Visible Geology: Creative online tools for teaching, learning, and communicating geologic concepts

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Visible Geology: Creative online tools for teaching, learning, and communicating geologic concepts

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Abstract

Computer based learning tools are becoming more prevalent in classrooms from elementary school to higher education. The potential value of interactive learning tools is particularly high in geoscience education where students can benefit from interactive tools that allow individuals to explore different processes in 1D, 2D, and 3D space. Traditionally, geoscience education has relied on laboratory exercises to provide students with the opportunity to explore dimensionality. In this paper we introduce Visible Geology, an innovative web-based application designed for geoscience education. Visible Geology enables visualization of geologic structures and processes through the use of interactive 3D models. As Visible Geology has been designed from a student-centric perspective, it has resulted in a simple and intuitive interface allowing students to creatively explore concepts. We present a case study of a large first year class at The University of British Columbia, and show the utility of Visible Geology in teaching geoscience concepts of relative geologic time and crosscutting relationships. The ease of use of the assignment, including automatic assessment, made this tool practical for deployment in classrooms of any size. The outcome of this type of large-scale deployment is that students, who would normally not experience a lab exercise, gain exposure to 3D thinking. The level of ownership and interactivity inherent in Visible Geology encourages engagement, leading learners to practice visualization and interpretation skills and discover geologic relationships.

Introduction

In undergraduate education there are a spectrum of tools and technologies that are used to teach about geologic principles. Many of the tools that are most readily available to undergraduate classrooms use pencil and paper, for example: geologic maps, cross-sections, and hand drawn block-diagram sketches. However, when dealing with 3D problems in geology these mediums are often inefficient and inaccurate for communicating concepts to novices. Media that does not directly use computer software often requires geologic models to be rendered in advance of the class, as a result they do not allow the students and instructors the flexibility to explore a variety concepts (i.e. the lessons are static).

Computer software for the geoscience industry (e.g. reservoir modeling tools) has long been available, and has been used in geoscience classrooms. However, the majority of this software is developed for industry use and has many features that are distracting and detract from the student experience, which only requires a small subset of the available features. Furthermore, these advanced software packages can have prohibitive learning curves, making them unsuitable for short exercises. By contrast, classroom-specific solutions often are presented as stand alone computer scripts (Charlesworth 1987; Schöpfer 2008) or

are presented with static content. These are effective at teaching targeted concepts (c.f. Pidburn *et al.* 2002; Fossen, 2010) but fall short when moving between concepts, as the technology and effort to create these animations is not scalable. Efforts to apply computer assisted drawing (CAD) tools for creation and interaction with geologic models (Jacobson 2001; Karabinos 2011) requires knowledge and familiarity in the CAD software; a skill that many instructors do not have. Recently, there has been work on open-ended, sketch-based, modelling for geoscience communication (Lidal *et al.* 2013; Natali *et al.* 2014). These sketch-based tools represent some of the recent developments targeted at allowing users to rapidly create their own geologic models.

Libarkin and Brick (2002) introduced a framework for classifying visualization and educational materials into static, animation and interactive visualizations. Each visualization classification within this framework has a number of advantages and disadvantages. The authors assess the design/development of activities, the ease of delivery, student engagement, and active versus passive learning of each visualization category. Static visualizations, with regard to the geosciences, often refer to geologic maps where students must put together many layers of information as abstractions of a three-dimensional environment (Libarkin and Brick, 2002). Animations and videos can help to guide a learner through a complex process, and can help to illustrate 3D environments with ease (c.f. Pidburn *et al.* 2002). Libarkin and Brick (2002) conclude that as visualizations become more interactive, learning moves from being passive to students being actively engaged in the content. Common examples of interactive tools in geoscience education often encompassed interacting with pre-made physical simulations, such as Modflow for groundwater flow. Other interactive tools, such as the Physics Education Technology (PhET) simulations, allow for students to explore targeted concepts (Perkins *et al.* 2006).

In another analysis of the aspects of simulations for educational materials, Clark *et al* 2009, suggest that educational activities be classified by the degree of user control. However, the framework suggested by Libarkin and Brick (2002) provide useful guides in the development of educational material, rather than solely in pedagogy evaluation. With the goal of educational material *development*, we believe that this framework can be extended to include an additional category for creative materials. This category would include tools where students are learning through creating rather than just interacting, and is in line with constructionism theories of learning (Papert & Harel, 1991). This illustrates an important distinction with regard to ownership and engagement, as the creation process includes the students in the discovery of concepts (Honey & Hilton, 2011). There is an increased level of engagement that results from students creating their own works (e.g. geologic models) and then interacting with them to achieve the desired learning outcomes. Not only does creation foster ownership, it encourages students to actively engage in the entire learning process.

