Transforming Museums and Colleges into an Effective Earth Science Partnership: Creating Student Explorations of Museum Exhibits for Undergraduate Education

PI: Kent Kirkby, University of Minnesota
Co-PI: Paul Morin, University of Minnesota

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Although science museums are a remarkable resource for secondary earth science education, at the undergraduate level they remain woefully underutilized. This proposal seeks to remedy this by creating a partnership between the Science Museum of Minnesota and the University of Minnesota to integrate museum resources with regional undergraduate programs. Two laboratory modules, built about interactive museum exhibits, will be constructed, assessed and revised. Students will be able to complete these modules independently without any support from instructors or museum staff. This ‘plug and play’ design will allow the modules to be incorporated into existing curriculums with minimal effort. One module will explore how animals’ skeletal design reflects their lifestyle and evolutionary lineage, while the other will utilize a new visualization technology. ‘Rain Table’ technology allows students to interactively simulate water flow across any part of the Earth’s surface. This allows them to contrast flow across fluvial-sculpted landscapes with flow in urban settings or across landscapes modified by non-fluvial processes, such as glacial areas or karst terrain. Each of these modules will also target common misconceptions and explicitly discuss the basis, design and limitations of the relevant scientific models.

The intellectual merit of the proposed activity is that it can transform the way museums and undergraduate programs collaborate, creating a potent educational partnership to improve and expand traditional earth science curriculums. Assessment activities for both modules will move beyond their educational efficacy to document students’ prior knowledge, identify misconceptions and develop effective methods to correct misconceptions. In the case of ‘Rain Table’ assessment will also determine how the visualization system itself alters students’ comprehension of water flow compared to traditional maps. Although focused on earth science, these educational research outcomes have relevance to all areas of science, technology, engineering and math (STEM) education.

Within the Minneapolis-St. Paul area, there are a score of undergraduate institutions that can immediately adopt the proposed modules, but the broader impacts of the proposed project is that its concept, practices and products can be adapted across a broad spectrum of disciplines in any urban area hosting a science museum. Moreover, as the modules are designed for the introductory undergraduate level, high school programs, home-schooled students, educator workshops and the general public can also utilize them and the Science Museum of Minnesota already has infrastructure in place to disseminate the modules to this broader community. Finally, for both merit and impact, the proposal introduces a new cutting-edge visualization technology to educational programs. Although the technology behind the ‘Rain Table’ holds tremendous potential as a way for students to display and manipulate immense data sets, as with any new technology, its educational potential cannot be fully realized until methods exist to integrate it into existing educational programs. These methods will be produced, tested and disseminated by this proposal.

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Introduction

Since construction of the original *Mouseion* at the Library of Alexandra in 295 BC, museums and universities have shared a common goal of education. Museums have developed outstanding educational partnerships with elementary and secondary school systems, but far fewer ties exist between museums and undergraduate institutions. A number of factors play a role in this, but chief among them is that integration of museum displays with college curriculums requires a tremendous effort. Museum displays geared toward general education seldom explicitly convey the content necessary to integrate them into undergraduate instruction. Consequently, the burden of integrating museum displays into college curriculum falls primarily on individual instructors. Relatively few have the time and energy to take on this translation, so museums remain an underutilized undergraduate education resource.

One viable way to correct this situation is the creation of educational materials that allow students to explore the deeper content of museum exhibits on their own by providing background and guidance to enable students to access this deeper content in self-guided explorations. To test this concept, this proposal requests funding for the creation of two undergraduate earth science laboratory modules based on exhibits at the Science Museum of Minnesota. During development stages, these modules will be used by students in the University of Minnesota's introductory geology program (annual enrollment >1800), but the completed products will be available to all regional undergraduate programs, as well as high school programs and the general public. As interactive learning is more effective than lecture or text-based instruction, modules will be constructed as stand-alone laboratory exercises with all necessary content and activities included. Their 'plug and play' design will allow the modules to be incorporated into existing course structures with minimal effort.

The proposal has the potential to transform the way museums and undergraduate institutions interact, as the modules' concept is easily exported to other museums and other disciplines. Both members of this partnership benefit equally. Participating colleges benefit from being able to expand the breadth of their curriculum and laboratory activities at no cost and minimal effort while gaining access to displays and exhibits that they could not purchase, store or maintain on their own. Museums benefit by access to university expertise in earth science and curriculum development, having other visitors see museum exhibits being used in real scientific explorations, and increasing the museum's profile among a demographic group largely missing from their current audience. At present, college-age visitors account for less than 5% of the Science Museum of Minnesota's adult visitors (less than 3% of the total audience) and even the 70-79 years old crowd swamps the college-age demographic. In fact, the sole age group with lower attendance numbers is visitors over 80 years of age. Only against the decreased mobility and increased mortality of this age range do college-age visitors finally gain a numerical superiority.

As the modules' success depends on their impact on museum and undergraduate programs, the project's evaluation will assess their efficiency from the perspective of both partner institutions. Evaluation staff from the Science Museum of Minnesota and the University of Minnesota's Center for Teaching and Learning will help assess the modules' impact on museum activities and undergraduate curriculum. Assessment parameters will identify logistical problems and measure changes in student comprehension. An educational research component will also document students' prior knowledge, identify their misconceptions, and try to comprehend how module activities and the visualization technology affect students' perception of the world they live in. This educational research has potential applications across all areas of science, technology, engineering and math (STEM) education.

