Masters Research Project Proposal

Reconstructing a new Species from the Burgess Shale, British Columbia: A Means of Translating Phylogenetic Research for an Informal Learning Setting

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Abstract

The exceptionally preserved fauna exemplified by the Burgess Shale of British Columbia are crucial for understanding the major adaptive radiations that occurred during the Cambrian explosion (Morris, 1989). Since the phylogenetic relationships of these organisms continues to be debated, recent research efforts have been concentrating on re-examining previous reconstructions and classifications of these organisms as more information and fossilized specimens become available (Brysse, 2008). The goal of this research project is to reconstruct and classify a newly discovered relative of *Anomalocaris* in order to infer aspects of this species' locomotion and ecology, and to gain a better understanding of the arthropod lineage; a topic that has been debated for over a century (Budd, 1996). The findings of this research will be used to develop a multimedia animation series for the Royal Ontario Museum's (ROM) upcoming *Dawn of Life* gallery. This educational tool will focus on the process of reconstructing and classifying a species and highlight how these findings enhance our understanding of early animal evolution and the relationship of extinct taxa to modern life. A museum pilot test will be conducted at the ROM in order to assess the efficacy of the visual solutions within an attention-competing environment. The results of this project will provide the general public with access to current research in the field of invertebrate paleontology and the opportunity to learn key concepts in evolutionary biology. Furthermore, this project will contribute to the growing understanding of how to engage the public with exploring scientific content in an informal learning environment.

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 fauna have allowed for detailed reconstructions and descriptions of these organisms' functional morphologies, thereby revealing modes of locomotion, sensory perception, and feeding strategies (Brysse, 2008). These specimens have proven to be invaluable in increasing our understanding of early animal evolution after the Cambrian explosion, in which a rapid diversification of organisms occurred (Brysse, 2008). However, the phylogenetic relationships of the organisms discovered at the Burgess Shale have been, and continue to be, highly controversial (Brysse, 2008). Recent research efforts have been concentrating on re-examining previous reconstructions and classifications of organisms as well as identifying and classifying new species as more information and fossils become available (Brysse, 2008). Despite the importance of this research, the information is often not presented in a manner that is digestible to the general public. However, museum exhibits including the *Dawn of Life* gallery at the Royal Ontario Museum (ROM) will be displaying fossil specimens from the Burgess Shale, along with recent ground-breaking research (Draaisma, 2018). This research will be presented through the use of educational visualization tools which aim to 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 utilizes both the visual and verbal channels, allowing for more effective cognitive processing (Mayer & Moreno, 2002). 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 paleontological displays in their ability to provide context for fossilized specimens (Economou, 1998). Currently, there are no multimedia animations about the reconstruction and classification of newly discovered species from the Burgess Shale and how these new fossil discoveries enhance our understanding of the origins of animal evolution. The aim of this research project is to address this gap.

Background

The fossil remains of the Burgess Shale are significant for several reasons. They include a wide variety of soft-bodied and hard-shelled 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). The diversity of fossil remains and the unique morphological characteristics exhibited may represent extinct clades that have never been examined before (Zhang, Shu, & Erwin, 2007). 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 (Zhang, Shu, & Erwin, 2007).

The organism to be studied and reconstructed for this research project is a close relative of *Anomalocaris*, an extinct genus that belongs to the family Anomalocarididae. The Anomalocaridids possess a unique combination of morphological characteristics which has led to a complicated history of discovery, description and interpretation (Collins, 1996). These characteristics include a segmented body with lateral swimming flaps bearing gills, a head with a pair of stalked eyes and a pair of frontal appendages, a circular mouth apparatus, and spiny plates that are often found dissociated from the rest of the body (Whittington & Briggs, 1985). These key features, in addition to indirect evidence of bite marks on trilobites, suggest a predatory mode of life (Nedin, 1999). The phylogenetic position of the Anomalocaridids continues to be controversial and a topic of great debate. Current studies suggest that the Anomalocaridids belong to the stem group of arthropods (Budd, 1996; Dewel & Dewel, 1998; Cotton and Braddy, 2004; Daley, Budd, Caron, Edgecombe, & Collins, 2009), with alternate interpretations regarding them as crown group arthropods (Chen, Waloszek, & Maas, 2004) or as a sister group to the arthropods (Daley & Peel, 2010).