Creative interactions result in a student product at the end of the process. This is not true of other interactive tools, and is an important distinction from the educational content developer's point of view, as there are many reasons to encourage these sorts of creative simulations: (1) the student product can be assessed, (2) the infrastructure needed to support student submissions can be scaled back to support any other interactive tool, the opposite is not true, and (3) creating and working with their own simulations improves student

engagement. It should be stressed that we are not arguing that one of these forms of media is better than any other. Learners need a variety of tools that scale to fit the curricula, the learning environment, and the types of questions that are relevant to them. However, from a development standpoint, we should be developing tools that are on the creative end of the spectrum. These tools must be modular, such that they can be disassembled and combined as interactive tools, animations, or static images to best address the learning outcome. The ability to provide a breadth of tools along the Libarkin and Brick (2002) framework from static to animation to interactive, as well as creative, from a single software platform would allow instructors to tailor visualizations to meet classroom goals and student abilities.

In this paper we present our work on a process-based geologic modelling environment designed specifically as a creative engagement and visualization tool for geoscience education. The software, called Visible Geology, addresses the gap between paper and pencil communication and complex expert software that is not designed for classroom applications. Visible Geology uses a simple, intuitive user interface to focus on features that are lacking in paper and pencil work, most notably 3D visualization and interaction, while avoiding many of the highly specialized features that are necessary in a full commercial application. The usefulness of creative geoscience software is highlighted with a classroom case study.

Visible Geology

Overview

Visible Geology allows students to be introduced to many geologic concepts and spatial skills in a virtual environment. This is done through a web-based, three-dimensional environment where students can create and interrogate their own geologic block models. The program begins with a blank model, users then add geologic beds and can add geologic deformation events like tilting, folding, and faulting. Additionally, simple intrusive dikes can be modelled, as well as unconformities. Users can also explore the interaction of geology with topography by drawing elevation contours to produce their own topographic models. Users can not only spatially manipulate their model, they can create cross-sections and boreholes to practice their visual penetrative abilities (Kali & Orion, 1996).

Visible Geology focuses on spatial skills and concepts that are commonly taught in undergraduate classrooms. Visible Geology is delivered through a web-based platform, which does not require plug-ins or other software installations. This ease of deployment and delivery has resulted in the highest student and faculty adoption rates both locally and internationally. The interface is designed to be self explanatory, employing user cues and short embedded videos to explain functionality. While developed for undergraduate geoscience majors, Visible Geology is applicable and accessible to a much broader audience, including industry applications. In the classroom setting, Visible Geology is particularly successful when it is used to augment paper-based lab activities. Sample learning activities have been developed that target introductory and structural geology curricula with learning objectives such as relative geologic history, fault characterization, apparent dip and thickness, interference folding, and stereonet interpretation. This section provides an overview of Visible Geology's modelling interface, the types of geologic events available, and the interactions/visualizations that the tool provides, as well as some of the concepts that can be addressed using these

tools. Finally, we present a case study illustrating Visible Geology in use in a large undergraduate classroom and our observations from the student feedback.

Creating a model

The Visible Geology application is shown in Figure 1. When the program loads it directs you to add your own geologic beds, and then allows you to interactively create your own geologic events such as tilting and folding. These events are additive, and build on top of other events, for example, the interference folding seen in Figure 1c is from the addition of two separate folding events. Visible Geology is extremely useful for exploring concepts such as relative geologic time, as the features are combinatorial and can work in any order. Students use Visible Geology to build the geologic history up from the beginning of the modelling process. This makes it is rather different than most commercial modelling packages that are mostly used to match observations, field data and present geologies as a combination of all historic events. While this is clearly a useful end goal, it is not motivated by pedagogy and does not allow learners to explore the interaction of events that lead to the geology being discussed. The basic geologic events that are implemented in Visible Geology include: tilting, folding, domes, basins, unconformities, dikes, faults, and fault bend folds. These simple building blocks are chosen to convey the basics of structural geology, however, the combination of these simple pieces can create complex geologic scenarios.