Results from Prior NSF/Federal Support - PI

For the past five years, the PI has undertaken a major revision of the Introductory Geology Program at the University of Minnesota. Although this renovation was funded by the Department of Education's Fund to Improve Post-Secondary Education (FIPSE), rather than NSF, it is relevant here as the PI has significant experience designing and creating laboratory exercises that resonate with majors and non-majors alike. In accordance with educational studies of how students learn (Donovan & Bransford, 2005), these laboratory exercises specifically elicit and build on students' prior knowledge to improve their understanding of earth processes to give them a greater appreciation of the many interactions between earth processes and human society (McConnell et al., 2005). The revision's goal was to transform the course into a national model of an effective 'concluding' earth science course, one that explicitly provides students with the knowledge they need to become more informed citizens in a global community that is greatly affected by the natural world. This goal was accomplished by the integration of three essential approaches: 1) the use of regional case studies to present earth science concepts in a context that is already familiar to students or easily visited; 2) an ambitious, but highly successful, computer visualization effort to facilitate students' use, and increase their understanding of, earth processes and geological data; and 3) woven throughout the project, a comprehensive quantitative evaluation of students' prior knowledge, misconceptions and changes in student knowledge. Revision of the program not only resulted in significant improvements in student performance and students' comprehension of earth processes, but also higher evaluations from students on all course components. In addition, the project's educational research component created an extensive database of students' prior knowledge and misconceptions concerning earth processes, a crucial resource for improving course instruction. New pedagogical approaches were also developed that built on students' prior knowledge to improve their comprehension of earth processes and overcome many deeply held misconceptions.

Results from Prior NSF/Federal Support – co-PI

"The Antarctic Geospatial Information Center: Collecting, Creating, Delivering and Archiving for the Community" (ANT 0753663 $1,369,613 - 2007) establishes a resource to provide geospatial support for Antarctic science and operations activities. AGIC is now used by researchers in Biology, Glaciology, and Geology. All of it products are available for use by the formal and informal education communities.

"Water Planet" (DRL 0515599 $2,998,104 - 2005) is a 5-10,000 square foot traveling exhibition which opened at the American Museum of Natural History in November 2007 and will open at the Science Museum of Minnesota Fall of 2008. It uses scientific visualization to explain how water shapes our planet's surface. One to three million visitors are expected to explore this exhibit each year over the next 10 years. Subjects such as surface water/ground water interaction, how water makes its way to the sea and the influence of humans on the water cycle are investigated.

"Collaborative Research: CoreWall - Integrated Environment for Interpretation of Geoscientific Data from Sediment and Crystalline Cores" (OCE 0602121, $280,542 - 2006) is currently developing software for the interpretation of all types of geologic cores. This software is now being used worldwide by the Antarctic Drilling Program (ANDRILL), the National Lacustrine Core Repository (LacCore) and investigators from the Integrated Ocean Drilling Program (IODP) among others.

The proposal "Collaborative Research The GeoWall – Stereo Visualization for the Earth Sciences" (EAR 0219246 $193,280 - 2005) developed, deployed and wrote software that led to over 500 stereo display systems being used around the country for research and education in the geosciences, education, biology, astronomy, and other sciences. Morin, collaborating with Peter van Keken at Michigan and Jason Leigh and Andy Johnson at the University of Illinois Chicago, dropped the cost of a geoscience stereo projection system, such as an ImmersaDesk, from over $400,000 per system to less than $10,000.

Current Status of Museum and Undergraduate Education Collaboration
Natural history museums typically offer a rich variety of educational programs and activities for elementary and middle school students. These are typically targeted to individual grade levels and are often tied to specific state and national science standards. At the high school level, museums offer a more limited suite of programs, but most have outreach programs, tours and some in-house seminars geared specifically towards high school audiences. Many also offer educator workshops for elementary and secondary science educators. However, at the undergraduate level, museum educational opportunities practically disappear. In an informal survey of museum education websites, all programs end at the high school level.

Undergraduate classes can take advantage of educational programs offered to the general public, such as behind the scene tours, lecture programs and one-hour or one-day classes, but there are few programs specifically tailored to undergraduate education. The American Museum of Natural History (AMNH) in New York stands out as a notable exception to this trend. It offers a suite of on-line courses that can be taken for graduate credit. AMNH staff also help convene a NSF CCLI-sponsored 'On the Cutting Edge' workshop explores teaching earth science to urban students in urban settings. However, these offerings are on-line, distance learning resources that make no use of the museum's in-house exhibits. Although most museums have additional web resources to supplement their exhibits, these typically consist of on-line presentations that are not integrated with the hall exhibits. Consequently, all of the opportunities available to undergraduate students utilize an on-line or leader-led educational approach. The proposed modules differ from these activities in that the modules will allow students to interactively investigate displays and exhibits as self-directed explorations. This type of exploration and interaction is precisely the goal that museum exhibits are designed to encourage. The proposal's innovation is simply to provide the necessary information and activities to facilitate this type of exploration at the undergraduate level.

Relevance to NSF Initiatives:
What is the intellectual merit of the proposed activity?
The goal of this proposal is to engage museums and undergraduate institutions in educational partnerships that integrate museum resources with undergraduate earth science curriculums. This program would serve as a model for similar partnerships in other regions and other disciplines, potentially transforming the way museums and universities collaborate to bring a largely underutilized resource into prominent use.

Modules will require students to gain and practice skills of careful observation, critical analysis, and testing of hypotheses. These skills are central to any science, but dinosaurs and the 'Rain Table' provide unique perspectives for their practice and engender an enthusiasm to their study that few traditional earth science topics can match. Module activities will place a greater emphasis on synthesis, analysis, application and evaluation, than on simple knowledge and comprehension, as these higher order skills are crucial to improving science literacy (McConnell et al., 2003). The proposal's research into students' understanding of the modules' core concepts will significantly help educators teach more effectively. Identifying existing misconceptions is a crucial first step in overcoming barriers to learning. By defining, documenting and using students' prior knowledge, educators can help students build a better understanding of their world (Donovan and Bransford, 2005).