Many aspects of Anomalocarididae morphology, diversity, and ecology remain unclear due to the 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 produce an accurate reconstruction (Gooding, 2004). Reconstructions often involve interpreting the morphological features of fossilized specimens based on analogy to modern counterparts, although these comparisons are often speculative (Gooding, 2004).

Classification of a New Species

New species discovered at the Burgess Shale are classified using a methodology of systematics known as cladistics. Cladistics is now the most widely used method of generating phylogenetic trees

(Brysse, 2008). Unlike evolutionary systematics, cladistics places no emphasis on unique characteristics, and instead seeks to identify shared derived characteristics (synapomorphies) that indicate common descent between species (Brysse, 2008). As a result, strange and unique characteristics, which includes derived characteristics not shared with other groups, are excluded from the phylogenetic analysis of a species entirely (Brysse, 2008). Two other concepts related to cladistics which are key to understanding Burgess Shale taxonomy are the crown group and stem group. Without these concepts it would not be possible to talk about the relationship of fossils organisms to modern life (Brysse, 2008). 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 (Brysse, 2008). 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 (Brysse, 2008). All members of stem groups are extinct and the group will be paraphyletic since some members will be more closely related to the crown group than others (Brysse, 2008). This is because synapomorphies connecting members of a crown group will have been acquired successively within the stem group (Brysse, 2008). Therefore, cladistics and the crown group and stem group concepts allow paleontologists to place new species within the extinct lineage leading to modern day arthropods (Brysse, 2008).

Arthropod Systematics

The phylogeny of arthropods has been debated for over a century, with an overall lack of consensus within the scientific community (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 not sufficient to be used in preparing cladograms for phylogenetic analyses (Haug, Briggs, & Haug, 2012). This is often because researchers focus on morphological features that differentiate new species from those that have been described previously (Haug, Briggs, & Haug, 2012). As a result, descriptions of new species focus on unique structures even though cladistics requires the identification of structures shared with other species (Haug, Briggs, & Haug, 2012). Consequently, the morphological descriptions of extinct species from the Burgess Shale are often incomprehensive and need to be reinterpreted (Haug, Briggs, & Haug, 2012).

Design Challenges and Considerations for Museum Displays

The ROM is currently developing a new permanent paleontology 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 (Draaisma, 2018). This gallery will also introduce key geological processes, evolutionary concepts and major evolutionary innovations (Draaisma, 2018).

Visualization tools in museums give the public access to current scientific research and data in a way that facilitates exploration and understanding (Frankel & Reid, 2008). However, the museum environment imposes its own constraints on learning with a visualization tool, since learning involves unmediated and short one-time only interactions with exhibits (National Research Council, 2009). One of the main challenges of a museum environment is designing a visualization tool that meets the needs of a broad and diverse audience (Hinrichs, Schmidt, & Carpendale, 2008). People who visit a museum exhibition differ greatly in terms of their age, prior knowledge, and social background (Hinrichs, Schmidt, & Carpendale, 2008). Some individuals visit museums to increase their understanding of a given subject, while others seek an entertaining and educational experience (Hinrichs, Schmidt, & Carpendale, 2008). The visitor's motivation for visiting a museum exhibit will ultimately influence their expectations and the way they explore it (Hinrichs, Schmidt, & Carpendale, 2008). In addition, museum visits are often limited by time, and the desire to see as much as possible results in exhibits competing for the attention of visitors (Hinrichs, Schmidt, & Carpendale, 2008). As a result, if a museum exhibit cannot capture the attention of a visitor within ten seconds it will likely be abandoned (Hornecker & Stifter, 2006).