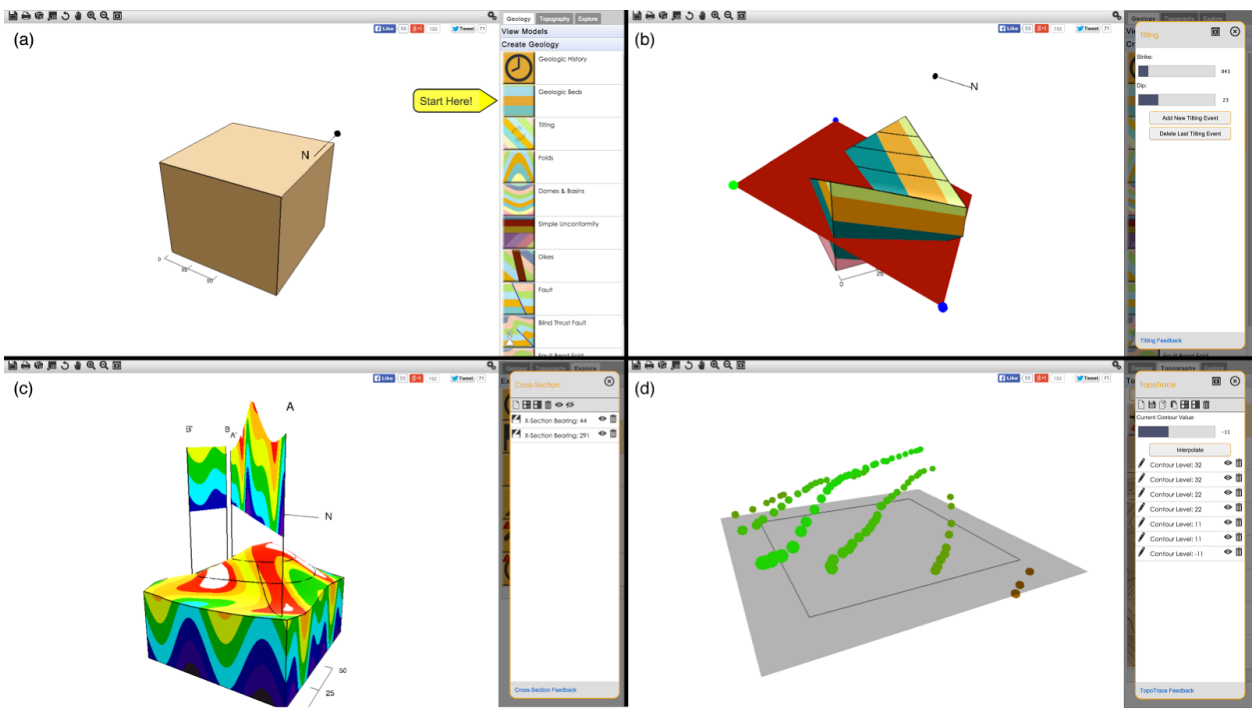

Figure 1: Screenshots of Visible Geology. a) Upon loading, the first screen directs users to add geologic beds, users are then encouraged to interact with their geologies, through b) the addition of geologic events such as tilting, folding, or faulting, and c) interrogation using the

cross-section and borehole tools. d) Individuals can create their own topography using the TopoTrace program.

Exploring a model

All models generated in Visible Geology can be viewed in plan view, as a 2D cross section, or rotated and viewed in 3D. Once a model is created, it can be interrogated using interactive tools such as cross-sections and boreholes, as well as measurement tools for distance and orientation. It is also possible to explore the influence of topography using pre-made topographies or by creating custom surfaces using the TopoTrace program (Figure 1d). TopoTrace allows the user to sketch contour lines, from these contours a block model surface is interpolated and displayed. The ability to easily create custom topographies is not only helpful in teaching concepts like contours and map reading, it combines with the custom geologic models for users to explore different types of outcrop patterns that manifest in a geologic map.

In addition to the geologic modelling program, there is a simple stereonet program embedded in the software that communicates with the geologic models created. The stereonet program is focused on teaching what this visualization tool actually communicates, as such, the program rotates into 3D *directly* from the 2D visualization. This interoperability combined with strike and dip measurements means that students can measure, for example, the orientation of a cylindrical fold at many points in space and instantly see the results on a stereonet. Providing and connecting a multitude of different ways to visualize data is important to ensuring the accessibility of these concepts to a broad audience.