What are the broader impacts of the proposed activity?
While this initial proposal focuses primarily on a partnership between the Science Museum of Minnesota and the University of Minnesota, the project's concept is exportable to any urban setting with museums and undergraduate institutions. As this includes nearly every major population center in the country, the modules have considerable value as models for similar programs elsewhere. The modules' approach and design also transcend discipline boundaries. The animal design module's evolutionary focus applies as much to biology as earth science, while stream flow is a crucial component of geography, environmental science, landscape architecture, and urban planning programs. The Science Museum of Minnesota already

has the reputation and infrastructure in place to promote the concept to other museums while the project team can take the lead in disseminating the concept through the academic community.

As the modules will be created for introductory undergraduate courses, area high school teachers could also use them as valuable additions to required class activities or as extra-credit options to broaden the range of covered material. The Science Museum of Minnesota has infrastructure in place for secondary education outreach so a mechanism already exists to disseminate modules to area schools. Although secondary education is not a specific goal of this proposal and no funds are requested to support it, the ease with which the modules can be disseminated and incorporated into secondary programs endows the modules with a significant secondary impact. In a similar manner, making the modules available through the Science Museum of Minnesota's web site allows the modules' use in informal science education, including home schooling, elementary and secondary educator training, as well as museum visitors. No funding is required to support this additional outreach as the infrastructure already exists; however, these uses greatly expand the modules' potential impact to a much broader community.

Finally, although the proposal is not specifically geared towards broadening the participation of underrepresented groups in science exploration, the interactive, visual nature of these non-traditional laboratory modules does seem to resonate particularly well with minority and female students. Minority students disproportionately volunteered to participate in the extra-credit testing of the proto-type animal design module. Many of them took the initiative to mention how much fun they had and ask whether the class could incorporate more opportunities similar to the prototype module. For the two semesters, only 47% and 40% of the classes' non-minority enrollment completed the extra credit modules but 65% and 49% of the minority students chose to participate. These increases occurred across all grade levels so they were not a reflection of in-class performance. While the increases are significant in their own right, it is important to remember that museum experience is typically more limited in these demographic groups. For many of these students, it was the first time they had visited the museum; for most, it was the first time as an adult. In the 2000 Census, the Minneapolis-St. Paul Metropolitan area had a minority population of 15.3%, but minorities only comprise 9% of the Science Museum of Minnesota's typical audience (Cohn et al., 2008), so the increased participation of minority students with the modules reverses this broader trend. In a similar manner, participation by gender also shows that the modules resonate well with female students. Over the prototype's two semesters of testing, 52% and 44% of female students participated, compared to only 47% and 39% respectively of male students. These gains bode well for the modules' appeal across gender and ethnic divisions.

Planned Modules:
The proposed initiative will create two modules that use museum resources in very different ways. 'Dinosaur Designs' will examine how animals' designs reflect their lifestyle and evolutionary history. 'Rain Table' will use a new visualization technology to allow students to interactively explore stream flow across the Earth's surface.

These modules also serve as two distinct models for similar interactions between colleges and museums in other cities. The Dinosaur Design module is an example of an integration in which a museum plays a passive role. In this model, the undergraduate institution builds instructional materials around museum exhibits that already exist and are part of the museum's permanent collection. In contrast, the Rain Table module presents a model of active museum participation in which the partner museum creates displays specifically designed for use by undergraduate classes.

Module Design:
The modules will be designed to be stand-alone, self-contained laboratory exercises. This 'plug and play' approach will allow instructors to incorporate the modules into their existing curriculums with minimal effort. Modules can be integrated into existing curriculums as required course components or as extra credit options that broaden the course content. Each module will consist of four elements:

- Introduction components, which student complete before visiting the museum. This Introduction will provide students with all the background information and concepts that students will use to complete the module's on-site activities so instructors will not have to devote class time or resources on module preparation.
- Pre-lab components, which are student self-assessment tools that target the modules' core concepts. These will allow students to gauge whether they adequately understand these concepts before visiting the museum. This saves time and minimizes frustration for participating students.
- On-site components, which are the self-guided student explorations that take place at the Science Museum of Minnesota.
- Post-lab evaluation components, which measure students' comprehension of the material and their ability to apply the module's core concepts to unfamiliar examples. The ability to apply new concepts to other situations is one of the crucial measures of student comprehension and learning.

'**Dinosaur Designs' Module:**

> *You can know the name of a bird in all the languages of the world, but when you're finished, you'll know absolutely nothing whatever about the bird... So let's look at the bird and see what it's doing -- that's what counts. I learned very early the difference between knowing the name of something and knowing something.*
>
> *- Richard Feynman*

Dinosaurs have a remarkable power to engage students, to instill a sense of wonder about the Earth and to drive home the concept that our world is constantly changing. Because of their universal appeal, dinosaurs are an excellent medium with which to convey many earth science concepts such as organic evolution, plate tectonics, integration of Earth systems, and even the social nature of scientific investigation. All too often though, dinosaurs are presented in the literature as geo-trivia, a list of names, terms and features with little regard to the framework within which they existed or the wealth of information encoded within their design. Relatively few earth science instructors are comfortable enough with dinosaur studies or animal design to guide their students through this deeper realm of information. Consequently, a remarkable pedagogical resource is often underutilized, one whose appeal bridges all demographic groups. In addition, because of space limitations, most museum displays only pay limited heed to present and past controversies in dinosaur interpretations. Yet these controversies are one of the best ways to illustrate the social nature of scientific investigation and how interpretations reflect society's evolving world view as well as new information.

