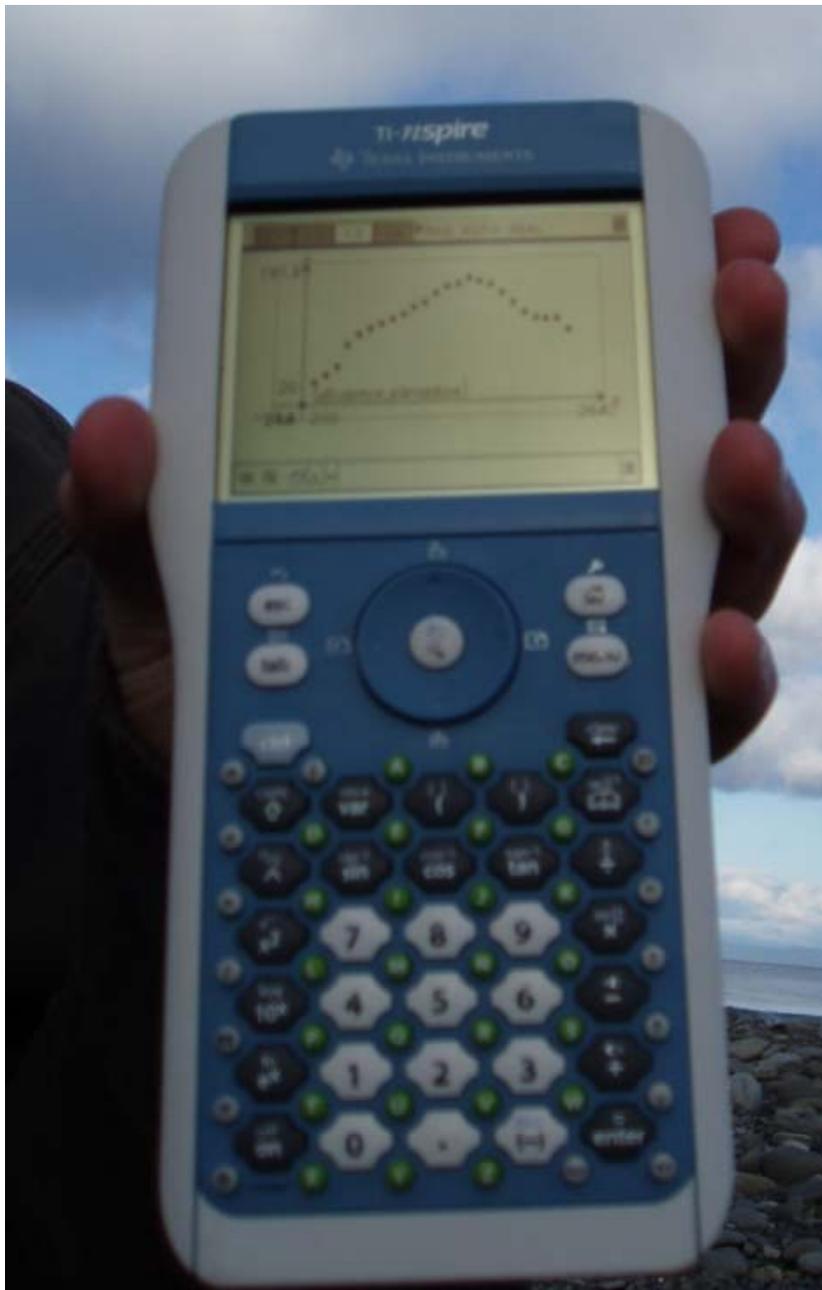


Fig. 4 Example of Beach Transect using Calculator Screen

All students worked in collaborative groups of three or four individuals, while they collected data using tape measures, meter sticks, levels, and protractors, but each individual was asked to use the shared data to generate his/her own graphical representation for the observations. The drawings on paper and, as depicted on screen via

the advanced graphical calculator, became part of the research team data at the end of the field trip. All students were asked to complete a post-test in which they were given an opportunity to reflect on, edit, amend or make additions to Xeroxed copies of their pre-test.

## **Data Analysis**

Data analysis utilized both quantitative and qualitative methods. Empirical results were culled from written pre- and post-tests that were administered over the two-day study. Interactive analysis using grounded theory comprised the ethnographical enterprise—based on participant observations, extensive field notes, and interviews with the participants (while en-route to the field sites and while doing data collection at the field sites). In a contextual experiential learning and teaching ecosystem of this potentially convoluted nature, the mixed method approach augmented, with triangulated narrative portrayal, the emergent findings.

A coding protocol and rubric was implemented in collaboration with the UW statistical department and the College of Education Learning Sciences faculty. Answer sheets were randomly assigned to trained coders for blind coding. High inter rater reliability (> 90%) was maintained throughout the coding. We focused on several aspects of the data in our interpretation of the findings, including the actual beach profile, the mathematical representation that students evolved as a result of collecting first-hand observations and measurements on the beach. We used a statistical software package (SPSS) to analyze the data. Findings and implications are discussed below.

The empirical experimental measures were enhanced with thick descriptive accounts (Geertz, 1973) of student activity *in situ*, and served to capture the messiness

and complexity of the outdoor environment. Detailed interactive analysis of students' statements and embodied discourses around their data collection and interpretation allowed the research team to think about what they knew (or would like to know) and helped them make sense of data. As participant observers the research group were interested in making meaning (Lareau & Shultz, 1996) of the complex different behaviors of the participants and their teachers. This was in addition to assessing their sequestered problem solving (Sears, 2005) capabilities with traditional tests. A grounded theory approach to data interpretation helped develop propositions (Emerson, Fretz, & Shaw, 1995) and formulate new questions based on what was found (Becker, 1998). This kind of methodological pluralism often results in deeper sense-making and superior research (Johnson & Onwuegbuzie, 2004) while at the same time lessening the risk of what Clifford Geertz so aptly said in describing the ethnographer in the wild as "a manic tinkerer adrift with his wits" (Geertz, 1995).

## **Findings**

Findings highlight three important considerations: (i) all participants showed a positive gain in knowledge both, in procedural and, more importantly, in conceptually connected knowledge; (ii) participants who had access to graphing calculators learned with understanding and appeared to be better able to draw inferences that connected inert knowledge with observed and grounded phenomena; and, (iii) low-achieving participants who had access to graphing calculators showed the highest gains. These findings will be discussed at depth in the next section and limitations and challenges for the future will be included.

The first finding, which was very important for the integrity of the intervention, was that all students improved significantly. In spite of this fact, there was a definite ceiling affect so that students who scored high on the pretest didn't have an opportunity to demonstrate more knowledge within the structural confines of our testing devices, we were able to detect that all students were highly engaged, deeply interested and worked hard in a collaborative way to insure that the project was completed and that everyone had an opportunity to contribute in a positive sense. This is not the typical reaction when students are bored, unchallenged or disengaged by schoolwork that they perceive as not meaningful to them. In fact the students in the Elwha dam removal Learning Project displayed high levels of engagement and interest throughout the proceedings even when the weather was foul, cold and unappealing in every way.

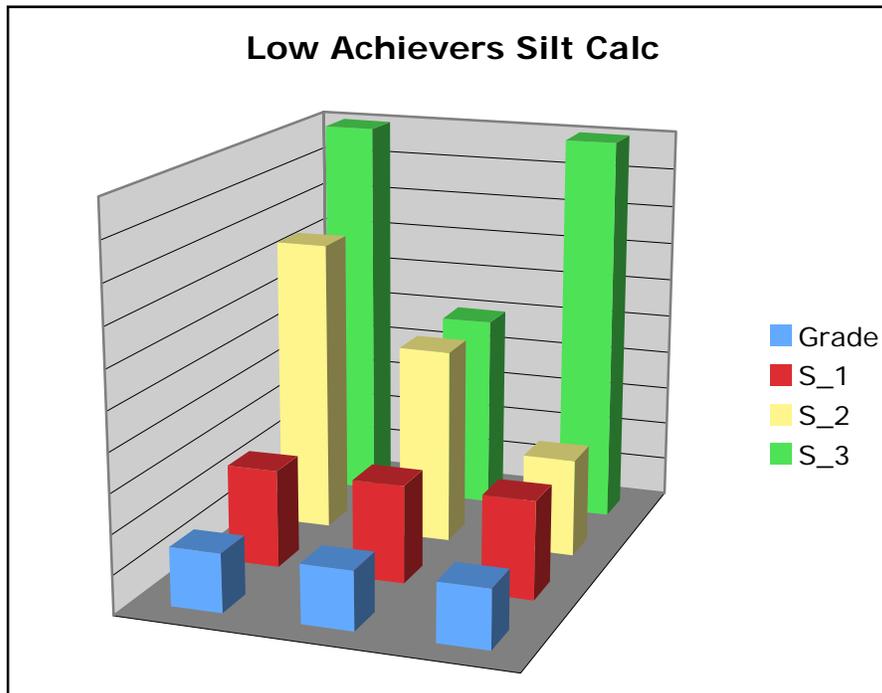


Fig. 5 Students with Calculator defining the sediment location

The chart above (fig. 5 Students with calculator defining the sediment location) is a depiction of students’ improvement over time in their interpretation of sediment deposit at the Glines Canyon dam lake. It is a clear example of new knowledge manifesting a shift in students’ thinking, gradually overcoming their preconceived ideas and acknowledging the metacognitive nuances that derive from repeated edits within a formative assessment framework.

Below is an outline of graphs and charts that were created as a result of the data collection we captured in the two-day period under investigation. The following figures draw attention to the salient findings and their implications for the learning sciences.

### Descriptive Statistics

Testing the difference or change in scores from pre to post test by group

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0	7	10.2857	7.06433	2.67007	3.7523	16.8191	1.0	19
1	9	32.4444	21.47738	7.15913	15.9355	48.9534	3.0	66
Total	16	22.7500	19.87125	4.96781	12.1614	33.3386	1.0	66

Fig. 5 Descriptive Statistics

The descriptive statistics above represent the two groups, 0 = “No Calculator” and 1 = “Calculator”. Means are 10.29 and 32.44, respectively. The mean result of the improvement in learning measures (change from Pre- to Post-test) is notable. By using the pre-test as the baseline student measure, the design resembles a repeated measure because it takes into account the baseline achievement of each student. From these scores it is evident that the Calculator Group had a standard deviation three times the size of the

No-Calculator Group. Levene's test of homogeneity of variance failed. We will discuss some implications concerning this below.

### ANOVA

dif\_pre\_post

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1933.349	1	1933.349	6.784	.021
Within Groups	3898.651	14	284.975		
Total	5923.000	15			

Fig. 6 One-way ANOVA

We carried out a one-way ANOVA test using SPSS. This test identified a significant treatment effect meaning that students who were randomly assigned the use of the calculator learned significantly more than those who used paper and pencil. In other words, using the advanced graphing calculator made a difference for student learning. The between group variance or the Variance accounted for by the difference between group 0, (No Calculator group), and group 1, (calculator group) is compared to the variance found within groups, taking into account the degrees of freedom. The result is an F value of 6.784 and a significant finding ( $p=0.021$ ).

