Research proposal: reconstruction and classification of newly discovered species ...

Burgess Shale, Cambrian, Anomalocaris, arthropods, taxonomy, phylogenetics, cladistics, reconstruction, museum, informal learning, multimedia, animation

Abstract

Introduction

The fossil beds of the Burgess Shale, located in the Canadian Rockies of British Columbia, contain some of the most exquisitely preserved remains of marine invertebrate organisms from the Middle Cambrian period (Brysse, 2008). The exceptional preservation of these fossilized fauna have allowed for detailed reconstructions and descriptions of these organisms functional morphologies thereby revealing modes of locomotion, sensory perception, and feeding strategies. Evidently, these specimens have proven to be invaluable in shedding light on the early evolution of animals shortly after the Cambrian explosion, in which most of the known animal phyla rapidly appeared and diversified (Brysse, 2008). However, the phylogenetic relationships of the Burgess Shale organisms have been, and continue to be, highly contested. Recent research efforts have been concentrating on re-examining previous reconstructions and classifications of the Burgess Shale organisms as well as identifying and classifying new species as new information and fossilized specimens become available. The findings of these studies are crucial for phylogenetic analysis and contribute to our understanding of not only the origin and early history of life on our planet, but the nature of evolution itself (Brysse, 2008).

Despite the inherent importance of this research, the general public's access to this information is often limited. However, museum exhibits including the Dawn of Life Gallery are hoping highlight the ROM's exquisite fossil collections, including fossil specimens from the Burgess Shale, along with new ground-breaking research which will convey the complex evolution of life on our planet and introduce key evolutionary concepts. Multimedia animation is an effective educational material for museum displays since it is engaging and allows for more effective cognitive processing by using both the visual and verbal channels (Mayer et al., 2014). This is especially important because learning within a museum environment is characterized by unmediated, episodic and short interactions with exhibit displays (National Research Council, 2009). In addition, multimedia animations have been found to be a powerful venue for teaching scientific concepts and processes with particular strengths for archaeological displays in their ability to provide context for fossilized specimens. Currently, there are no multimedia animations about the reconstruction and classification of newly discovered species from the Burgess Shale and how these new finds enhance our understanding of early animal evolution. The aim of this research project is to address this gap.

Current reconstruction methods typically involve camera lucida drawings based on photographed specimens which are then prepared in Adobe Photoshop and Illustrator (Daley, Budd, Caron, Edgecombe, & Collins, 2009). Although 3D reconstructions of Burgess Shale organisms have been created, none have been used to

Background

The fossil remains of the Cambrian period, exemplified by the Burgess Shale of British Columbia, are significant for several reasons. These recovered fossils include a wide variety of soft-bodied and skeletonized organisms which provide a unique insight into Cambrian life (Zhang, Shu, & Erwin, 2007), and allow researchers to understand the major adaptive radiations at the beginning of the Cambrian explosion (Morris, 1989). In addition, the diversity of fossil remains and the unique morphological characteristics exhibited may represent extinct clades that have never been examined before. Furthermore, these fossil remains are exceptionally preserved, allowing researchers to interpret the anatomical details of these organisms in great depth and infer aspects of the organisms' locomotion and ecology.

Arthropod Systematics

The organism to be studied and reconstructed for this research project is a close relative of Anomalocaris, an extinct genus that belongs to the familyanomalocarididae. The anomalocaridids possess a unique comination of morphological features which has led to a complex history of discovery, description and interpretation (Collins, 1996). They possessed a body with prominent lateral flaps and gills, a head with stalked eyes, frontal appendages, a circular mouth apparatus, and head shields that are often found dissociated from the rest of the body (Whittington and Briggs, 1985). These key features in addition to indirect evidence of bite marks on trilobites, suggests a predatory mode of life (Nedin, 1999). Anomalocaris was originally described from Mount Stephen in Canada (Whiteaves, 1892), and anomalocaridids have since been described from the Burgess Shale and other localities in the Canadian Rocky Mountains (Briggs, 1979), the

Chengjiang fauna in China, the Emu Bay Shale in Australia, and various sites in the USA and Poland. Recent analyses suggest that they belong to the stem group of arthropods (Budd, 1996, 1999; Dewel and Dewel, 1998; Cotton and Braddy, 2004; Daley et al., 2009), although their phylogenetic position is controversial, with alternate interpretations regarding them as crown group arthropods (e. g., Chen et al., 2004) or as a sister group to the arthropods (Hou and Bergström, 2012).