In the classroom

Early in the development process Visible Geology saw direct application in the classroom environment, as we have further developed the software it has been used to address a range of learning outcomes. Here we will describe three high-level concepts that are well communicated in Visible Geology and which many assignments have been developed for: (1) apparent dip using cross-sections, (2) cylindrical folds using stereonets, and (3) relative geologic time. These concepts are addressed using the tools in Visible Geology and were chosen to highlight the ability of Visible Geology to (a) encourage students to think in three dimensions; (b) connect geology, data, and abstract visualizations; and (c) discover concepts through guided exploration in a simulation environment.

Apparent Dip

Apparent dip is an important concept for students to grasp in introductory geology, geologic mapping, field courses and structural geology. This concept relies heavily on 3D thinking and manipulation, and can be explored with the cross-section tools available in Visible Geology. Figure 2 shows the result of taking cross-sections through a set of dipping geologic layers. As a learning objective, we ask students to make observations about how the angle of the beds change in each cross-section as the bearing of the cross-section changes. Changing the dipping angle of layers can be completed quickly, enabling students to experience a variety of scenarios in a short timeframe. These exercises encourage students

to build mental models of apparent dip, and help them to visualize how dipping layers manifest in different cross-sections. These concepts and mental models are critical for students to master, as the projections and intersections of real geologies are significantly more complex, yet are defined by these basic 3D interactions.

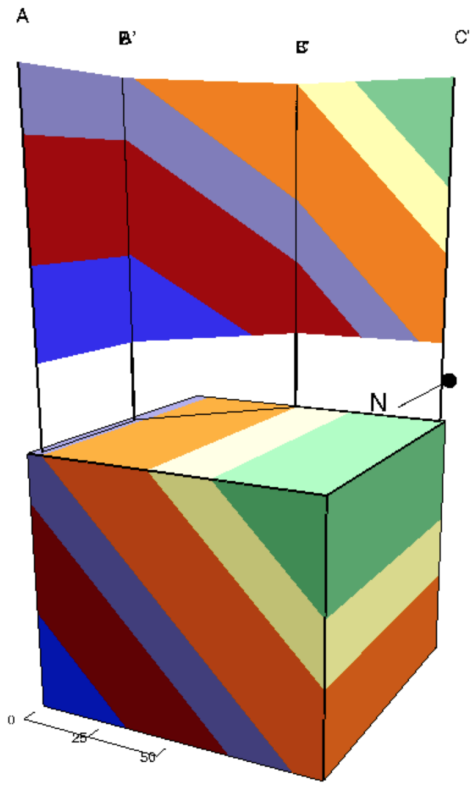

Figure 2: Apparent dip is illustrated using cross-sections taken on a variety of bearings through dipping layers.

Folds and Stereonets

A exercise that is often completed in geologic field schools is the mapping of a geologic fold. The activity is often extended through analysis of strike and dip measurements using a stereonet. The visualizations of geology, data, and stereonets is often treated separately, requiring effort from students to tie these concepts and visualizations together. Using the tools in Visible Geology a student can rapidly create geologic folds, collect strike and dip data, analyze that data on a stereonet, and tie that visualization back to the 3D geology (Figure 3). The entire cycle outline above from geologic model building to stereonet analysis and 3D visualization only takes a few minutes, enabling students to work through the process several times with a variety of different examples. Rapid prototyping, real-time visualization, and linked representations of data provide students with an integrated and contextualized understanding of the entire process. These tools are extremely critical in teaching the stereonet visualization of data - a concept that is difficult to communicate and as a result is often poorly taught.