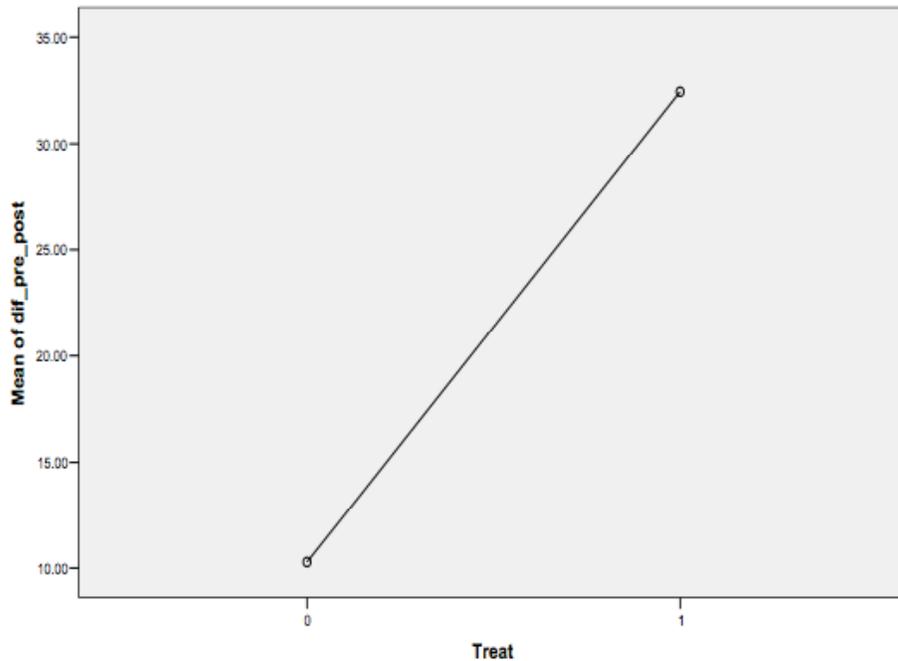


Fig. 7 Mean Difference Pre- and Post-test

The mean difference between groups is shown in figure 7. and illustrates the average difference in gain between pre- and post-test, with the Calculator group (1) averaging a gain of 32 points, 22 points higher than the students who did not have use of the calculators. It is worth emphasizing that these groups were randomly created, with students randomly assigned to either the No Calculator (0) group or the Calculator (1) group. This experimental design result indicates that a treatment effect did occur and suggests pursuing a larger study with a greater N that would allow for cluster effect to be considered, such as the effects of nesting within a group of students who were all given the calculator.

The significant effect found in this small study is an important finding and congruent with previous findings about the use of calculators in mathematics and

mathematical representations, by other educational scientists (Greenfield & Cocking, 1996; Roschelle & Kaput, 1996; Scardamalia & Bereiter, 1993).

It is worth noting that the students with moderate pretest scores seemed to have gained the most in the Calculator Group. Below (fig. 8) is a revised table to help visualize the gains made by student by treatment.

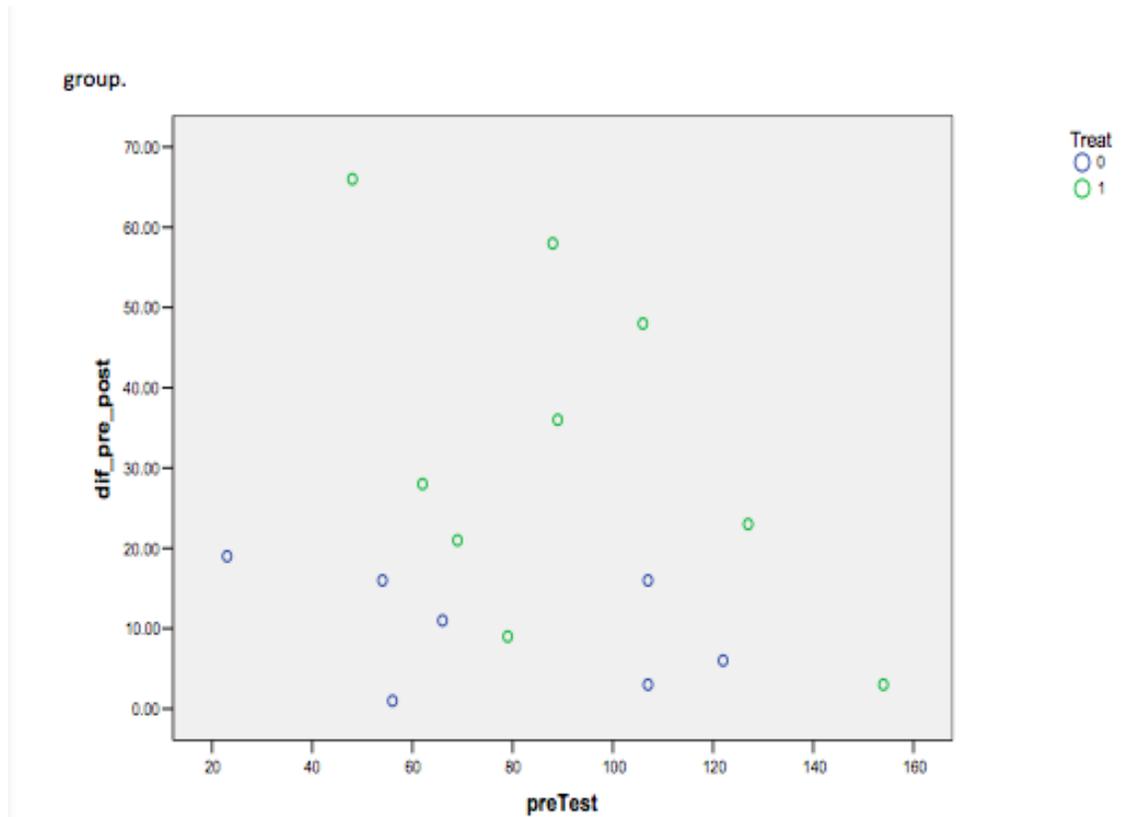


Fig. 8 Gain in Scores by Pre-test and Treatment Group  
Blue = No Calculator; Green = Calculator

This is an extremely important result and most unexpected. If the multi-representational component of the advanced graphing calculator permits a low-achieving student to gain deeper understanding of difficult concepts this could have very powerful implications for improving learning in math and science classrooms. Given that there is emerging evidence in the neuro-cognition field (Delazer et al., 2005; Varma, McCandliss, & Schwartz, 2008), that working memory is at play with the visuo-spatial feedback loop,

it is worth investigating further. What if the immediacy of the visuo-spatial feedback had direct impact on a student's ability to draw inferences and make connections with the physical landscape in question? The potential for augmenting the learning experience for traditionally low-achievers by utilizing the affordances of the advanced graphing calculator cannot be overlooked. More research needs to be done in this area, research that draws from both fields—the neurosciences field as well as the learning sciences field. This would appear to be an opportunity for the bridging of both fields.

We noted earlier that there was a discrepancy in the homogeneity of variance measures. It is clear from Fig. 8 why Levene's test failed. There is far more variation in the calculator group where the greater gains were made. We should keep in mind that there is also a ceiling effect in which students, who are already pre-testing high, have less room to show improvement. It must be stated, also, that there was evidence of a ceiling effect in the results of the tests that were carried out on the dam drawings with crayons. These occurred over time in bus journeys during the coming-and-going to the various sites. It is more than likely that the high-achiever group could be expected to grasp even more difficult concepts and deeper understandings in future work of this nature, using this methodology.

In the next section, we will explore the findings that emerged as a result of the participant observations, the ethnographical deductions based on grounded theory in which we link learning with deep understanding and students' ability to make connections across domains because of the use of visuo-spatial feedback loops presented by the advanced graphing calculators.

## Results of Ethnographic Analyses

Some of the central questions that were uppermost for the research inquiry team revolved around participants' ability for deep understanding of primary processes in the geographical landscape as a result of the two-day field activity. In particular, we wanted to know if students would acquire an ability to establish connections across knowledge domains, using facts and observed data that typically would be prone to remain disconnected and inert, e.g., rocks and pebbles in the matrix in the very prominent bluff behind the beach displayed rounded forms—evidence of abrasion by fluvial action, as opposed to glacial action, which would have resulted in more angular forms—and ended up as part of the beach transect for the students. Would the students, who measured these pebbles and rocks, even skipped them across the water, realize the connection they have to the bluff behind them? Would the introduction of the advanced graphing calculator bring about a situation where mathematics, language and social studies could integrate cohesively in a colloidal way so that deep and persistent connections about phenomena would result? Would this be obvious to the research team through students' levels of engagement, order of questions (high or low), amount of questioning, and stamina for inquiry through the two-day field activity?

In the following sequence of events and speech excerpts there is ample evidence of an emerging integration of mathematical, geographical, social and verbal worlds as the outdoor informal learning ecosystem becomes manifest. In the next section we will attempt to highlight a number of defining moments where deep connections are established, shifts in thinking are in evidence, and collaborative social networks are emerging around field activities in the informal learning environment.

(Note: All names are fictitious to protect anonymity. The reference to the “rock” refers to a talking tool. The individual who holds the rock has the floor. This was a group strategy for presenting results at the end of the project, when everybody was back in the home classroom.)

This excerpt comes from participant observer field notes by one of the University of Washington researchers on day one on the beach:

A front of dark clouds is developing offshore. A student shivers, looks up and remarks that it is going to rain. An OPI Instructor says hopefully that the front might be moving away from them. Everyone notes the sky, watches the clouds for a few moments and some students comment that actually it is moving toward them.

Meanwhile, the data collection activity is proceeding systematically:

Student A: handling rocks: "3 ½ cm, 3.5 cm." (Deliberately skips it across the water.)

Student B: "Yell the numbers."

Student C (with Calculator): "Rock!" (followed by number) "Negative 17.5!"

Good collaboration, developing social networks and positive self-esteem are typical elements of the observations that the research team made during the beach-transect work and the dam-descriptive work.

## **Social Networks**

There is a growing literature on the importance of strong social networks in the informal workplace environment (Ackerman, Pipek, & Wulf, 2003; Bell, 2004; Bransford et al., 2005). Social networks are typically active in classroom settings already. However, in the informal environment outside of the classroom, on buses, and on the beach or by the lake, these pre-existing social networks can get imprinted anew. The research team in the *Elwha Dam Removal Learning Project* paid careful attention to emergent social networks, in addition to nuances in existing social networks that might have implications for adaptive expertise and a preparation for future learning.

There is evidence that students began working in collaborative groups with a certain amount of unease, but, as the project progressed through two days of extensive group work, they seemed to become more comfortable in their collaborative quest for

new knowledge and less hampered by shyness, or low self-esteem. The following short excerpts highlight the progression from what could be termed ‘self-shaping’ or identity framing episodes to ‘problem solving’ incidences. The shift from nervous self-establishment to functional ‘adaptive expert’ role is evidenced through embodied speech events through identity-seeking installments that focus on the ‘person’ as opposed to the ‘question’ under discussion. As you can witness, over time the mood appears to change to an engaged mutually-inspiring discussion around a very simple observation that remains at large—at least until traditional classroom management techniques come crashing in on the players.