Many aspects of the anomalocarididae morphology, diversity, and ecology also remain unclear due to scarcity of complete specimens and the manner in which they are preserved (Daley, Budd, Caron, Edgecombe, & Collins, 2009). Since fossil specimens of the Burgess Shale are flattened, multiple specimens preserved at different angles are required to reconstruct a species (Gooding, 2004). Given this and many other difficulties, fossil imprints are often interpreted by analogy to the morphology of modern counterparts.

Reconstruction Process

The 2-D diagrams are provisional interpretations of the more complex phenomenology of the

' raw' fossil imprints. They are labelled to indicate structures that could represent a plausible anatomy. 19 Of

course, expert knowledge about possibilities influences the selection of features from the diagram.

This example illustrates some key features of visual thinking also found in other cases. First, there is a

dialectical play of personal and public representations. 24 Second, diagrams select and highlight certain

features of the ' raw' (un-interpreted) imprint. Third, a technology (the camera lucida) is used to produce

abstractions which scientists then work with, using techniques devised to bypass difficult mental tasks such

as working out 2-D projections of complex 3-D structures. 25 Fourth: the selected features are used to

construct a 3-D model capable of integrating information from diverse knowledge domains. Fifth:

information-rich, integrated representations are developed into process models that explain both the original

2-D imprints and the 3-D anatomical features they are now shown to display. 26 Sixth: the complex models

are evaluated by abstracting simpler visualizations from them and comparing these to the source patterns.

Cladistics

New species discovered at the Burgess Shale are classified using a methodology of systematics known as cladistics, which gradually replaced the old method of evolutionary systematics. Cladistics is now the most widely used method of generating phylogenetic trees. Unlike evolutionary systematics, cladistics gives no weight to unique characters, and instead seeks to identify shared derived characters (synapomorphies) that indicate common descent between species. With this methodology, bizarre and unique attributes, which includes derived characters not shared with other groups, are excluded from the phylogenetic analysis of a species entirely. Two other concepts related to cladistics which are key to understanding Burgess Shale taxonomy are the crown and stem group concepts. Without these concepts it would not be possible to talk about the relationship of fossils to modern life. The crown group is a clade which consists of the latest common ancestor of a monophyletic group of extant organisms plus all the descendants of this ancestor, whether living or extinct. The stem group consists of organisms which are closer to the crown group than to any other extant clade, but do not fall within the crown group. Stem groups are extinct and will be paraphyletic since some members will be more closely related to the crown group than others are. This is because not all synapomorphies connecting members of a crown group will be acquired at once and will instead have been acquired successively within the stem group. Using cladistics and the crown and stem group concept, paleontologists can place new species within the extinct lineage leading to modern day arthropods.

Problem

The phylogeny of the arthropods has been a focus of heated debate for over a century, with an overall lack of consensus, apart from the probable relationship of the trilobites to the chelicerates (Budd, 1996). Although it is easier to describe fossil species entirely, due to the lack of detail available compared to extant species (Haug, Briggs, & Haug, 2012), many descriptions of fossils are inadequate to allow them to be used directly to prepare cladistic matrices for phylogenetic analyses. This is usually because authors concentrate on morphological features that differentiate new species from those previously described. Thus, the focus is on structures that are unique even though cladistic matrices require structures that are shared with other species. As a consequence, morphological details in many phylogenetic matrices have to be reinterpreted, often without the benefit of a comprehensive description.

Design Challenges and Considerations for Museum Displays

The ROM is currently developing a new permanent palaeontology gallery to open in 2020 called the Willner Madge Dawn of Life Gallery. This gallery will highlight the ROM's superb fossil collections, which will include fossil specimens from the Burgess Shale, along with new ground-breaking research which will convey the rich and complex story of the evolution of life on our planet. This gallery will also introduce key geological processes, evolutionary concepts and major evolutionary innovations.