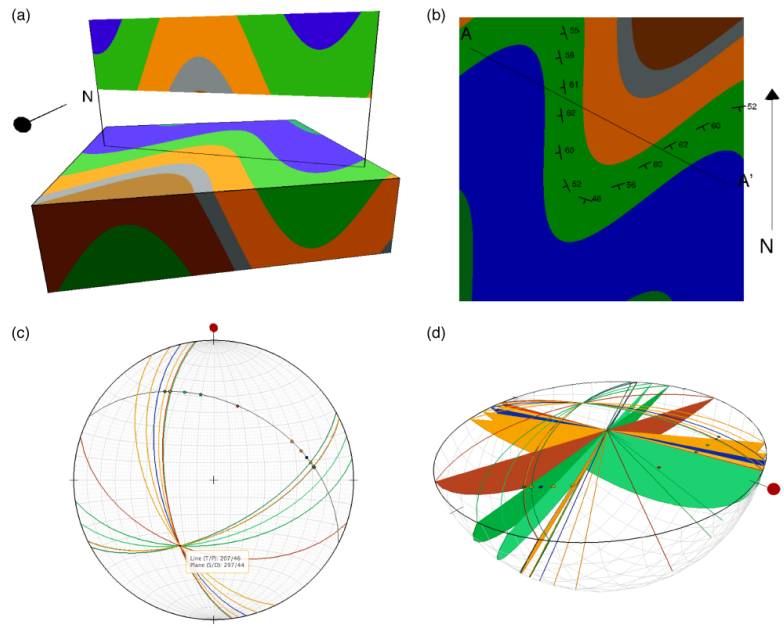

Figure 3: Modelling and visualizing a cylindrical geologic fold: (a) three-dimensional block diagram; (b) measurements of strike and dip at multiple locations in a single geologic layer; (c) visualization of strike and dip data in the stereonet program; (d) visualization of stereonet data in 3D.

Relative Geologic Time

Relative geologic time is often a precursor to discussions of deep geologic time and an introduction to how geologists reason their way through complex problems. The timing of events can often be distinguished through the interactions of geologic events with the previously existing structures. Geologic cross-sections are a commonly used teaching and assessment tool in introductory geology classes, as they test a variety of geologic principles, including: the principles of original horizontality, lateral continuity, superposition, and cross-cutting relationships. Traditional assignments provide students with a cross-section and require them to apply these rules to determine the order of events (e.g. Figure 4a). However, the static nature of the cross-sections can limit learning outcomes, as it does not allow individuals to create and explore the interaction of geologic events on different geologies. Interpretation of static cross sections relies more on the memorization of principles than on visualizing processes interacting through geologic time. In contrast, creative learning environments, like Visible Geology, encourage users to create and view models through both time and space. This allows students access to direct experimentation with the individual geologic processes, which ultimately allows them to make predictions based on experience rather than relying on memorized rules.

Although assignments on relative geologic history can start from slightly less complicated geologic sections than shown in Figure 4a, by the nature of the assignment they require students to deconstruct an existing geology. There are few tools available to students to easily go in the opposite direction: forward through time rather than backwards. Visible

Geology allows students to both construct and deconstruct a geologic history, connecting the dimensionality of time with the manifestation of process. The ability to easily move forward and backward through geologic time presents a significant learning opportunity for students. It allows students explore and visualize the interaction of geologic events with the surrounding geology, as well as with existing events. Figure 4b shows a similar geologic history that has been created using Visible Geology. In this case, the student is able to add all events themselves, iteratively constructing a geologic history, scrolling through time, and observing the result of various combinations of geologic events. This is something that is only possible in a simulation environment, where a user can determine inputs and observe the results of those inputs. For example, by changing the order of a dike and a faulting event the student can be guided to create a description of cross-cutting relationships rather than be given this description *a priori*.