The following discussion took place after the second day in the field when students were debriefing back in the classroom. The classroom teacher was sitting to one side. A persistent question sought a solution. The solution was probably within grasp when the teacher stepped in and unwittingly shut the discussion down, as if he was uncomfortable with the fact that the students were not receiving clear information with direct solutions from the instructors. His tone of voice and his body language had an immediate reaction on the class. The students immediately accepted his result as THE ACCEPTED result, and dropped the question. There was no further discussion about ‘current best theory’ or ‘what if’ scenarios.

#### Excerpt 1 (when choosing spokesperson for each group)

Girl: (YV): I should have done a plus sign... next time my secret code name will be ...MS ha ha, the symbol... or, its going to be BOY...

Girl: (MS): Will we get OPI shirts?

Girl: (RS): I don't know what to say.. (Points at classmate.) Peter... as leader...

Boy (JH): ... ok everyone needs to vote for Todd... Todd for president. ok... Todd for president...

(He nods toward the board.) is it those things up there? (referring to what to talk about... )

(RS): I got hit by a wave yesterday.... laughing....

(JH): I still don't understand why we have to do these field trips in almost winter.. laughs ha ha.. I mean .. come on.. couldn't they have made it for the summer or something....

(RS): well like when it is warmer...

Other boy: (PT): if its warmer maybe, but not the summer when that's my time to be out of school...

(JH): OK well June or something....

## Excerpt 2 (Getting down to business. Twenty minutes has slipped by.)

Boy: (PC): The thing that was most surprising was that .. on the first beach we visited we thought there would be huge rocks away from the water and small rocks close to the water... but they were all the same size. It was kind of weird.

(RS): where we were yesterday?

(PC): Yeah. All the rocks were the same size. We thought they'd be bigger the farther away from the water. Maybe its... because of the tide.. the tide comes up and pushes all the rocks the same...

Girl: (RT): maybe the shape of the beach has something to do with it...

General chatter... a few inaudible comments, but around the clarifying the question...

(PC): Where we first did our transect of the rocks on the beach all the rocks were the same size... I was expecting all the rocks to be bigger away from the water... and smaller near the water...

Boy: SH: (SH is normally a shy person and rarely volunteers a theory. Jumps in. strong body language - deep engagement. He is pointing with outstretched finger back and forth in a shape that resembles the Ediz spit, where they had made the transect on day 1) That little spit goes out around ... and water goes on both sides of it... There is water on both sides and... and if the tide is high enough it is easy to get to those rocks in the middle... and erode them more.. I think...

New Girl: (AK): So wouldn't that kinda be like because uhmmm... the day that the tide's high.. it's all under water and... also, like, its all kinda, like, the land .. its always there.. its covered and it was pushed up there... from the waves coming in. (makes shape with fingers to resemble waves coming from two directions and moving all the rocks together to the beach.

New Boy: (RF): (looking directly at AK.) Maybe the answer is that this is the... it happens. I like that answer. (Looking directly at PC.) You ask a hard question. (giggles, laughter..)

New girl: (ZO): Maybe its because.. uhm...mmm when we were measuring it out there.. it was all... we were on a gaining beach... and so its being built up... and it obviously had to start somewhere.. so those big rocks were brought in to start it, and they keep being brought in... so, maybe that's why the rocks are big and .. small... everywhere. (short conversation between her and the boy next to her as he tries to interpret her thoughts (inaudible). She says, hmmm and then, Yeah.)

The word storm seems to have cropped up, we don't know who mentioned storm.

(RF): ...probably. Because there was that big storm not so long ago. Had pretty big waves that brought a whole bunch of new rock in.

OPI Instructor: Those are four really great theories. A lot of times in science you are not going to have a specific... like ahmm...

(The Classroom Teacher who was not supposed to be part of the discussion. suddenly.. stands up deliberately ready to interrupt..)

OPI Instructor: ...answer, just good ideas about how it could have happened. Especially when...

Classroom Teacher: (interrupts) ... well it also could be a combination of all these theories.. (Deliberate body language. Uses hands to give air of authority. As soon as he speaks .. class accepts the answer. As if it was over. End of discussion.) Would the students have come around to figuring out that the rocks actually came directly from weathering of the bluff behind the beach if they were allowed to continue their deliberation?

OPI Instructor: Most of the things... when you study the natural world.. you don't have just one thing that leads to another thing..

(he uses elaborate hand actions to show intricate overlays and interactions.)

... and lots of things combining  
(he looks to the teacher for approval)  
...creating different effects. (Tosses the stone in his hand.)  
Think you guys all have done a great job.

It was over. The final summation of the OPI instructor, with obvious approval from the classroom teacher, quenched the spark of creative problem solving as if it had been hit by the stone in his hand! Would the students who were beginning to show signs of collaborative encounter with science, who were taking intellectual risks, stepping into uncomfortable stances outside their usual classroom comfort zones; would they have made the connection—that the stones on the beach were the same stones in the bluff behind the beach? Would they understand that the gradual and continuous erosion of the bluff by agents of weathering, like freeze/thaw action, rain, sun, wind, gravity and so on, had resulted in the stones ending up on the beach? Would they extrapolate that it was wave action and storms that helped in distributing these same stones along the beach. Were these tenuous connections on the verge of creation?

## **Connectedness**

It was possible to detect elements of the “look and see” approach that some of the students were engaged in as they examined their surroundings and tried to make sense of what they saw. It is extremely important to note the clear connection between the immediacy of the visuo-spatial feedback loops and the physical landscape underfoot as a tangible connector between the cyber and physical worlds. Following is a selection from the field notes of one of the investigators where this visuo-spatial feedback is vital to their understanding of the emerging picture of the beach profile at their feet:

After they have captured their measurements we viewed the beach profile on screen. I reminded them of the "zoom-stat" command, which automatically sets the scale so the graph appears properly.

Students agreed that it was a gaining beach.

We moved to the next tabs (plots of elevation and distance vs. sediment size).

Student A: "Wow, look at that!" (Looking intensely at the graph of his own data that suddenly flashed on the screen, not as numbers but as a linear representation that displayed a shape.)

There was no clear relationship between sediment size and elevation or distance. All students looked closely at the graph, and constantly looked between the calculator display and the beach before them.

The research team was interested in not only empirical findings—scores on tests at the end of a sequence of learning events—but more fully, and particularly, on the development of adaptive expertise (Bransford et al., 2006; Bransford et al., 2005; O'Mahony et al., 2007) and its propensity toward a preparation for future learning. We looked specifically for moments where the students: began to trust one another in social networks; began to ask deep and thoughtful questions of one another as well as of the OPI instructors, and to find occasions that indicated they were willing to step out of their comfort zones and take the ultimate intellectual risk in front of peers.

We will demonstrate that in this instance, a combination of engagement, questioning, attitude, self-esteem, and intellectual curiosity as a result of the informal work with advanced graphing calculators, point to a student who is not the typical bored, disengaged potential drop-out, but, a curious, interested individual who is adapting to change and taking charge of his own learning.

## **Questioning**

There is an extensive literature that describes the efficacy of high- versus low-order questioning (Mills, Rice, Berliner, & Rousseau, 1980) and the importance of the length of questions (Newmann, Wehlage, & Lamborn, 1992). Questions became a critical form of intellectual curiosity for the students in the Elwha Dam Removal Project. Most of the good questions came from the students themselves and, unfortunately, some never got

resolved (there is evidence that the instructors were not prepared to think in this exploratory fashion or understand the ideas behind the theoretical assumptions surrounding adaptive expertise). Another intriguing reason to do future work in this area and extend the research over a number of months so to revisit difficult concepts over time. This will allow the students to make meaning and foster a deep understanding of what they are discovering. We found that the students were fully motivated and highly engaged in issues surrounding their beach transect and the information they received pertaining to the removal of the dams. This was reflected in the frequency, the amount, and the order of the questions that emerged unprompted and spontaneous in the post fieldwork classroom discussion. Following is a description of a student's observations that connects her own observations to some big questions:

Girl (AQ): Stands, holds rock plays with it between both hands.

Before..., I used to see the beach as somewhere really nice to go to relax and stuff... Now I don't (shaking her head and smiling)

(general laughing... few giggles.)

It was really cold. And.. um.. yeah...

I guess I didn't really notice the different profiles (makes shape of her own beach profile with free hand) of the beach.. and um...

(Pauses, thinking...)

now I did, obviously... and yep... that's pretty much it.

(Nodding and tossing the rock between left and right hand.)

UW Researcher: So.. uh.. so ..uh what was surprising?

AQ: Umhmm the cold!

Several key questions emerged from the students themselves that never received an answer. There was one attempt to follow a logical 'what if' discussion in a proto-scientific approach to its conclusion, but, unfortunately, it got truncated, if unwittingly, by the classroom teacher (See: discussion on pp. 32-33). The following is an example of two very significant questions that were fielded from the floor and which, if properly

analyzed would have delivered a very deep understanding of the processes and functions of the events witnessed by the students over the two-day exploration.

Q 1: The thing that was most surprising was that .. on the first beach we visited we thought there would be huge rocks away from the water and small rocks close to the water... but they were all the same size. It was kind of weird?

Q 2: But I thought all sediments behind dams would be piled up against the dam but it was dropped off at the beginning of the lake and there isn't hardly any against the dam?

Q 3: What still needs to be explained is uhmm... How does the shape of the uhmm...mm beach show uhm...m whether its being eroded away or whether its being built up?

These are intensely vital questions that demonstrate an interest in understanding all the processes involved in the work of rivers, including lakes and dams and the work involved in oceans including beach formation and erosion. Could this level of intellectual curiosity that is expressed as one output of the work carried on by students using an advanced graphing calculator be linked to the impact of the immediacy of the visuo-spatial feedback loop and the fluidity of the mathematical representations? These are good questions that warrant closer investigation in future studies.

The importance of making connections between what was spoken, what was heard, what was seen, and what was written about is critical in the development of adaptive expertise. Would the introduction of advanced graphical calculators generate a connectedness across knowledge domains for the participants and enable them to capitalize on their intellectual curiosity in a way that helped them connect new ideas and propositions into a cohesive and deep understanding of what they were seeing and doing. At the same time, through an organic engagement and natural motivation could we observe instances of individuals essentially eliminating disconnected funds of inert knowledge? The following short excerpt is documentation of one female student letting go of preconceived ideas, of exploring new connections with her own observations. But above all, it is a really solid example of a reflective deliberation where she questions her

own ability to know and how she knows. This kind of metacognitive refrain is very important in the preparation for future learning.

Girl (LB): Sure. ahmmm.. what was surprising for us was that ...like... we thought we knew more about ... like.. the beach ..we found that we did not know that much that we thought we did... a-aand... I learned personally a lot about the beach profile and how the different rocks change along the river.. or not so much the river but the .. ahm...mm the beach itself.

The biggest surprise for me was that I didn't know as much as I thought about it... and what the dams were made of.. um what the Elwha dam was made out of.. ahh... cars... ahmm old cars and garbage... and trees and big rocks and... covered with layers of cement... rather than the whole thing being cement. That surprised me because I figured that it would be cement and wouldn't have old junk in it to hold up water and a lake. it must be strong enough, because it did hold it up. It's not falling down.