Visualization tools in museums gives the public access to current scientific research and data in a way that facilitates exploration and understanding (Frankel & Reid, 2008; Johnson et al., 2006). However, the museum

environment, where learning is characterized by unmediated, episodic and short interactions with exhibits (National Research Council, 2009), imposes its own constraints on learning with a visualization tool. One of the main challenges of a museum environment is designing a visualization tool that meets the needs a broad and diverse audience. People who visit a museum exhibition differ vastly in their age, knowledge, and social background. Some people visit an exhibition to add to their growing knowledge, while others are looking for an entertaining and educational experience [15, 22]. This influences people's expectations of an exhibition and the way they explore it. In addition, museum visitors are often under pressure because they want to see as much of the museum as possible within a certain amount of time. Due to the wealth of information commonly available in museums, exhibits are competing with each other for the attention of visitors. As a result, an exhibit that cannot create an incentive within ten seconds is usually abandoned [15].

Successful strategies for engaging visitors with exploring data through visualization tools in museum settings still need to be identified. However, there are a number of design considerations that do help to enhance the overall efficacy of museum displays.

Appeal

The visual appeal of information visualization in a museum context is highly important since

it influences people's motivation to approach the visualization as an exhibit, the amount of time they actually invest in exploring it, and how they perceive and absorb the information it is presenting.

Data

Within a museum setting the information display is usually required to be dependent on the exhibition content. Thus, one of the design considerations is how the chosen data will contribute to, reflect on, or extend the context it is situated in.

Representation

Visual displays designed for museums face the likelihood that visitors will only spend a short period of time with an exhibit and rarely visit it more than once [15]. In addition, exhibit experiences are rarely mediated by staff. Therefore, the data representation should be intuitive to understand, engaging for exploration, and simple enough to have people understand the meaning quickly so that they can focus on exploring the actual information content.

Display Technology

The choice of display technology is an important factor that affects many aspects including overall visibility, input possibilities, and integration with the other exhibits. Since visitors often explore a museum exhibit in groups [22, 27], large display technologies may be preferred over smaller displays as they enable the exploration of the visualization in a collaborative way. Many examples show that one of the criteria for successful information

visualization in museum space is to allow multiple people to actively or passively experience the visualization at the same time [1, 2, 26].

Multimedia Application for Museum Displays

Multimedia learning tools consisting of pictures (such as animation) and words (such as narration) offer a potentially powerful venue for teaching scientific concepts and processes. As a result, multimedia animation has been widely applied to the educational field in the appropriate form. Multimedia applications have particular strengths for archaeological displays in their ability to provide an idea of the original appearance of the fossilized organisms on display as well as an explanation of archaeological work itself (Economou, 1998). However, the design of multimedia animation ultimately determines the effectives of the teaching tool in promoting meaningful learning.

Interaction Strategy

According to Mayer, multimedia learning will be more effective when learning material is interactive and in control of the learners. Since learners don't all study at the same speed, having the ability to control the speed of information presented will produce better learning outcomes. For this reason, the multimedia animation to be developed will be partitioned into a series of multimedia animations which the viewers can control by clicking start, pause, forward, and backward.

Reducing Cognitive Load

Mayer's multimedia principle holds that deeper learning occurs when information is presented in words and pictures than in words only (Mayer, 2002). According to dual-coding theory, human's process information in different visual and verbal channels that are relatively independent (Clark & Paivio, 1991). Therefore, multimedia animations which involve pictures and narrated text take advantage of the both of these channels, creating a fuller and more structured representation of the information that contributes to the acquisition of knowledge (Clark & Paivio, 1991).