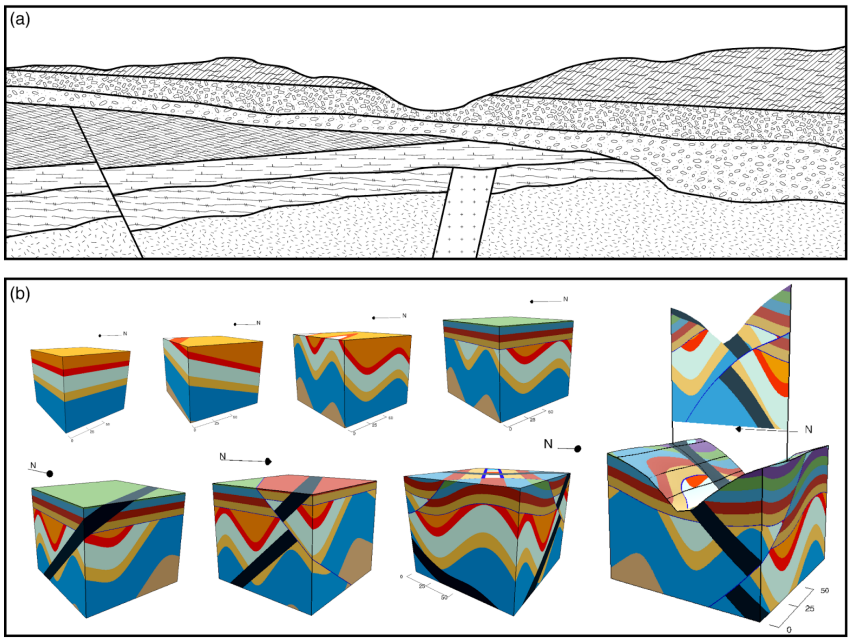

Figure 4: Visualizations used to explore relative geologic time: (a) a cross section requires students to deconstruct geologic events; (b) Visible Geology allows students to construct and deconstruct geologic models to explore the order of geologic events.

Case Study

To obtain a better understanding of the value of Visible Geology for learning outcomes, we partnered with The University of British Columbia (UBC) to integrate our tools into an introductory geology class. In January 2013, we developed an interactive geologic history assignment for an introductory geology class of approximately 100 students. The assignment required students to identify the relative order of geologic events through time. This exercise had been taught previously using simple geologic cross-sections showing crosscutting relationships; from these cross-sections students inferred the relative age of geologic events (e.g. Figure 4a). While the Visible Geology assignment provided the same learning outcomes as previous exercises, students were offered a unique experience where

they were allowed to first create their own geologic events. This experience allowed them to directly see how the timing of a geologic events manifested in the model and resulting cross-sections. Student-generated models could be shared amongst peers, as well as the instructor. The scalability of the Visible Geology platform made this tool practical for deployment in this large class, and the automated assessment of this exercise reduced instructor workload.

The size of this class made the inclusion of an external laboratory component unfeasible. We developed a two part assignment that was distributed, performed and assessed entirely online through the Visible Geology platform. No additional resources or personnel were devoted to the assignment. As a result, this assignment was done outside of class time without supervision. Students were guided through the assignment using a short document. In the end, the developed assignment was optional and extra curricular - incentivized only by a 1% participation score, 46 students completed the assignment. The incorporation of the Visible Geology exercise into the class exposed students that would not normally have experienced a lab exercise to interactive 3D thinking. Engaging tools and software that allow for unique user experiences are critical for moving to scalable, engaging, online learning environments.

The questions and results of a short survey of the participating students is shown in Figure 5, with selected open-ended feedback shown in Table 1. The majority (93%) of students agreed or strongly agreed that Visible Geology is a very useful way to visualize geologic interactions, and 78% strongly agreed or agreed that the use of these tools translated to improved visualization of other geologic block diagrams in the course. 9% and 11% of the students who participated in the exercise disagreed or strongly disagreed that the exercise improved their understanding of stratigraphy and relative geologic history, respectively, two concepts that were central to the assignment. This is likely due to the hands-off nature of this assignment, which required students to guide their own learning process. Students who had a tenuous grip on relative geologic time and concepts in stratigraphy likely were not able to come up with questions to guide their own exploration. Future versions of this assignment will include more supporting materials and questions to help guide student exploration and improved understanding of key concepts. Even with minimal explanation on how to use the tool, only 11% of the students indicated having a difficult time interacting with the software (Figure 5). The majority of students who used Visible Geology saw the value of these sorts of tools being applied to other courses and concepts, with over half of the open ended feedback soliciting positive responses about the experience with these tools.

The geologic history assignment deployed in this introductory classroom was possible because (a) Visible Geology is a stand alone tool that can be used in parallel with existing assignments and curricula, (b) it is scalable tool with a minimal learning curve, and (c) the web-based delivery allows for access of the tool from any device with a web-browser. Additionally, the ease of deployment and automated assessment minimize instructor workload. The feedback from students reinforced our intuition that the creative process leads to ownership and engagement in learning these geologic concepts. The students valued the 3D interactive nature of these tools, and self reported that the visualization skills transferred to

other aspects of their course. These tools are not completely stand alone - they require supporting materials from instructors to help guide student learning. A more in depth discussion of integrating external simulations into courses can be found in Clark et al (2009) regarding the nature and extent of the surrounding material. In future versions of this assignment, instructors at UBC are including additional materials to guide the students exploration process.