That engagement, questioning, reflective thinking, metacognitive refrains and collaborative deliberation took place among this group of sixteen-year-olds is remarkable in itself, but witnessing the intensity of the questions, the energy of the engagement and the enthusiasm of the collaborative exchanges was a testament to the meaningfulness of the task at hand, and the technological equipment brought to bear on it.

## **Formative Assessment**

Assessment is a major portion of the framework of creating innovative learning ecosystems that foster adaptive expertise and promote a preparation for future learning. A number of driving questions emerged around the use of formative assessment techniques that we hypothesized would encourage the students to begin to be metacognitive about their own lack of knowledge, and demonstrate through reflective questioning and discussions their taking express ownership of their own learning. Many would argue that this kind of activity in the informal environment is an indicator of better preparedness for future learning (O'Mahony et al., 2007; O'Mahony & Gawel, 2007). The following observation and question is expressly indicative of a shift in thinking, an occasion when the student is risking being wrong and publicly admitting it in front of his peers. This, we acknowledge is a primary exemplar of the adaptive expert, the person who is willing to

put himself outside his comfort zone and be willing to learn. This bodes well for the methodology of the study on the Elwha dam removal project and the equipment, including the advanced graphical calculator with immediate visuo-spatial feedback loops. This following excerpt is testimony that describes an individual's journey into metacognitive territory, while at the same time an example of his release from some of his 'sacred cows,' the preconceived ideas that were made visible as a result of the experiential discovery methodology:

Boy, (CJ): But uhmmm what was.. for me... I already knew this, but I was wrong.. uhm was different... was a little bit to me.. was uhmm... I thought all sediments behind dams would be piled up against the dam... but it was dropped off at the beginning of the lake (elaborate hand actions to point to the far end of the lake...) and there isn't hardly any against the dam.

What still needs to be explained is uhmm. (elaborate hand actions again) How does the shape of the uhm...mm beach show uhm...m whether its being eroded away or whether its being built up?

As mentioned earlier, we suspected that students would have serious difficulty letting go of commonly held preconceptions relating to where the sediment was deposited in the lake behind the dam. Even when they were expressly told, that the sediment is not lying up against the wall of the dam, they still persist in drawing the mound of sediment right behind the dam wall, not just the first time, but sometimes twice and more times. Eventually they, as (CJ) in the case of the individual above, shift their thinking so that they begin to grasp that, it-is-not-where-the-barrier-is-that-counts, but where the river slows down or stops. The river slows down when it spreads out at the head of the lake. Rivers typically speed up when they are restricted by narrow channels or assisted with steep gradient.

The elimination of preconceived ideas is a serious matter for teaching and learning and has grave consequences for both parties. The first steps are usually to 'make visible' what the student knows so that the teacher understands the nature of the task

ahead (Bransford, Darling-Hammond, & LePage, 2005). This is accomplished through careful use of formative assessment techniques, techniques that were implicit in the design model that we used in the Elwha project. Success in this process leads to sound metacognitive practices (Bransford, Darling-Hammond, & LePage, 2005; Vosniadou & Brewer, 1992) and ideally helps the individual take charge of his/her own learning. Many occasions facilitated formative assessment exercises and moments of collaborative reflection—crayon drawing on the buses, while hiking to the field activity sites. We witnessed moments of ‘making visible’ and encountered the ‘shift-in-thinking’ that is indicative of an adaptive expert in the making (Schwartz, Bransford, & Sears, 2005). The following short excerpt elaborates on this point and succinctly establishes connections and documents theory-in-action as it emerged from the hands-on and immediate visuo-spatial feedback loops that this work entailed:

Facilitator handed out the dam illustration activity (with crayons) and asked students to color it in per the instructions. They are on the bus day 2 on their way to the Glines Canyon Dam.

Student (JK): We were totally wrong last time... (in reference to misrepresenting the sediment placement the last time they did the activity.)

Student (LS): Mine so totally rocks! (Looking, smiling... at her drawing.)

Student (DE): Wow... the sky looks amazing. (There are broken clouds, and the mountains are suddenly backlit rather dramatically.)

In that last excerpt, we witness a delicate movement in mental condition, a shift in preconceived thoughts and a willingness to learn new things. We could see a shift in their thinking—opening the door for metacognitive explorations at this level and unfolding what we like to term ‘metacognition-in-action’. Equally important is the caring attitude, the tacit collaboration, and embodied adaptive-ness and flexibility of the classmates.

We expected the use of handheld graphing calculator documents to be an imposition to their traditional methodologies. We were wrong. It seems that the introduction of the graphing device was met with overall positive emotions and as shown

earlier in the empirical findings, positive learning results. Following is an excerpt, which was typical of the attitude of the students and was echoed by many as they reported-out on their two-day river project:

LB: They are way high tech. (Pass the rock.) Uh...mmm... they are really high tech and... uh...mm... they had different screens, like tab pages, and everything you tried to do... you had to go to someplace else to get to it. Like a little computer!

K: Did you like it?

LB: Yeah.

SB: (Reaches for the rock ... jumps in... very engaged, enthusiastically volunteering.) I thought it was surprisingly easy... for something complicated like that... to profile a beach. I figured it would be really hard to do... but it was surprising how easy you could do it. It was a good calculator... nice. (Nodding positively... engaged, positive body language. Very serious.)

LB: I agree.

We hoped that we would find moments where students were verifying facts in the field, such as theories and ideas that they brought with them from school or past experience that might stand to deeper scrutiny. We identified instances where students appeared to make connections to real life places and events and note the enthusiastic engagement so different to when they are forced to memorize inert disconnected knowledge from a textbook. We are reminded of the tyranny of the textbook, the one impression that serves all. How do we get to shared-expertise if we are forced to engage with the one text? Neither of us is an expert but we learn a great deal by exploring together. In the following excerpt, the students are standing on Ediz Spit, a sandy feature of the costal foreshore by the estuary of the Elwha River. It highlights an engagement and energy that emerges from shared learning and adaptive exploration:

Boy (KM): where did the spit come from?

a couple students answer...

Girl (JH): ...the river, the Elwha.

Boy (PS): ...the bluffs.

(KM): ...the spit is important for making a harbor,

(JH): it's a nice place to visit.

(PS): ... the Coast Guard needs it.

The cloudbank offshore, gets darker and the contrast between the patch of blue (hole) above the harbor and the darkness above the Strait becomes greater.

(JH): Beautiful! (looking at the clouds and the blue patch overhead.)

(KM): Are those clouds coming toward us?

The sun on the water near the shore becomes brighter and turns the water a bright turquoise, standing out against the dark gray water farther offshore.

(JH): The water looks so pretty...

(PS): Like the Caribbean. I went there once.

There is no doubt that students learn through curious investigation—when they are more engaged, more motivated, more excited about their immediate surroundings. In the case of the Elwha Dam Removal Project they are intimately included in mathematical and geographical field activities and their attitudes and energies showcase their capacity to transfer from disconnected inert knowledge to deep understanding of big ideas. At the same time there is evidence from documentary self-reports that the instructors (OPI and Classroom teacher), were more engaged and more enthusiastic about this project because of the advantages of being able to demonstrate advanced mathematical functions with multiple representation on the calculator. This is in line with other findings from other research groups, (Heller, Curtis, Jaffe, & Verboncoeur, 2005) that innovative use of calculator screens and document attachments can help motivate teachers. This kind of technological gadgetry not only impressed them, they were adamant that it helped the students achieve a better understanding of the difficult concepts. They liked the advanced graphing calculators and were upset when they were not allowed keep them at the end of the project.

## **Limitations and Recommendations**

A specific limitation of this study is sample size. There is solid preliminary data in this pilot study that gives every indication that there is more to learn in the future. The clear finding of a treatment effect is in itself good reason to pursue this treatment with a

larger sample and consider other aspects of the treatment design such as cohort and nesting effect. An initial step might be to conduct a power analysis to determine the number of students, cohorts, and schools that might be needed in order to detect an effect under nested conditions. Although the test of homogeneity of variance, Levene's test, indicated that the two groups do not share equal variances, interestingly, it may be the achievement level of the student that should be accounted for. Increasing the sample size would also allow for students to be paired by achievement level and then placed randomly in treatment or control group. This would allow for a more comprehensive statistical analysis in terms of student achievement, allow for regression and other multivariate statistical techniques.

The research team unanimously agreed that future studies would provide an opportunity to follow-up with the students after one month, three months, six months and one year. This kind of longitudinal study would ascertain if the embryonic adaptive expert that we detected exists over time and in other situations.

Other recommendations involved moving the location to a new beach with different physical attributes at work to investigate if the methodology would allow transfer of inquiry for big questions. This would be a major component of the acquiring of learning attributes that foster adaptive expertise and a real indicator for preparation for future learning. We also recommend this kind of local stewardship program since the students, who took part in the two-day activity, declare to attaining a passion for stewardship of their local environment, and say they seek to preserve the heritage and culture of endemic communities. We recommend it, too, for the teachers, who by their interaction with these students-at-work, are better prepared for future teaching because they capture a deep

understanding of pedagogical content knowledge related to scientific method, cultural heritage, and environmental stewardship.

## **Future**

This study extends work that has been carried out in the learning sciences relating to learning in informal environments. Social networks that became established during innovative classroom experiences were observed to self-propagate throughout the day in a way that effected learning and engagement.

The introduction of the advanced graphing calculators provided an innovative and fun way to structure mathematical materials that scaffolded student learning, increased individual participation in social networks, and enhanced self-esteem and identity while manipulating mathematically derived functions and data-driven real-world and real-time outcomes.

This study examined learning outcomes. Empirical findings on pre- and post-tests indicated a significant effect pertaining to improvement of students who had access to the advanced graphing calculator. Meanwhile, interaction analyses conducted on researchers' field notes, students' self-reports, and group discussions showed noteworthy differences—and these are probably more important for defining a preparation for future learning than just scores on knowledge at the end of a course.

## **Classroom Networking Technology**

We are very excited about the capability of the calculator equipment for improving social networks within the classroom. Although it is envisaged as a device that enables the teacher to make visible much of the classroom activities, we see it as something that the students adapt and include in their repertoire of social networking

skills and include the added functionality of having mathematical advantages that go along with the social.

As conceived, the handheld graphing calculator enables communication with representation via a classroom networking technology, making possible new forms of classroom communication—teachers can send students one or more screens of preconfigured representations. In addition, students or teachers can harvest examples of work and rapidly bring these examples up for discussion. Functionality also allows aggregation of student work with obvious advantages for the math class discussion. The classroom networking capabilities can allow everyone to see what students are thinking and doing so that all can be helped to improve. Students can communicate by sending mathematical representations to the shared display. Using the classroom network in this fashion, emphasizes the idea of distributed expertise, computational strength in numbers, and collaboration as a tool for learning among peers.

Learning outcomes in general seemed to supercede expectations in terms of facilitating students in their attempts to draw conclusions, make connections and overcome the tyranny of inert chunks of disconnected information in the brain. We infer strong support in preparation for future learning from this type of grounded practice where learning-in-action is evidenced. The central question, whether the use of advanced graphing calculators would generate and enable an intellectual landscape, by connecting ideas and propositions while essentially eliminating disconnected funds of inert knowledge, appears to be borne out and substantiated. We believe that learning in the outdoors with advanced technological devices in STEM facilitates different kinds of learning; that we can achieve functional improvement in understanding for big ideas and

sharing knowledge; that this can be achieved with a blend of teacher-led interactions and small group and student-led explorations.