'Dinosaur Designs', one of the proposed modules, will try to correct this. Built about a crucial theme of this often overlooked information, namely how the design of an animal reflects its lifestyle and evolutionary lineage, the module will also relate trends in dinosaur designs to important developments in the evolution of our present world's ecosystem. The Mesozoic was the time when much of our present world's physical and ecological framework developed so dinosaurs are a useful way to give students a different perspective to understand the world they live in. Although the theme falls outside the normal range of traditional earth science courses, the choice was deliberately made to allow instructors to expand their curriculum without investing a great deal of time and effort. Having animal design as the module's central theme also means that it will be of interest to biology programs as well as earth science courses.

He paced like a Franciscan Preacher up and down behind a long show-case … in his hand a huge hyena's skull. He suddenly dashed down the steps… rushed then on me, pointing the hyena full in my face, (shouting) "What rules the world?" "Haven't an idea", I said. "The stomach, sir," he cried (again mounting his rostrum), "rules the world. The great ones eat the less, and the less the lesser still."
- description of a William Buckland lecture by Sir Henry Acland

William Buckland described the first dinosaur known to European and American science. Although oversimplified, Buckland's pronouncement of the driving force behind life remains surprisingly accurate. To a remarkable extent, an animal's design reflects modifications for acquiring and processing food. These range from the streamlined, lightweight frame of theropod dinosaurs to innovations that gave herbivorous dinosaurs larger guts and highly modified skulls to more effectively process the plants they lived on. The few features not ruled by the stomach can be understood in terms of defense, sex and social interactions. Relatively few students have encountered the idea of considering why animals are designed the way they are, so the question can spark their interest and provide a different perspective on evolution. Dinosaurs can provide a non-confrontational way to expose students to the concept of evolution and the evidence behind it. Without exception, student response to a prototype version of the dinosaur design module has been exceptionally favorable.

Specific topics that will be covered in the 'Dinosaur Designs' module include:

- How acquisition of an erect stance and bipedal gait propelled early dinosaurs towards a 150-million domination of terrestrial ecosystems.
- How limb designs and proportions reflect the relative speed of animals and in quadruped dinosaurs, evidence of bipedal ancestry.
- How the design of dinosaur hands and feet reflect the relative importance of manipulation or weight-bearing in different dinosaur groups.
- Modifications of hips, vertebra and ribs that allowed herbivorous dinosaurs to gain a much larger gut in order to process relatively low nutritional land plants.
- How differences in how tails are designed can be interpreted in terms of competing purposes such as balance, running, heat regulation and defense.
- How dinosaur skulls were modified towards different styles of predation or more effective ways to process plants and stay alive in a predator-rich world.
- How the rise of angiosperms is reflected in the design of herbivorous dinosaur lines over time.
- In addition to the non-avian dinosaurs, pterosaurs and birds will be included to show how two distinctly different lines independently evolved flight and how their body designs reflect differences in their approach to flight as well as their evolutionary heritages.
- The role of heat-regulation, gender differences, sexual competition, and social interactions in other features of dinosaur designs.

At first glance, mounted dinosaur skeletons appear to fall at the opposite end of a spectrum from other highly interactive visitor-driven museum displays. Visitors passively observe the skeletons, moving among them to read placard information on name, age and location. However, these displays can be used in a far more dynamic way. As students move around a skeleton to view it from different angles, crouch low to see the design of a hip, the fusion of neck vertebrae beneath a ceratopian frill, or struggle to glimpse the design of a skull twenty feet above them, they are engaged in a different type of interactivity; one that is as engaging as pushing buttons or moving a mouse. They end up seeing a skeleton and understanding it in ways more passive museum visitors cannot comprehend.

Figure 1. Stegosaurus mount at the Science Museum of Minnesota's Paleontology Hall.

A stegosaurus mount at the Science Museum of Minnesota provides an example of this different approach to exploring animal designs (Figure 1). Placards bear the traditional museum display data such as name, age, and location. A small side display gives some additional information on the possible role of the stegosaurus' plates in thermal regulation. The average museum visitor spends less than two minutes at the stegosaurus skeleton before moving on to other exhibits never realizing the tremendous depth of information encoded in the animal's design before them. In contrast, students completing the module will have to move around the skeleton to view it from different angles to try to interpret why this skeleton's details differ from those of the other displayed dinosaur skeletons.

Buckland's 'rule of the stomach' provides one approach to explore this deeper data. Stegosaurs were among the early dinosaur groups to exploit an herbivorous lifestyle and all land plants are difficult to digest, especially the relatively low nutrition gymnosperms and ferns that dominated the Jurassic world. One of the simplest ways animals overcame this problem was to acquire a large gut. This provided space to hold plant material in the digestive tract longer in order to gain as much of its nutrition as possible. Stegosaurus back vertebrae became vertically extended well above the spinal column and its ribs arched up and out from these extensions to provide more space for the gut (Figure 2). Even the animal's hip was reconfigured to allow more space for the digestive tract. Larger size has its costs though so stegosaurs adopted a quadruped stance. This resulted in considerable modifications to the scapula and fore limb to accommodate a quadruped gait, although traces of the animal's bipedal ancestors remain in its limb proportions. Large size also limits an animal's ability to move quickly and to shed heat. The tail vertebrae evolved to allow tail spikes to be used in defense and bony plates developed to help shed heat. By the end, although the display remains the same, students using the module will come away with a far greater understanding of how the animal's design reflects its lifestyle and evolutionary lineage than is currently possible.