However, the cognitive load theory presented by Mayer explains how the processing capacities of visual and verbal working memories are severely limited (Baddeley, 1992; Chandler & Sweller, 1991; Sweller, 1999). In short, presenting too many elements to be processed in visual or verbal working memory can lead to overload in which some of the elements are not processed. Four of Mayer's design principles — contiguity, coherence, modality, and redundancy — reflect the theme that students learn more deeply when their visual and/or verbal working memories are not overloaded. In particular, constructivist learning is most likely to occur when learners' needs have corresponding visual and verbal representations in working memory at the same time.

In the contiguity principle, individuals learn more deeply when they do not have to hold the entire animation in working memory until the narration is presented or vice versa. Compared to simultaneous presentation of animation and narration, successive presentation of animation and narration is more likely to create cognitive overload, resulting in reduced levels of understanding.

In the coherence principle, individuals learn more deeply when they do not have to process extraneous words and sounds in verbal working memory or extra pictures in visual working memory. Compared to concise presentation of animation and narration, embellished presentation is more likely to create cognitive overload that results in reduced levels of understanding.

In the modality principle, students learn more deeply when visual working memory is not overloaded by having to process both animation and printed text. When words are presented as printed text, they compete for processing resources with animation in visual working memory, thus resulting in less opportunity to build understanding. When words are presented as spoken text, they do not overload visual working memory, thus allowing for deeper understanding.

Finally, the same reasoning applies to the redundancy principle in which presenting both animation and printed text results in overloading visual working memory. Therefore, it is better to present an animation with narration alone.

Research Aims & Objectives

Primary Objective

The primary objective of this research project is to improve the accessibility of current research on Cambrian organisms from the Burgess Shale to the general public. More specifically, this project aims to facilitate public understanding of the evolutionary history of early lifeforms through the

phylogenetic analysis of morphological characteristics found in extinct taxa from the Cambrian period.

This primary objective will be achieved through the creation of an animation that conveys the 3D reconstruction process of an extinct species from fossil remains and how the identification of diagnostic features from reconstructions provides insight into the evolutionary relationship of extinct organisms to living taxa.

Secondary Goals

1. To ensure that the 3D reconstruction of this newly discovered species is as accurate as possible given the limited fossil remains and research on related taxa that is available. Creating an accurate 3D reconstruction is crucial for the identification of morphological features that are involved in the classification of the species.

2. To ensure that the animation incorporates visual cues that engages and maintains the interest of a broad and diverse audience within an attention-competing environment.

3. To implement an iterative design process that involves ongoing feedback from content experts and a museum pilot study to assess the effectiveness of the learning tool.

Methods

Target Audience

The target audience for this research project will be natural history museum visitors since the final visualization will be displayed at the Royal Ontario Museum. In recent years the ROM has experienced a significant increase in school visits making students a large part of their visitor demographic. The secondary focus of this project will be for the scientific community and researchers of invertebrate paleontology.

Design Strategy

The design strategy for this project will involve two components: 1) the three-dimensional reconstruction of an extinct organism from fossil remains provided by the ROM and 2) the creation of an animation that conveys the reconstruction process as well as the classification and phylogenetic placement of this organism with respect to extant taxa.

Reconstruction Process:

The reconstruction of the organism will involve a number of major steps (Briggs & Williams, 1981):

1. Interpreting the state of the organism's preservation. This includes determining whether the organism's body parts have retained their original position relative to one another.

2. Determining how the differently preserved configurations of the organism relate to its original position relative to the matrix it is embedded within.

3. Producing preliminary sketches of the organism's outline based on fossil remains that show dorsal and lateral views (if available) and supplemented by fossil remains that show intermediate orientations.

4. Producing detailed sketches of the organism's external anatomy and key morphological characteristics through consultations with the content experts.

5. Modelling the organism in Zbrush. Sketches of the organism's body plan and anatomy from different perspectives will be imported into Zbrush to use as templates for each plane to ensure that the scale and proportions of the organism can be modelled accurately.

6. Testing the reconstruction by comparing the model with the compacted specimens to see if any disparities are apparent and if so providing possible explanations for them.

7. Modification of the reconstruction to meet the requirements of step 6. Steps 6 and 7 are repeated until a satisfactory model is achieved.