While all students improved their knowledge and understanding, as evidenced from pre- and post-tests, as well as self-reports and ethnographic deliberations, findings suggest that the largest improvements in both understanding and knowledge occurred in the low-achiever cohort. It is noteworthy that participants in this Elwha Dam Removal Project began to understand processes in a deep way, derived contextual connections pertaining to the complexity of coastal marine sites and drainage basins as a result of studying the dam implementation. And finally, both students and teachers appeared better informed and more willing to learn new things, including a participation in the local community and in stewardship of their local landscape and environment. But above all, the pedagogical content knowledge that emerged from this informal learning intervention has widespread implications for classroom teachers everywhere and, in particular, for high-tech equipment manufacturers in educational devices like the advanced graphing calculator.

## References

- Ackerman, M. S., Pipek, V., & Wulf, V. (2003). *Sharing Expertise: Beyond Knowledge Management*. Cambridge MA: MIT Press.
- Allaway, J. (2004). *Understanding the Elwha: A strategy for research and education programs on the Elwha River*. Spokane, WA: Huxley College of the Environment.
- Anderson, R. C., & Pearson, P. D. (1984). A schema-theoretic view of basic processes in reading comprehension. In P. D. Pearson (Ed.), *Handbook of Reading Research* (pp. 255-291). White Plains, NY: Longman.
- Becker, H. S. (1998). *Tricks of the Trade: How to think about your research while you're doing it*. Chicago: University of Chicago Press.
- Bell, P. (2004). Promoting students' argument construction and collaborative debate in the science classroom. In M. Linn, P. Bell & E. Davis (Eds.), *Internet Environments for Science Education*. Mahwah, NJ: Erlbaum.
- Black, P., & William, D. (1998). *Inside the black box: Raising standards through classroom assessment*. London: King's College.
- Bransford, J. D. (2007). Preparing people for rapidly changing environments. *Journal of Engineering Education*.
- Bransford, J. D., Barron, B. J., Pea, R., Meltzoff, A., Kuhl, P., Bell, P., et al. (2006). Foundations and opportunities for an interdisciplinary science of learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*. New York: Cambridge University Press.
- Bransford, J. D., Brown, A. L., & Cocking, R. (Eds.). (2000). *How People Learn: Brain, Mind, Experience and School*. Washington, DC: National Academy Press.
- Bransford, J. D., Darling-Hammond, L., & LePage, P. (2005). Preparing Teachers for a Changing World: Introduction. In L. Darling-Hammond & J. Bransford (Eds.), *Preparing Teachers for a Changing World: What teachers should Learn and be able to do* (pp. 1-39). San Francisco, CA: Jossey-Bass.
- Bransford, J. D., & Schwartz, D. L. (2008). *It takes expertise to make expertise: Some thoughts about why and how*: In Press.
- Bransford, J. D., Vye, N. J., Stevens, R., Kuhl, P., Schwartz, D. L., Bell, P., et al. (2005). Learning Theories and Education: Toward a Decade of Synergy. In *Handbook on Psychology*. Washington DC.
- Brenner, M., Mayer, R., Moseley, B., Brar, T., Duran, R., Smith-Reed, B., et al. (1997). Learning by understanding: The role of multiple representations in learning algebra. *American Educational Research Journal*, 34(4), 663-689.
- Cabeza, R., & Nyberg, L. (2000). Imaging cognition ii: an empirical review of 275 PET and fmri studies. *Journal of Cognitive Neuroscience*, 12, 1-47.
- Casey, J. (2006, January 6th). Storm continues eating away at Angeles Point. *Peninsula Daily News, Port Angeles, WA*.
- Center for Regional Economic Competitiveness. (2007). *Labor market opportunities in the Nashville economic market area: An assessment of the region's workforce demand and supply*. Nashville, TN.

- Delazer, M., Ischebeck, A., Domahs, F., Zamarian, L., Koppelstaetter, F., Siednetopf, C. M., et al. (2005). Learning by strategies and learning by drill: Evidence from an fMRI study. *NeuroImage*, 25, 838-849.
- Dillon, J. T., & Wittrock, M. C. (1984). Research on questioning and discussion. *Educational Leadership*, 42(3), 50-56.
- Emerson, R. M., Fretz, R. I., & Shaw, L. L. (1995). *Writing Ethnographic Fieldnotes*. Chicago: University of Chicago Press.
- Freilich, J. (2008). Elwha River Learning Opportunities. In K. O'Mahony (Ed.) (pp. 3. As research coordinator for the National Parks System, and in particular the North Coast and Cascades Research Learning Network Dr. Freilich was interested in discussing the Elwha project and the contribution that the study could make to the learning sciences.). Seattle: University of Washington.
- Fuchs, L. S., & Fuchs, D. (1986). Effects of systematic formative evaluation: A meta-analysis. *Exceptional Children*, 53(3), 199-208.
- Gawel, D. J., & O'Mahony, T. K. (2008). Learn how you learn: National Society of Black Engineers.
- Geertz, C. (1973). Thick description: Toward an interpretive theory of culture. In *The Interpretation of Culture* (pp. 3-30). New York: Basic Books.
- Geertz, C. (1995). *After the fact: Two countries, four decades, one anthropologist*. Cambridge: Harvard University Press.
- Greenfield, P. M., & Cocking, R. R. (1996). *Interacting with video* (Vol. II). Norwood, NJ: Ablex Publishing Corp.
- Harris, T. R., Bransford, J. D., & Brophy, S. P. (2002). Roles for the learning sciences and learning technologies in biomedical engineering education: A review of recent advances. *Annual Review of Biomedical Engineering*, 4, 29-48.
- Hatano, G., & Greeno, J. G. (1999). Commentary: Alternative perspectives on transfer and transfer studies. *International Journal of Educational Research*, 31(7), 645-654.
- Hatano, G., & Inagaki, K. (1986). Two Courses of Expertise. In H. Stevenson, H. Azuma & K. Hakuta (Eds.), *Child development and Education in Japan* (pp. 262-272). New York: Freeman.
- Hatano, G., & Osuro, Y. (2003). Commentary: Re-conceptualizing School Learning Using Insight from Expertise Research. *Educational Researcher*, 32, 26-29.
- Heller, J. L., Curtis, D. A., Jaffe, R., & Verboncoeur, C. J. (2005). *Impact of handheld graphing calculator use on student achievement in Algebra I*. Oakland, CA: Heller Research Associates
- Hutchins, E. (Ed.). (1993). *Learning to navigate*. Cambridge, UK: Cambridge University Press.
- Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational researcher*, 33(7), 14-26.
- Lareau, A., & Shultz, J. (1996). Introduction: The longest journey begins with one step. In A. Lareau & J. Shultz (Eds.), *Journeys Through Ethnography: Realistic accounts of fieldwork* (pp. 1-8). Boulder, CO: Westview Press.
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

- Lee, V. E., Smith, J. B., Perry, T. E., & Smylie, M. A. (1999). Social support, academic press, and student achievement; A view from the middle grades in Chicago, Chicago, IL: Consortium on Chicago school research. In F. M. Newman (Ed.), *Student engagement and achievement in American secondary schools*. New York: Teachers College Press.
- LIFE. (2008). *The LIFE Center: Learning in informal and formal environments*. Seattle, WA: University of Washington.
- Medina, J. (2008). *Brain Rules: 12 principles for surviving and thriving at work, home and school*. San Francisco: Pear Press.
- Mills, S., Rice, C., Berliner, D., & Rousseau, E. (1980). The correspondence between teacher questions and student answers in classroom discourse. *Journal of Experimental Education*, 48, 194-204.
- Newmann, F., Wehlage, G., & Lamborn, S. (1992). The significance and sources of student engagement. In F. Newmann (Ed.), *Student engagement and achievement in American secondary schools*. New York: Teachers College Press.
- NRC. (2000). *How people learn: Brain, mind, experience, and school*. Retrieved from <http://www.nap.edu/html/howpeople1/>.
- O'Mahony, T. K., Bransford, J. D., Vye, N. J., Richie, M., Linn, K., Dang, V., et al. (2007). Creating environments for continuous learning: Adaptive organizations & adaptive expertise. *Cognition & Instruction, In Press*.
- O'Mahony, T. K., & Gawel, D. J. (2007). Learn how you learn: An introduction to metacognitive processes for high school students who are entering college: University of Washington.
- Randle, T., Young, C., Melena, J., & Ouellette, E. (1996). *Sediment analysis and modeling of the river erosion alternative* (No. Document ETS-PN-95-9): U.S. Bureau of Reclamation Document
- Redfield, D. L., & Rousseau, E. (1981). A meta-analysis of experimental research on teacher questioning behavior. *Review of educational research*, 51(2), 237-245.
- Roschelle, J., & Kaput, J. (1996). SimCalc Mathworlds for the mathematics of change. *Communications of the ACM*, 39(8), 97-99.
- Samson, G. E., Strykowski, B., Weinstein, T., & Walberg, H. J. (1987). The effects of teacher questioning levels on student achievement: A quantitative synthesis. *Journal of Educational research*, 80(5), 290-295.
- Sawyer, K. (2006). *Cambridge handbook of the learning sciences*. New York: Cambridge University Press.
- Scardamalia, M., & Bereiter, C. (1993). Computer support for knowledge-building communities. *Journal of the Learning Sciences*, 3(3), 265-283.
- Schwartz, D. L., & Bransford, J. D. (1998). A Time for Telling. *Cognition and Instruction*, 16(4), 475-522.
- Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. In J. Mestre (Ed.), *Transfer of learning: Research and perspectives* (pp. 1-51). Greenwich, CT: Information Age Publishing.
- Sears, D. (2005). *Effects of innovation versus efficiency tasks on recall and transfer in individual; and collaborative learning contexts*. Paper presented at the Conference Name|. Retrieved Access Date|. from URL|.

- The Boeing Company. (2007). *Charting the Course: The Boeing Company Annual Report 2006*. Chicago.
- Varma, S., McCandliss, B. D., & Schwartz, D. L. (2008). Scientific and pragmatic challenges for bridging education and neuroscience. *Educational Researcher*, 37(3), 140-152.
- Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24, 123-183.
- Vye, N. J., Schwartz, D. L., Bransford, J. D., Barron, B. J., Zech, L., & Vanderbilt, C. a. T. G. a. (1999). SMART environments that support monitoring, reflection, and revision. In D. Hacker, J. Dunlosky & Graesser (Eds.), *Metacognition in educational theory and practice*. Mahwah, NJ: Erlbaum.
- Whitehead, A. N. (1929). *The aims of education*. New York: MacMillan.