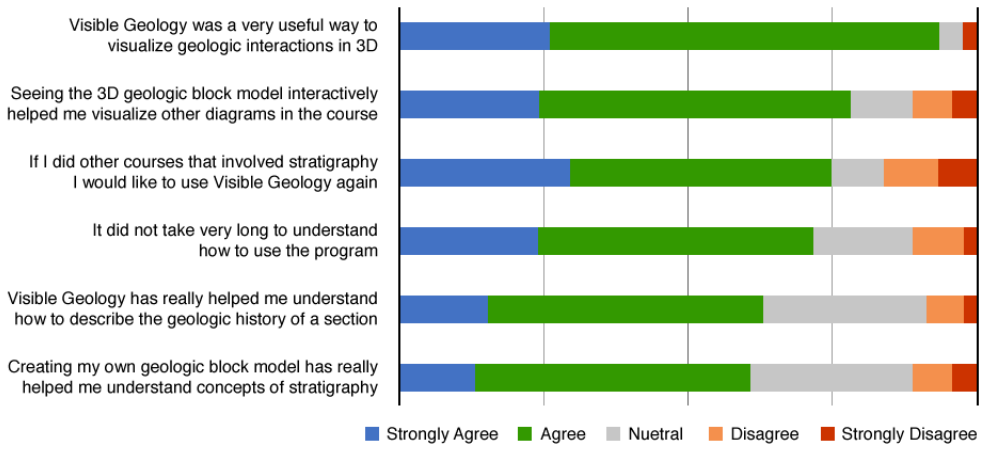

Figure 5: Feedback from 46 students on their experience using Visible Geology in a geologic history assignment.

Table 1: Selected feedback from students highlighting the value of creative tools for ownership and engagement.

It was great to have a visual view of it and be able to make my own, rather than look at someone else's example in a textbook.
Fooling around and creating my own variations has definitely made it even easier to visualize how the history of an area was influenced.
It was very interesting to be able to create my own stratigraphy and be able to alter it.

Discussion

Our primary motivation in the development of the Visible Geology platform was to engage students and teachers for enhanced understanding of geologic processes through the creation and exploration of geologies developed in our platform. Since its release in September 2011, Visible Geology users have created more than 200,000 geologic models, shared their experience from every continent on Earth, and engaged in online forums promoting its ongoing use and development. Engaged Visible Geology users have successfully relayed the platform's utility primarily through personal correspondence, social media platforms and blogs. Visible Geology receives weekly emails, tweets etc. providing feedback and suggestions on improving the platform. A selection of the feedback from

students and teachers is highlighted in Table 2. These quotes demonstrate the need for these type of easily accessible and simple tools in conveying concepts in the geosciences.

Table 2: Selected feedback from students and teachers using Visible Geology.

Student Quotes	Teacher Quotes
As a student struggling to grasp 3-D structures, this is the greatest tool I have ever seen. I will owe most of my success in my structural geology and mapping courses to this, so thank you.	The site is a tremendous learning tool! Will definitely be working with this when I teach structural geology next semester.
I am giggling maniacally and getting really excited about cross-sections. Oh, the joy of fictitious geology.	Many students of geology, including majors, find visualizing 3D structural geology very difficult. This is a great tool to make that possible.
This is the best way I've seen to easily get a grasp of stereonets. I wish I had those [visualizations] when I was learning stereonets. (I took nearly 2 years to figure out what was going on).	This is definitely the coolest geo-education development I've seen in a LONG time.
Several of us have used your models to help visualize concepts. Really like what you're doing. Thanks so much.	You've done such a nice job in making the site user-friendly that I'm giving [the students] zero instructions about how to use it.

Much of the existing data about Visible Geology is anecdotal in nature, however there are some key assessments that can be made from these data. Visible Geology: (1) helps people to visualize geologic concepts across dimensions and tools such as stereonets, (2) provides engaging learning environments that encourage personalized experiences through creative exploration, and (3) provides a simulated environment that enables people to construct and deconstruct geologic models enabling a broad range of experiences that are not possible through traditional paper-based methods. Our discussion focuses on the last two points, and extends the framework from Libarkin and Brick (2002). We will continue to use the concept of relative geologic history to illustrate the spectrum of visualizations that can enhance geoscience communication.