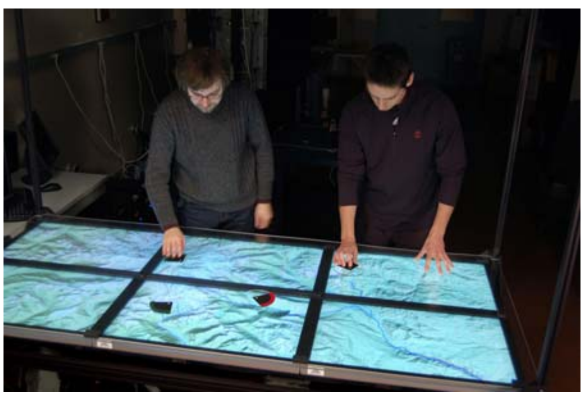
Figure 2. – Side view of stegosaurus mount at Science Museum of Minnesota. Note how the extended vertical processes on the back vertebrae and the arched ribs created a much larger area for the animal's digestive tract.

'Rain Table' Module:

> *Moving water…has a fascinating vitality. It has power and grace and associations. It has a thousand colors and a thousand shapes, yet it follows laws so definite that the tiniest streamlet is an exact replica of a great river."* *- Roderick Haig-Brown*

At first glance, water flow seems like such a deceptively simple concept. Water flows downhill. What could be easier to understand? However, water movement across the Earth's surface is among the most misunderstood concepts in earth science. A host of misconceptions abounds concerning water flow, from rivers always flowing south, curving due to the Earth's spin, or rivers' immutable nature. The only consistent aspect is that students and the general public underestimate the complexity and continuity of water flow. The movement of water across the Earth is the integrating connection between its physical and biological systems. Combine these misconceptions with the realization that water use issues will be among the most crucial and complex social and political issues facing the next generation and it is difficult to overstate the importance of being able to teach a strong understanding of natural water flow.

Without a doubt, the best way to understand water flow is to watch the movement of water across the Earth's surface. However, this is not possible in most lab settings and physical models cannot capture the intricacies of unrestricted stream flow across large areas. In addition, although many aspects of stream flow are independent of scale, students can still struggle with the conceptual leap from physical model to the real world, failing to grasp the connections praised by Haig-Brown.



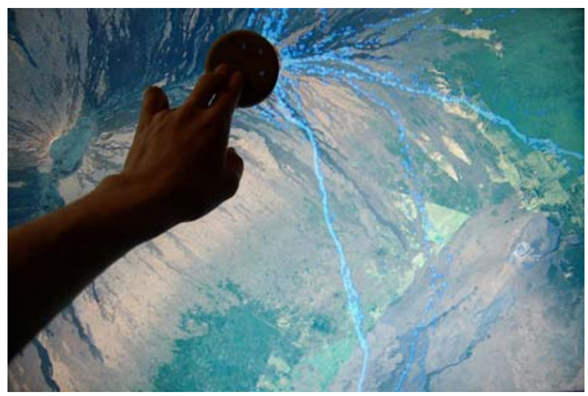


Figure 3 – Prototype version of 'Rain Table' system. Display consists of multiple panels integrated to show a detailed digital elevation surface. Moveable discs determine where rain will fall to flow over earth's surface.

To overcome these obstacles, the project team initiated a partnership with the Electronic Visualization Laboratory of the University of Illinois at Chicago, the Science Museum of Minnesota, and the National Center for Earth-Surface Dynamics to create a new visualization technology that will allow students to follow water flow across any part of the Earth's surface. This 'Rain Table' visualization system allows students to interactively explore stream flow across any part of the Earth's surface (Figure 3). Digital elevation maps are loaded into the display and students or museum visitors can use up to six 'pucks' to determine where rain, in the form of small blue dots, should fall. This virtual 'rainwater' then flows across the visualized surface following the intricacies of the digital elevation data to mimic real-life stream flow. Multiple rain points allow students to collaboratively explore and develop concepts of water flow, drainage basins, sediment transport, groundwater recharge, and river management schemes such as dam construction or dam removal. Using the 'Rain Table' is as simple as moving a computer mouse and even at the pre-school age there is no learning curve involved in its use. This ease of use will greatly increase its utility as a teaching tool (Libarkin and Brick, 2002).

Students and museum visitors will start by exploring stream flow in their hometown area before expanding their exploration to other regions. As shown by earlier work by the project team, this hometown start should make it easier for users to bridge the conceptual leap between visualization and real world. A prototype of the 'Rain Table' technology has already been developed by the partnership, proving its feasibility. Currently the Science Museum of Minnesota is developing a more robust 'Rain Table' version that can survive the high use demands of an interactive museum display. If reviewers have difficulty grasping a mental image of the 'Rain Table' in action, a short video clip of the prototype system in use is posted at:

http://www.youtube.com/watch?v=rc5I774Mnh4

This URL contains no additional material on the 'Rain Table'. It is merely a useful visual image as it can be difficult to visualize a new educational technology from a written description.

The educational potential of the 'Rain Table' is staggering and intrigues every earth science instructor who has seen it in action. However, there are significant logistical barriers to placing 'Rain Table' systems in undergraduate classrooms. At a cost of roughly $100K, 'Rain Table' exceeds the budget of many smaller programs. Larger programs that can afford its purchase price are still faced with the dilemma of storing a large display that may only be used a few weeks out of the year and requires significant technical expertise for its support. Partnering with a museum is a simple cost-effective way to resolve these difficulties. Museums have the expertise, ability and need to maintain the systems year-round as part of their permanent displays. Collaborating with a museum allows undergraduate programs to use these displays for their classes while the museum ends up with a display that not only intrigues its main target audience, but draws in a demographic seldom seen in their halls.