## ***Appendices***

<b>Appendix i</b>	<b>Recruitment Letter</b>
<b>Appendix ii</b>	<b>Consent Form</b>
<b>Appendix iii</b>	<b>Pre-Test and Demographic Survey</b>
<b>Appendix iv</b>	<b>Elwha River and Dam Profile Sketch</b>
<b>Appendix v</b>	<b>Hands-on Data Collection</b>

## Appendix i Recruitment Letter

### UNIVERSITY OF WASHINGTON CONSENT FORM

University of Washington/Olympic Park Institute/Texas Instruments  
Elwha River Math & Science Activities

6/14/08

**Re:** University of Washington/Olympic Park Institute/Texas Instruments Elwha River Math & Science Activities

Dear Parent,

Our names are Kieran O'Mahoney and Tom Baer, doctoral students at the College of Education at the University of Washington. We are working with the Olympic Park Institute on a research study about how students learn math, science, and geography outdoors.

We are looking for high school math and science students to be part of a study, and Mr. Mowe at Crescent School gave us your name as someone who might be interested.

This study will be part of a field trip to the Olympic Park Institute attended by Mr. Mowe's students. Participation in the study is voluntary, and will not stop your child from fully participating in the field trip. Your child's grades will not be affected by whether you choose to have your child be in the study or not.

As part of the field trip, the class will graph the shape of a beach. Participation in the study means that your child may get to use a new type of calculator, and that your child's work will be collected. We will not collect student names, so the work will be anonymous. We will analyze the student work to help improve math and science education. We will give your child an Olympic Park Institute T-shirt and a University of Washington Huskies T-shirt for your child's time and inconvenience.

If you are interested in having your child considered for participation, or would like more information about the study, please review and sign the attached parent consent form. Then return one copy of the signed consent form to Mr. ~~Mowe~~. The forms give additional details about the study, to help you decide whether you wish to have your child participate.

If you would like more information about the study, please contact Mr. Mowe, or Kieran O'Mahony at [tko2@u.washington.edu](mailto:tko2@u.washington.edu). (Please note that although we keep e-mails private, we cannot ensure the confidentiality of information sent via e-mail.)

Thank you for considering participation in our study.

Sincerely,

\_\_\_\_\_  
Timothy Kieran O'Mahony, FRGS

\_\_\_\_\_  
Tom Baer, M.Ed.

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## Appendix ii Consent Form

PARENTAL CONSENT FORM: UW/OPI/TI Elwha Study

### UNIVERSITY OF WASHINGTON CONSENT FORM

University of Washington/Olympic Park Institute/Texas Instruments  
Elwha River Math & Science Activities

#### Researchers:

Stephen Kerr, Ph.D., Professor, College of Education, 206-616-4480, [stkerr@u.washington.edu](mailto:stkerr@u.washington.edu)  
Timothy Kieran O'Mahony, Doctoral Candidate, College of Education, 206-484-6014  
[tko2@u.washington.edu](mailto:tko2@u.washington.edu)  
Tom Baer, Graduate Student, College of Education, 206-947-1471,  
[baert@u.washington.edu](mailto:baert@u.washington.edu)

*Please note that we cannot ensure the confidentiality of information sent via email.*

#### Researcher's statement

We are asking your child to be in a research study. The purpose of this consent form is to give you the information you will need to help you decide whether to allow your child be in the study or not. Please read the form carefully. You may ask questions about the purpose of the research, what we would ask your child to do, the possible risks and benefits, your child's rights as a volunteer, and anything else about the research or this form that is not clear. When we have answered all your questions, you can decide if you want your child to be in the study or not. This process is called "informed consent." We will give you a copy of this form for your records.

#### PURPOSE OF THE STUDY

We would like to teach a class 2 different ways and see which way is better. The classes will be very similar, but different types of calculators will be used.

#### PROCEDURES

As part of the study, your child will participate in an outdoor education lesson related to how rocks and sands are eroded, transported, and deposited by the Elwha River. The lesson will be structured around learning how scientists monitor the river, and students will act as scientists by going to the river and taking measurement of a sediment deposit.

We will teach the lesson 2 different ways. Students will be assigned to a lesson by chance, such as through the toss of a coin. Although we want to know which way of teaching the lesson is better, students will learn about science from either lesson.

Your child will complete an anonymous questionnaire before and after taking measurements and analyzing data. He or she will also present will also present what he or she learned. Your child might be asked to participate in small group and class discussions and might be asked follow up questions.

If you choose to allow your child to participate in the study, we would like to use your child's tests and class work (such as his or her presentation of findings) as data to analyze for the study.

If you do choose to not allow your child participate in the study, then your child will participate in the same activities, but your child's tests and class work will not be used for the study.

We would also like to watch each group to see how the teaching is going. We will take notes of what each group is doing. We are more interested in how the group is doing, so we won't follow any particular person.

#### RISKS, STRESS, OR DISCOMFORT

Some people feel that providing information for research is an invasion of privacy. We have addressed concerns for your privacy in a section below.

#### BENEFITS OF THE STUDY

We hope this study will tell us how to better teach outdoor classes and to make outdoor learning more fun.

Although we hope the findings from this study benefit society, your child might not directly benefit from taking part in the study.

#### PRIVACY

Your child's test data will not be linked to your child's name. Your child will choose a secret code that only your child will know. Information about your child is anonymous. Your child will not be identified by name in any published reports of this research.

Government or university staffs sometimes review studies such as this one to make sure they are being done safely and legally. If a review of this study takes place, your child's records may be examined. The reviewers will protect your privacy. The study records will not be used to put you or your child at legal risk of harm.

OTHER INFORMATION

Taking part in this research is voluntary. Your child may stop at any time. Choosing to be in this study or to not be in this study, will not affect your child's classroom grades in any way. If you choose not to allow your child to participate, the research team will not have access to any of your child's work or test data.

If you have questions about the field trip or wish to see any of the field trip materials, please contact Mr. Mowe. (If he does not know the answer, he will refer you to one of the researchers at the top of this form.)

---

Printed name of researcher	Signature of researcher	Date
----------------------------	-------------------------	------

Participant's statement

This study has been explained to me. I volunteer to have my child take part in this research. I have had a chance to ask questions. If I have questions later about the research, I can ask one of the researchers. If I have questions about my child's rights as a research participant, I can call the Human Subjects Division at (206) 543-0098. I will receive a copy of this consent form.

---

Printed name of participant	Signature of participant	Date
-----------------------------	--------------------------	------

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## Appendix iii Pre-Test and demographic Survey

Code Name: \_\_\_\_\_

**Answer ALL questions to the best of your ability.**

1. When you finish school for the day, what do you most like to do with your time? Answer in the space provided.

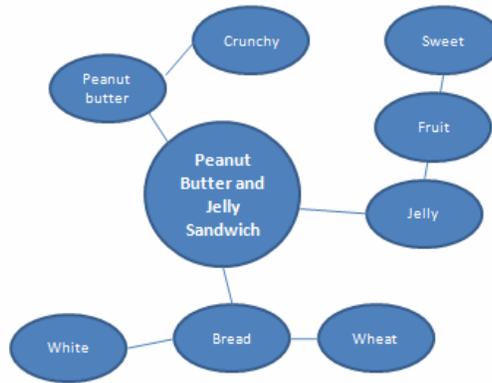
2. When you graduate from high school, what would you like to do? Answer in the space provided.

For questions 3-9, circle 1-5 to indicate your agreement or disagreement with the statements. Use this scale:

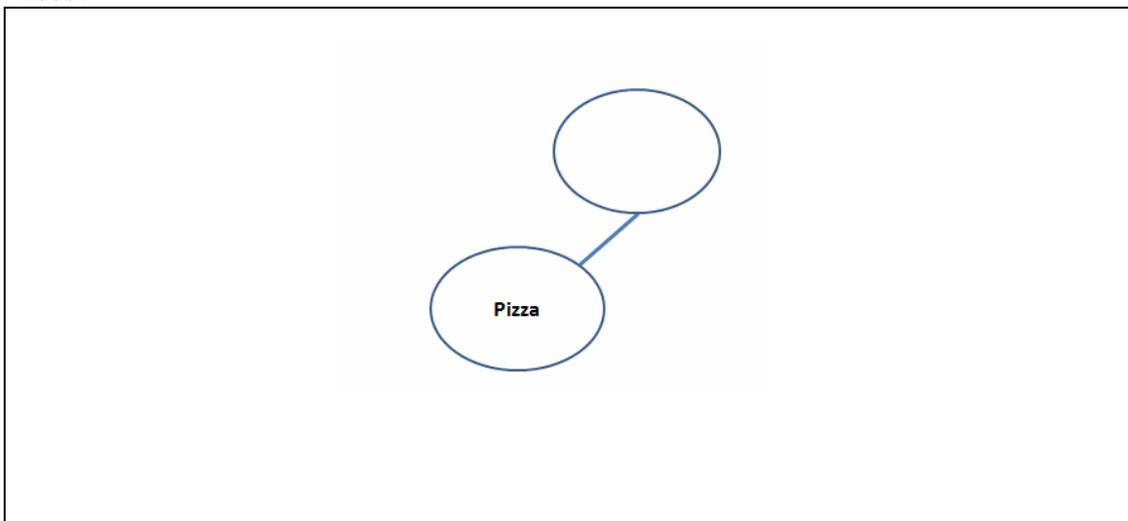
<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Neutral</b>	<b>Agree</b>	<b>Strongly Agree</b>
1	2	3	4	5

3. I am good at math.				
1	2	3	4	5
4. I am skilled at using graphing calculators.				
1	2	3	4	5
5. I like math at school.				
1	2	3	4	5
6. I like working in small groups when doing math.				
1	2	3	4	5
7. I like to do math alone.				
1	2	3	4	5
8. I would rather do more math outdoors.				
1	2	3	4	5
9. I think that removing the dams on the Elwha is a good idea.				
1	2	3	4	5

10. Here is an example of a *concept map*, which is a diagram that shows how a person's ideas are related. This example shows one person's concept of "peanut butter and jelly sandwich." The main idea is in the center, and related ideas are connected to it:

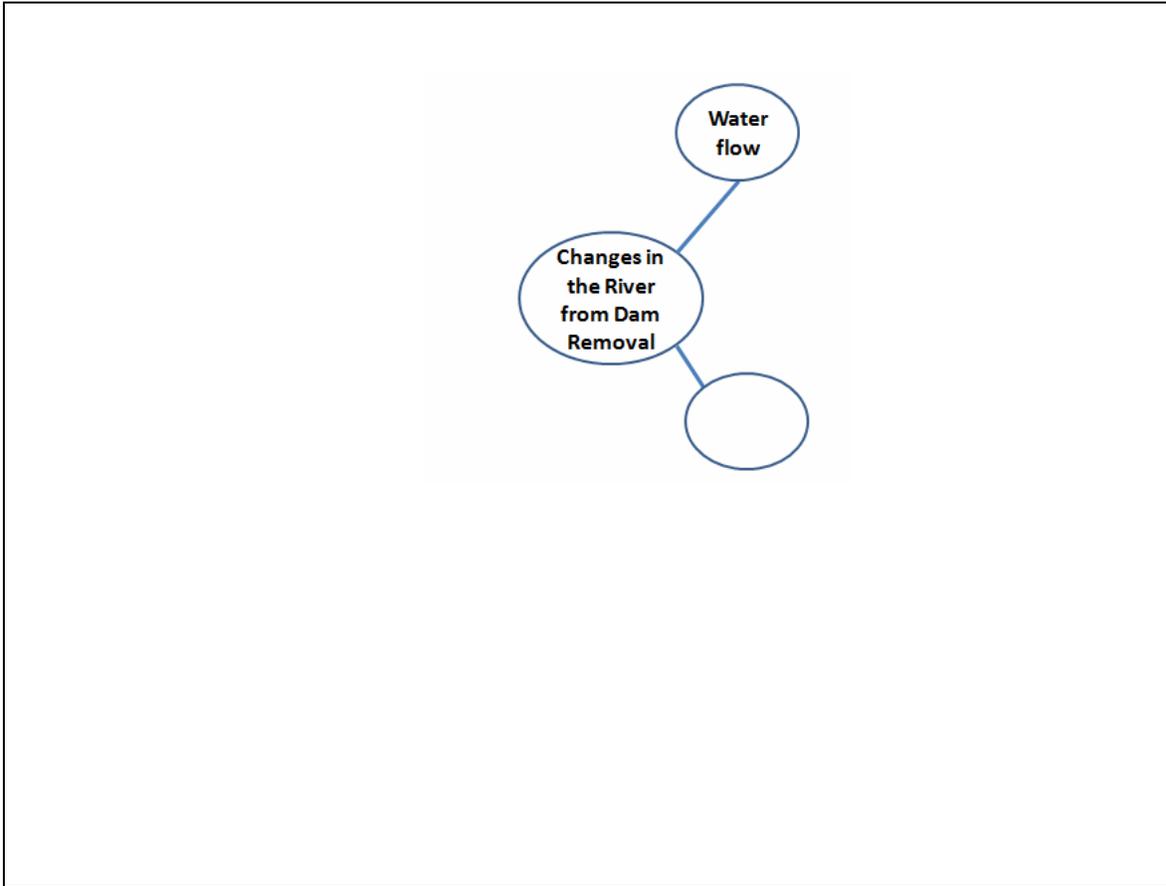


In the space provided, practice making a concept map that shows your main ideas about pizza. The map has been started for you; add as many lines and circles as you need.



11. In the space provided, create a concept map that shows the existing ideas you might have about how the Elwha River will change when the dams are removed. The map has been started for you; add as many lines and circles as you need.

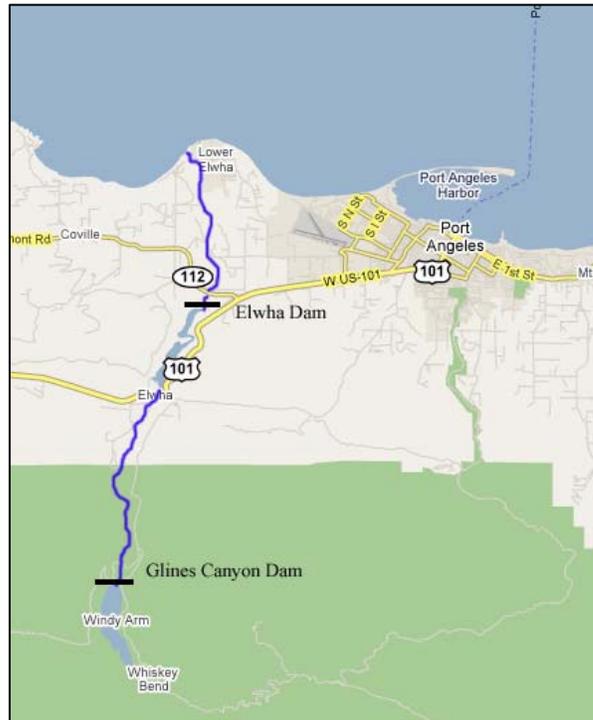
12.



*Extra blank page for drafts of concept map, if needed*

13. This map shows the lower Elwha River and the Strait of Juan de Fuca, as they exist today. Label the areas where rocks and dirt are probably being:

- a. Eroded (taken away)
- b. Transported (moved along with the water)
- c. Deposited (dropped out of the water)



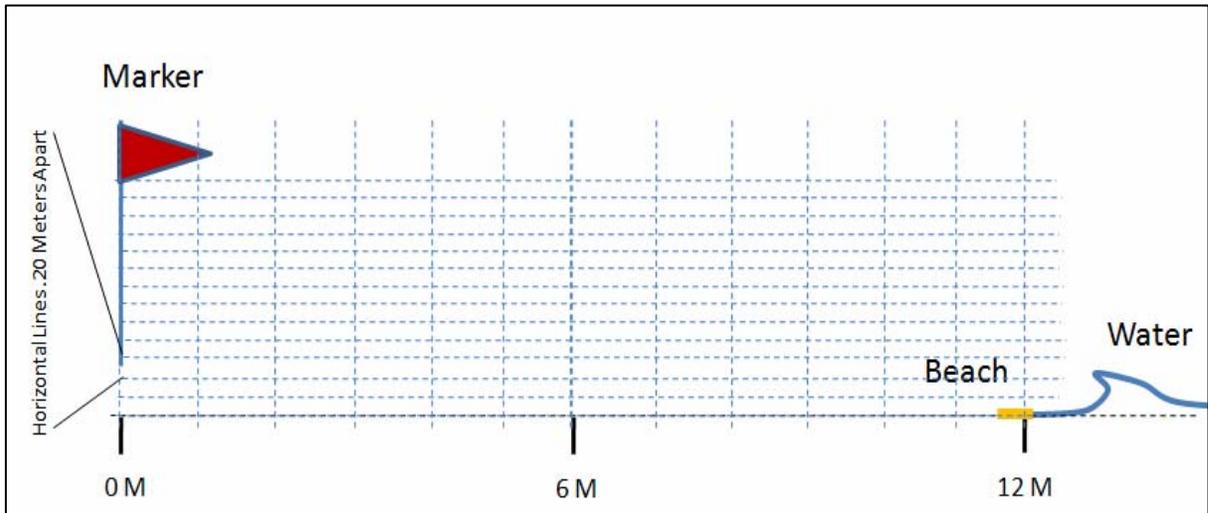
14. This table shows height measurements of a beach, taken at 1-meter intervals, from a marker

Distance from Marker (Meters)	Change in Elevation <i>between</i> Measurements (Meters)	Absolute Elevation (relative to marker)
1	+0.2	+0.2
2	+0.2	+0.4
3	+0.2	+0.6
4	+0.1	+0.7
5	0	+0.7
6	-0.2	+0.5
7	-0.4	+0.1
8	-0.1	0
9	-0.2	-0.2
10	-0.1	-0.3
11	-0.1	-0.4
12	-0.1	-0.5

on shore to the waterline, 12 meters away.

Draw a profile of

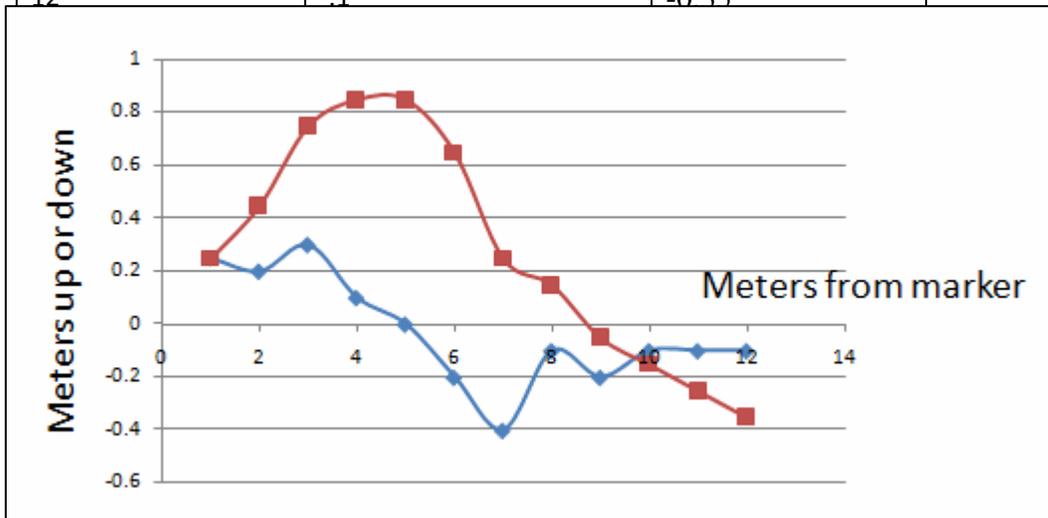
a beach that would be consistent with the data table above.  
(Note that the vertical lines are 1 meter apart, and the horizontal lines are .20 meters apart.)



15. This table shows height measurements of a beach, taken at 1-meter intervals, from a marker on shore to the waterline, 12 meters away.

Distance from Marker (Meters)	Change in Elevation <i>between</i> Measurements (Meters)	Absolute Elevation (relative to marker)
1	+0.25	+0.25
2	+0.2	+0.45
3	+0.3	+0.75
4	+0.1	+0.85
5	0	+0.85
6	-0.2	+0.65
7	-0.4	+0.25
8	-0.1	+0.15
9	-0.2	-0.05
10	-0.1	-0.15
11	-0.1	-0.25
12	-0.1	-0.35

Here is a graph of the same data.



- a. What does the blue line show and what does the red line show?

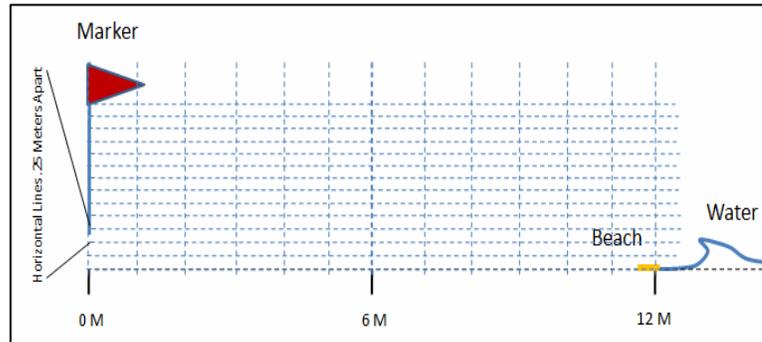
- b. At 10-12 meters from the marker, why is the blue line flat while the red line is descending?