The schematic in Figure 6 shows a spectrum of tools used to teach relative geologic time. This spectrum ranges from static (Figure 6a) to creative (Figure 6d). All of these tools have the same specified learning outcome. The static representation in Figure 6a presents a geologic formation that requires the student to apply the rules learned in lecture to identify the

order of geologic events. We use the word static to highlight that the *content* of the viewer is static, that is, there is a single geologic model. An animation can show the learner the geologic history at many stages of development, but is still based on a static model (Figure 6b). Many geologic concepts are difficult to conceptualize solely from the final stage of geologic history, as such, animations and videos are excellent tools to aid in visualizing these concepts (c.f. Pidburn *et al.* 2002). The next stage in the framework introduces more interactive features (Figure 6c). In the case of relative geologic time, changing the relative order of events is a pertinent interactive control. In this example, the learner is able to drag-and-drop the geologic events, and *simulate* the result of that change. This interactive feature is a critical change, as it now changes from an interactive animation to a simulation tool where learners can propose and test their own rules to distinguish relative geologic ages. Finally, Figure 6d is most similar to Visible Geology where users can both create and rearrange their own geologic models. This additional control allows learners to test a null hypothesis, for example, to produce a geologic block model that has an ambiguous geologic history. This requires a student to not only identify the relationships that must exist to determine relative geologic ages, but also to come up with counter-examples and critically think about when it is not possible. The framework illustrated in Figure 6 can be easily extended to other concepts, and is useful in the development of targeted learning tools.

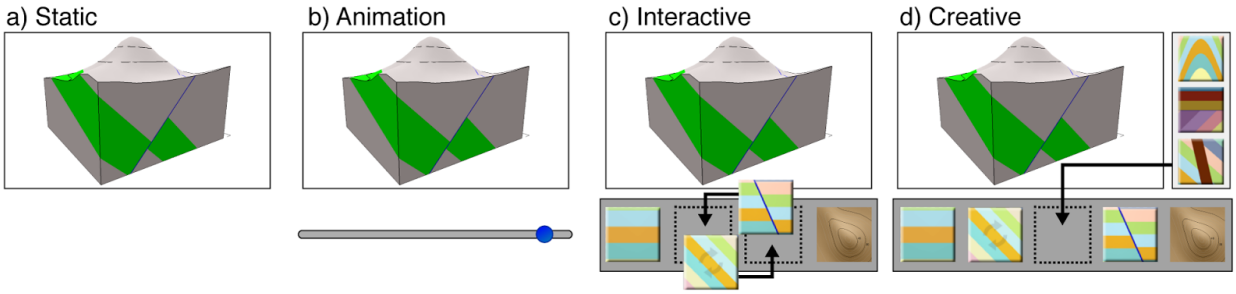

Figure 6: A spectrum of visualization learning tools from static to interactive that convey the concepts behind relative geologic history.

<u>Future Work</u>

Many of the results that have been gleaned from 3 years of feedback and iterations of Visible Geology are largely qualitative. Future work will study some of these concepts through a more quantitative lens, with pre- and post-testing of students as they use these tools, and the integration of targeted assessments into the Visible Geology platform. As PhET simulations demonstrate, targeted learning exercises can be extremely valuable. However, these exercises must be developed strategically to ensure that they do not detract from the creative process that is the foundation of Visible Geology.

Conclusions

Visible Geology is a web-based geoscience tool that provides students with an opportunity to creatively simulate geologic processes in a 3D environment. It has been used

to convey geologic concepts such as relative geologic time and stereonet visualization across a breadth of settings and experiences. Feedback from the focused case study at The University of British Columbia and engaged users worldwide have identified a number of positive learning outcomes, notably these visualizations help learners connect spatial and temporal dimensions. The high level of engagement from learners using our tools is fostered through ownership of models in a fun and playful environment and peer-to-peer sharing and collaboration. These tools are designed for rapid prototyping, allowing the experiences in Visible Geology to be repeated with different models of varying complexity, encouraging students to build up concepts through experience and interrogation.

Extending the Libarkin and Brick (2002) framework to include creative visualizations is helpful in discussing some of the constructionism learning styles embedded in Visible Geology. More importantly, developing a creative experience for learners requires designing instructional materials that can be scaled back to cover any other sort of visualization tool. The opposite is not true and provides Visible Geology users with a uniquely versatile tool. Visible Geology provides an interactive, and immersive environment for students to explore geologic concepts and practice their spatial skills. The interactive and modular nature of Visible Geology allows it to be tailored for many unique situations. It is not passive visualization, it promotes creation, integration and discovery.

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