One of the most common misconceptions concerning stream flow is that it solely consists of flowing water. Remarkably few students are consciously aware of the amount of sediment transport that takes place within streams. To counteract this, the 'Rain Table' module will also include an exploration based about on the Science Museum of Minnesota's interactive 'Dam Removal' exhibit. This consists of a small sediment transport flume with Plexiglas walls that provides students with a side view of sediment transport by running water. Students can add a dam to interrupt the stream flow and create a dammed lake. As they do this, the sediment transported by the stream immediately begins to fill in the lake. When students remove the dam, stream flow quickly cuts down through the accumulated sediment to restore the stream's origin profile. Visually, the exhibit is striking and its interactive nature helps students to understand and retain the idea of dynamic sediment transport by river systems. In one exhibit, students can explore sediment erosion, transport and deposition, understand dams more clearly, recognize the problems of poorly conceived dam sites, and gain an appreciation of how stream flow can sculpt the Earth's surface. As a physical model, it is an ideal choice to complement the module's 'Rain Table' visualization system.

Watersheds are another concept very poorly understood by many students, especially urban students whose experience with water flow is primarily limited to sewers, culverts, ditches and the occasional stretch of river passing between heavily developed banks (Shepardson et al., 2005; Shepardson et al., 2007). Even the fact that streams actively shape the Earth's surface rather than passively flow across it is a concept that escaped naturalists until the late 1800's exploration of the southwest United States and still remains poorly understood by many students. Again, urban students have the most trouble with this concept as they tend to be less familiar with the flow of water across large areas. Both of these concepts become immediately apparent while exploring the flow of water across the Earth's surface in the 'Rain Table' making it an effective mechanism to convey these concepts to the region's predominantly urban student population.

Specific topics to the 'Rain Table' module will introduce include:

- How stream flow relates to precipitation rates and patterns.
- The self-organizing nature of water flow as smaller tributaries join to form larger streams.
- How stream flow sculpts the Earth's surface and the ties between topography and stream patterns.
- What the concept of a watershed is and how watersheds play a role in understanding how rainfall or human activities in one area can cause flooding or pollution concerns for downstream areas.
- Sediment transport by streams and the concept of how stream erosion and deposition ties to stream velocity.
- The dynamic nature of stream flow and stream-related processes.
- Dam construction, impacts and removal.

Pilot Prototype Test of Concept

To test the feasibility of the proposed module concept, a prototype version of the 'Dinosaur Designs' module was offered as an extra credit option during the 2007-2008 academic year. It should be emphasized that this prototype was only a series of questions, not a fully developed module as it lacked all of the supporting material and evaluation components. Its sole purpose was to test whether the idea of having students travel to the Science Museum of Minnesota to complete independent explorations was even viable. No light-rail or direct bus lines run from the University of Minnesota to the Science Museum of Minnesota and parking at both institutions is limited and expensive. The project team was uncertain how students would react to the idea of traveling to and from the museum and, once at the museum, whether they could complete an independent exploration with limited support materials and no instructor help. As it turned out, student response to the assignment was overwhelmingly positive.

In over fourteen years of teaching with extremely high evaluations, the PI has never experienced an educational innovation that met with such unparalleled enthusiasm on the part of participating students. Even without any formal evaluation or assessment instrument, roughly 35% to 40% of the participating students took the initiative to email or seek out the PI to mention how much they enjoyed the experience. In contrast, marketing programs typically consider a 5% unsolicited response rate as being very significant. As important, student responses included everything a museum partner wants to see or hear with such an initiative. Students brought their family and friends along to museum, specifically mentioned that they hoped to return, some of them even the same day. A demographic that museums rarely sees was raving about their museum experience.

A selection of email comments from students concerning their experience with the pilot prototype:

> *I went to the museum many times as a child with my parents, but I could not believe how much more I learned from the displays doing this. I saw things I had never seen before and it made the dinosaurs come alive.*
>
> *Just wanted to tell you that I never had so much fun completing a school project. After I finished with the dinosaurs I headed over to the experiment gallery. I do not know who was more excited, me or the 8-year old who showed me through the displays!*
>
> *I went with my friend who is still commenting on what a great tour guide I was and is amazed at the type of information I was able to explain. I am confident that…I will be able to use that "self-guided tour" for many years to come as I am positive I will be taking my future classroom students on field trips to the Science Museum.*
>
> *That trip to the science museum was hands-down the BEST museum visit I have experienced (although the Vatican was pretty interesting…).*

If the pilot version of 'Dinosaurs Designs' can beat the Vatican, the concept appears to have potential.

Evaluation Program & Educational Research:
In order to be successful, the proposed modules have to improve students' comprehension of the modules' core concepts. They also have to accomplish this without having a negative impact on the partner institutions' existing programs. Consequently, proposal evaluation must include the perspective of everyone involved, from students and instructors to museum staff. Project evaluation will proceed on three fronts. Staff from the Science Museum of Minnesota's evaluation department will spearhead the program's evaluation as students complete the exercises at the museum. Information gathering will include a survey completed by all participants, interviews of a subset of the participants, as well as on-site observations. On the university side, staff from the Center for Teaching and Learning will assist the P.I. with evaluating changes in student understanding of the modules' core concepts as measured on pre-instruction and post-instruction surveys as well as the modules' evaluation components. The design of the pre-instruction and post-instruction surveys will be similar to that of the Geoscience Concept Inventory (Libarkin et al., 2002; McConnell et al., 2005).