16. This data set shows elevations, along with measurements of the average size of pebbles in the sediment.

Distance from Marker (Meters)	Change in Elevation <i>between</i> Measurements (Meters)	Absolute Elevation (relative to marker)	Average Sediment Pebble Size (Meters)
1	+.25	+0.25	.01
2	+.2	+0.45	.07
3	+.3	+0.75	.08
4	+.1	+0.85	.06
5	0	+0.85	.05
6	-.2	+0.65	.01
7	-.4	+0.25	.001
8	-.1	+0.15	.003
9	-.2	-0.05	.001
10	-.1	-0.15	.003
11	-.1	-0.25	.002
12	-.1	-0.35	.001

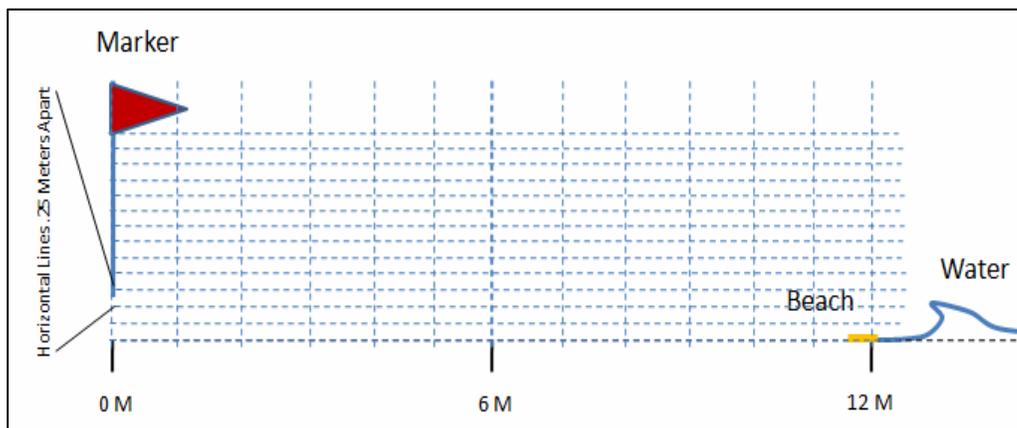
Describe, in your own words, the relationship between the sediment pebble size and the beach shape:

17. a. What would a beach profile look like if sand and gravel were being eroded (taken away) by waves? For your answer, draw such a profile:



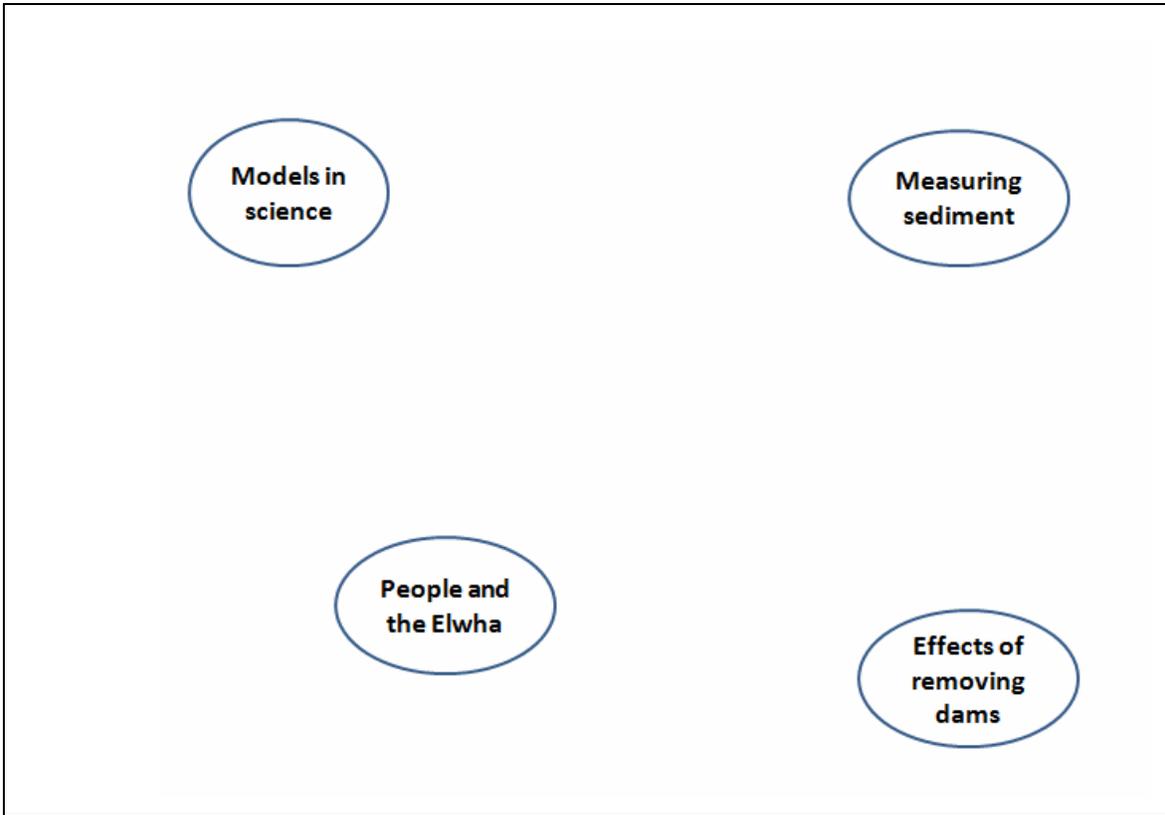
- b. In your own words, give a reason why the beach would be shaped this way, if sand and gravel were being eroded away by waves.

18. a. What would a beach profile look like if sand and gravel were being deposited (added to the beach) by waves? For your answer, draw such profile:



- b. In your own words, give a reason why the beach would be shaped this way, if sand and gravel were being added by waves.

19. In the space provided, create a concept map that shows how these concepts could be related. You can either use the arrangement here, or start over in the blank space provided on the next page.



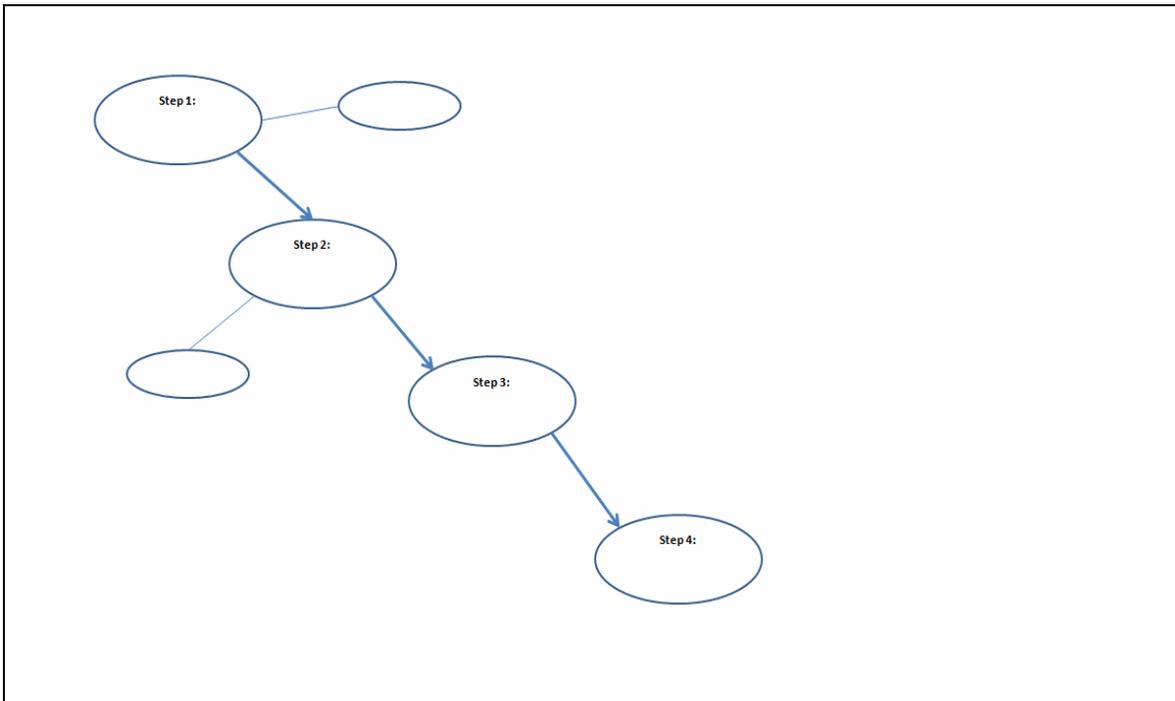
*Extra blank page for drafts of concept map, if needed*

20. Imagine that you are investigating this hypothesis:

**"Beach gravel tends to include larger pebbles as you move farther from the water."**

Create a concept map that shows the main steps you would take to gather data, analyze it, and present your findings. The map has been started for you; add as many circles and lines as you need.

Also, you do not need to use all steps if you wish to present in fewer than four steps.



*Extra blank page for drafts of concept map, if needed*

21. Describe in your own words why it could happen that larger pebbles are farther from the shoreline. It seems odd, but it could happen. Come up with your best theory as to why that might occur. in the following box labeled: Current Best Theory, describe your ideas.

*Current Best Theory:*

22. As a young scientist you make observations, collect data and discuss your findings with your fellow young scientists. Now give some serious thought as to what will happen to the following stakeholders when the dams are taken down. Write one sentence for each of the stakeholders below as you see it. What will happen to (the):

a. town where you live (or nearest to where you live).

b. City of Port Angeles (if you do not live in Port Angeles).

c. Lower Elwha Klallam people.

d. shoreline in the Strait of Juan de Fuca.



23. Write in your own words two short sentences for each item below:

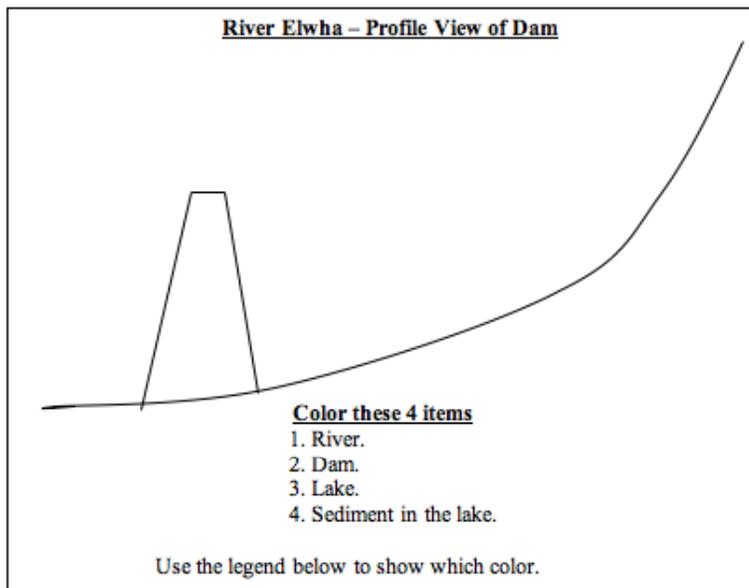
a. What was the best part of today's activities?

b. What surprised you the most?

c. What do you still not understand and would like to bring up in a class discussion?

## Appendix iv Elwha River/dam Profile Sketch (Crayon)

<b><u>Secret Code</u></b>	
1. Bus to	<input type="checkbox"/> Beach
	<input type="checkbox"/> Lake
2. Day	<input type="checkbox"/> 1
	<input type="checkbox"/> 2
3. Time	<input type="checkbox"/> AM
	<input type="checkbox"/> PM



<b><u>Legend</u></b>	
River	= <input type="checkbox"/> Color
Dam	= <input type="checkbox"/> Color
Lake	= <input type="checkbox"/> Color
Silt/sediment	= <input type="checkbox"/> Color

## Appendix v Hands-on Data Collection



Elwha Dam removal Study: Students on beach transect collecting data, #1



Elwha Dam removal Study: Students on beach transect collecting data, #2



Elwha Dam removal Study: Students on beach transect collecting data, #3



Elwha Dam removal Study: Students using advanced graphing calculator



Elwha Dam removal Study: In front of the dam, #1



Elwha Dam removal Study: In front of the dam, #2



Elwha Dam removal Study: Glines Canyon dam, #1



Elwha Dam removal Study: Glines Canyon dam, #2