Animation Process:

1. Script and Storyboard: A preliminary script will be written with consultation from my committee to determine the events that will take place in the animation. Following the script, the storyboard will be created by sketching key shots of each animation. Iterations of the script and storyboard will be made following feedback provided by my committee in order ensure that the information is accurate and that the messages communicated are effective and those intended by the institution (ROM).

2. Animatic: The script will be narrated using Adobe Audition and an animated version of the final storyboard will be created to sync with this narration in Adobe After Effects. Creating this animatic will help to determine appropriate pacing for the narration as well as the how the visuals will sync with the audio.

3. Asset Creation: The 3D assets for the 3D portions of the animation will be modelled using Zbrush. This will include the 3D reconstruction of a newly discovered species from the Burgess Shale which will be developed using the techniques described above. The 2D assets for the 2D portions of the animation will be created using adobe Illustrator and Adobe Photoshop.

4. Animating: The 3D portions of the animations will be animated using ZBrush and the 2D portions will be animated using Adobe After Effects. The final animation will be created and edited in Adobe After Effects.

Assessments

A museum pilot test will be carried out by the supervisory committee of this project at the Royal Ontario Museum. A research ethics protocol will be submitted to the University of Toronto Research Ethics Board (REB) and the field study will commence once ethics approval has been obtained. A sign will inform visitors about the study being conducted and an optional questionnaire will be available for visitors to fill out. Quantitative and qualitative questions will be asked to evaluate: the efficacy of the visual solutions, storytelling and pacing of the animation; viewer attention and interest in the visual display, and retention and comprehension of knowledge. Results of the field study will help to inform the iterative design

process. Once the research goals have been met, the final iteration of the visual tool will be incorporated into the ROM's Dawn of Life gallery in 2020.

Usage

The final tool will be a series of multimedia animations that will be displayed in the Willner Madge Dawn of Life gallery at the Royal Ontario Museum. These animations will be integrated with the other displays of the gallery and complement the educational material and chronological storytelling presented. In addition, these animations will be available through various online media, such as the Royal Ontario Museum website, to potentially be used as a supplementary learning tool for students.

Significance

The description of extinct species is fundamental to the science of zoology, including taxonomy, phylogenetic systematics, functional morphology and ultimately evolutionary biology and ecology (Haug, Briggs, & Haug, 2012). Morphological investigations of newly discovered specimens from the Burgess Shale helps to refine the descriptions and reconstructions of these extinct species and improve current phylogenetic analyses of these extinct taxa (Haug, Briggs, & Haug, 2012). This project aims to develop a better understanding of the close relatives of Anomalocaris through reconstruction and morphological analysis. The study of newly identified specimens allows for the construction of speculative but crucial hypotheses for the evolution of major arthropod features and the placement of these organisms within the arthropod lineage (Budd, 1996).

In addition, creating a multimedia animation series that will be integrated into the ROMS new Dawn of Life Exhibit will provide the general public with access to current scientific research in the field of invertebrate paleontology, while celebrating scientific advancements in this field (Henriksen & Froyland, 2000). Creating a museum display will also provide the opportunity to visualize key evolutionary concepts including the phylogenetic analysis and classification of extinct species. Making these learning tools available in a museum setting can help to improve scientific literacy in the general public by providing exposure to the scientific method and nature of science (NOS) (Meisel, 2010), which is widely accepted to be a primary goal of science education (Lederman 1992).

Design considerations for this multimedia animation will facilitate meaningful exploration of the subject matter.

Although multimedia learning tools tend to present information as absolute truth or the only authoritative interpretation (Economou, 1998), this technology can instead be used as a way to present alternative views and admit doubt and uncertainty when it exists (Economou, 1998). This includes the uncertainty and competing hypotheses presented for the phylogenetic relationship of extinct species from the Burgess Shale. In addition, this project will be the first to create and evaluate an educational animation series on the reconstruction and classification of a newly discovered extinct species from the Burgess Shale. Through the development of these animations, this project will investigate design strategies for creating educational displays for museums that addresses a broad a diverse target audience. The results of this project will contribute to the growing

understanding of how to engage the public with exploring scientific datasets in an informal learning context.

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