A graduate student assistant will play an important role in the project's evaluation, opening a third evaluation effort built around one-on-one interviews with students to try to determine changes in their understand of animal design or stream flow. Students in one UMN geology lecture section will be offered the opportunity to participate in these extra-credit evaluation sessions. Participants will include students who completed the 'Dinosaur Designs' module, students who completed the 'Rain Table' module, and students who did not complete either module as part of their lab activities. Sessions will consist of a variety of short questions and activities that participants complete, followed by one-on-one interviews with the graduate student. The interviews will build on the participant's responses to construct a better understanding of how they perceive the modules' core concepts.

In past projects, this approach has been remarkably successful in documenting the efficacy of new educational technologies (Rapp et al., 2007) and in revealing fundamental student misconceptions about earth science processes. The interplay of conversation can uncover deeply held misconceptions that remain hidden to other course evaluation components (Libarkin et al., 2005). In previous in-house studies, students were far more comfortable describing their understanding of earth processes with someone close to their age. Consequently, the graduate student will play an invaluable role in the project's educational research component. With graduate student support included, evaluation and educational research activities account for over 40% of the proposal's requested funds.

Overall, the proposal's success will be defined by the following criteria:

- Significant improvement in students' understanding of the modules core concepts as measured by pre-instruction and post-instruction surveys, performance on module activities, and students' ability to extrapolate those concepts to unfamiliar cases of animal design or stream flow.
- A significant level of student participation during the project's voluntary extra-credit stage.
- Satisfactory evaluations on surveys designed to measure participants' impression of their experience and improvement in their understanding of the modules' core concepts.
- Low levels of logistical difficulties reported by museum staff, hall docents and university lab instructors.

Specific measured components of the project evaluation will include:

SMM Evaluation:

- Satisfactory reviews of participants' impression of their experience with the modules on qualitative evaluations.
- Average amount of time spent completing module compared to average time spent by normal museum visitors on other interactive exhibits and average time of other museum activities.

- Participants’ ability to explain core concepts of modules in randomly chosen interviews.
- Shifts in participants’ world view as measured by open-ended questions on the exhibits, essentially how often the project team’s stated goals for each module are mirrored by participant’s description of the module’s purpose, content and what they felt they learned.

UMN Evaluation:

- Changes in student performance on pre-instruction and post-instruction surveys taken at the semester’s beginning and end.
- Quantitative measures of participant performance on pre-lab and post-lab evaluation components.
- Differences in understanding of module’s core concepts as determined in extra-credit sessions run by graduate student with students who did and did not complete the modules.
- Interviews with museum staff and hall docents on modules’ impact on normal museum activities, as well as interviews with lab instructors on the module’s impact on the existing laboratory curriculum.

Evaluation of focus will change over the project’s term. During the first year, the science museum and university evaluations will place a greater emphasis on determining potential hurdles to the modules’ adoption and use, identifying areas of potential confusion or misunderstanding in the module content, and establishing a base-line understanding of changes in student performance and understanding as they complete the modules. This focus will shift during the second year to a more detailed evaluation of the revised modules’ effectiveness in both improving students comprehension of the core concepts and the ease with which the modules dovetail with existing museum activities and undergraduate curriculums.

In a similar manner, the emphasis of the educational research component will also evolve over the projects’ term. During the initial parts of the study, the focus of the graduate student-led interviews will be on identifying and documenting students’ prior knowledge and misconceptions concerning the modules’ core concepts. As the project matures, this focus will shift to documenting how and why the modules alter participants’ understanding of the core concepts.

Dissemination Activities

Integration of new educational materials into existing curriculums is probably the greatest barrier to their dissemination and adoption. No matter how effective, exciting, or creative a new pedagogical innovation is, if its adoption requires significant effort, its implementation will be minimal. This proposal addresses this problem by consciously attempting to minimize instructors’ burden in module adoption. Each module will be designed as a self-contained, stand-along laboratory exercise that contains all background and logistical information necessary for its completion. Instructors will be able to integrate these ‘plug and play’ modules into existing curriculums without devoting lab or lecture time to their implementation. Even logistical information, such as parking information, bus routes, and maps will be included with the module materials.

Initial dissemination of the modules, assessment data, and research findings will focus on regional undergraduate institutions who can take immediate advantage of the modules and the Science Museum of Minnesota’s displays. From earlier activities developing GeoWall Stereo visualization systems, 3-D color anaglyph maps and curriculum development, the project team already has an established network of contacts with area colleges. Advertising the modules within the region can be accomplished easily and quickly. As the Science Museum of Minnesota and University of Minnesota web sites will host all the module materials, area colleges can have their students download the modules directly, without the need for any internal infrastructure at participating institutions. Complete modules will also be offered to the National Science Digital Library (NSDL). The project team will use NSDL collection tools and guidelines to assure that the materials are accessible in NSDL, creating metadata records that catalog each of the module sections by title, URL, description, resource creator, education level and subject keywords.

Project Team Capabilities and Expertise

The project team is ideally suited for this project. Kirkby, the project PI, has over 14 years experience interpreting earth science concepts for students and his introductory geology course consistently receives some of the highest student evaluations at the University of Minnesota, which is atypical of large introductory science courses (Arreola, 2000; Hippensteel and Martin, 2005). He has spent the past four years creating and evaluating a new suite of in-house laboratory exercises that have dramatically improved student understanding of earth science concepts as measured by significant improvements on pre-instruction and post-instruction surveys, and improved students' satisfaction with the course as measured by student evaluations of the laboratory sessions. Morin, the co-PI, is one of the foremost scientific visualizations specialists. His images are being used in departments across the country and recently formed the core illustrations for a new introductory geology text. Morin was the co-creator of the GeoWall stereo visualization system and spearheaded the establishment of a grass-roots community supporting the use of GeoWall in undergraduate education (GeoWall.org). He also has considerable experience in museum collaborations such as the Water: H_2O= Life exhibit and upcoming Future Earth exhibits. Together the project team has pioneered new methods of integrating 3-D color anaglyph maps into earth science curriculum that significantly improve students' comprehension of mapped surfaces across all grade levels and demographic groups (Rapp et al., 2007). In addition, the project team has an established network of contacts and educational partnerships across the region that can greatly aid dissemination of the completed project materials. With over 500 GeoWall systems in use across the country and over 40,000 of their 3-D color anaglyph maps distributed to other institutions, the project team has a proven track record of successful dissemination.

Future Effort

If this exploratory project proves successful, dissemination of the modules and concept to other programs will be the goal of a Phase II expansion CCLI proposal. This second stage will produce 1-3 new modules and focus on dissemination. Of the current proposal's modules, 'Rain Table' will be redesigned into a traveling exhibit and 'Dinosaur Design's will be expanded so other museums can more easily adopt it to their specific dinosaur displays. The Science Museum of Minnesota will advertise and disseminate the concept to other museums while the University of Minnesota takes the lead on academic dissemination.

Project Timeline:

PROJECT COMPONENTS	Activities & Objectives
	Spring 2009
Module Development & Testing	• Revision of 'Dinosaur Designs' (DD) prototype to full module status with field testing of module as extra credit assignment offered to full laboratory enrollment of roughly 500 students. • Draft design of 'Rain Table' (RT) module to be more fully developed during Summer 2009.
Assessment & Evaluation	• Develop and test initial evaluation instruments, such as pre-instruction and post-instruction surveys. • Solicit feedback from students, museum staff and lab instructors on impact of modules on existing program to identify strengths and potential problems before full deployment of modules. • Complete pre- and post-instructional surveys of all students in GEO 1001 program to establish base line for program's subsequent evaluation and document first assessment of modules impact on student comprehension and performance
Educational Research	• Design instruments for first phase of one-on-one interviews offered as extra credit assignments to lecture students. • Begin first phase of interviews with emphasis on documenting student's prior knowledge of animal design or stream flow (randomly selected for each student) and identifying student misconceptions concerning these core concepts.
	Summer 2009
Module Development & Testing	• Full revision of DD module. • Development of RT module prototype for testing.
Assessment & Evaluation	• Summary assessment of first semester evaluation. • Revision of final evaluation instruments.
	Fall 2009 – Spring 2010
Module Development & Testing	• Revision of RT prototype to full module status during Fall 2009 with field testing of module by Spring 2010. • Full deployment and final evaluation of DD module.
Assessment & Evaluation	• Continued evaluation of module's impact on student performance on pre-instruction and post-instruction surveys; students' understanding of core concepts and their ability to extrapolate modules' core concepts to unknown cases. • Documentation of modules' use on existing museum activities and undergraduate curriculum.
Educational Research	• Shift focus of interview program to how and why students' understanding of modules' core concepts changes are a result of module completion. • Design and test exercises and interview sessions that explore how students' perceptions of stream flow are affected by use of 'Rain Table' visualization technology.
Dissemination	• Presentation of project's concept and initial evaluation at national conferences and regional meeting.

Summer 2010

Module Development & Testing	• Full revision and development of RT module. • Final reversion of DD module.
Assessment & Evaluation	• Summary assessment of evaluation program to date. • Identification of targets for final semester evaluation.

Fall 2010

Module Development & Testing	• Final revision of RT module. • Post final versions of both modules on partner web sites.
Assessment & Evaluation	• Final semester evaluation of targeted points identified during summer 2010. • Final documentation of modules' use on existing museum activities and undergraduate curriculum.
Educational Research	• Targeted interview session program to clarify points / test ideas. • Document findings and conclusions of research program.
Dissemination	• Presentation of project's materials, final evaluation, and education research outcomes at national conferences and regional meeting. • Demonstration and dissemination of completed modules to regional undergraduate programs.

Project Deliverables:

- Two complete, Internet deliverable, laboratory modules built about museum exhibits that allow undergraduate students to complete self-directed explorations of crucial concepts in earth science education. Modules will be self-contained, 'plug and play' units that include all materials necessary for students to complete the explorations and instructors to integrate the modules into existing curriculums.
- Two distinct models of how museum displays can be integrated into undergraduate curriculums. The 'Dinosaur Designs' module is an example of collaboration where the museum plays a passive role. A college simply builds modules about the museum's permanent displays. With the 'Rain Table', the museum plays a more active role; specifically building or redesigning display to work in undergraduate education. These models can be exported to other regions and other disciplines. They have the potential to transform the way museums, universities and colleges collaborate to improve undergraduate education.
- Complete evaluation of modules and project concept from the perspective of both museum and undergraduate institutions. This evaluation will encompass the efficacy of the modules in improving student performance and comprehension of the modules' core concepts as well as the modules logistical impact on current museum activities and undergraduate programs.
- A research dataset of students' prior knowledge of, and misconceptions concerning, the modules' core concepts. The project's educational research component will document how student perceive these core concepts as well as how and why their perceptions and comprehension changes as they complete the modules' activities. Understanding this intellectual evolution is not only crucial to improving earth science educational practices, it also has enormous potential for improving science, technology, engineering and math (STEM) education across all disciplines.

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