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. These considerations include the visual appeal, the data included, the representation of this data, and technology used for the display.

Visual Appeal

An important aspect of visualization tools designed for museums is the visual appeal of the information. Visual appeal influences visitors' motivation to approach the display, the amount of time spent interacting with the display, and how the information presented is perceived and understood (Hinrichs, Schmidt, & Carpendale, 2008).

Data

The information being presented by a museum display must also integrate with the exhibit content and theme (Hinrichs, Schmidt, & Carpendale, 2008). Thus, another design consideration is how the information (data) being visualized will contribute to and reflect the content of the exhibit (Hinrichs, Schmidt, & Carpendale, 2008).

Representation

Since exhibit experiences are rarely mediated by staff, the visual representation of information should be intuitive, engaging, and appropriately simplified so as to reduce cognitive load and promote exploration of the information content (Hinrichs, Schmidt, & Carpendale, 2008).

Display Technology

The size of display technology used is an important design consideration since it will affect the overall visibility and integration of the visualization tool within the exhibit (Hinrichs, Schmidt, & Carpendale, 2008). Since museum visitors usually explore exhibits in groups, large display technologies are more effective as they allow visitors to explore the visualization tool in a collaborative way (Hinrichs, Schmidt, & Carpendale, 2008). Studies have shown that a successful visualization tool for a museum setting is one that allows visitors to actively or passively experience the display at once (Viégas, Perry, Howe, & Donath, 2004).

Multimedia Applications for Museum Displays

Multimedia learning tools consisting of pictures, such as animation, and words, such as narration, offer an effective medium for teaching scientific concepts and processes (Mayer, 2002). Multimedia applications have particular strengths for paleontological displays in their ability to provide an idea of the original appearance of the fossilized organisms on display as well as an explanation of paleontological work itself (Economou, 1998). However, the design of multimedia animation ultimately determines the effectiveness of the teaching tool in promoting meaningful learning.

Interaction Strategy

According to Mayer (2002), multimedia learning will be more effective when learning material is interactive and in control of the learners. Since learners study at different speeds, having the ability to control the speed at which information is presented will produce better learning outcomes (Mayer, 2002). 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 & Moreno, 2002). According to dual-coding theory, humans 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 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 capacity of visual and verbal working memory are very limited (Mayer & Moreno, 2002). Having the visual or verbal working memory process too many elements at once can lead to cognitive overload resulting in some elements not being processed (Mayer & Moreno, 2002). Four design principles — contiguity, coherence, modality, and redundancy — are all related to this idea that students learn more effectively when their visual and verbal working memory are not overloaded (Mayer & Moreno, 2002).

The contiguity principle states that more effective learning occurs when animation and narration are presented simultaneously since the entire animation does not need to be held in working memory until the narration is presented and vice versa (Mayer & Moreno, 2002). Therefore, presenting animation and narration successively is more likely to cause cognitive overload and result in reduced levels of understanding (Mayer & Moreno, 2002). With the coherence principle, more effective learning occurs when individuals do not have to process extraneous textual or pictorial elements in the verbal and visual working memory respectively (Mayer & Moreno, 2002). As a result, presentations that include concise animation and narration reduce the likelihood of cognitive overload and increase the level of understanding compared to presentations that are embellished (Mayer & Moreno, 2002). With the modality principle, more effective learning occurs when visual working memory does not need to process both animation and printed text (Mayer & Moreno, 2002). Unlike narration, which utilizes the verbal working channel, printed text competes with animation for processing resources in visual working memory, resulting in cognitive overload (Mayer & Moreno, 2002). Therefore, presenting words as narration prevents the overload of visual working memory and allows for deeper understanding (Mayer & Moreno, 2002). Similar reasoning is applied to the redundancy principle in which the presentation of both animation and printed text results in cognitive overload in the visual working memory (Mayer & Moreno, 2002). Therefore, more effective learning occurs when animation is presented with narration alone rather than narration and printed text (Mayer & Moreno, 2002).

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 relationships 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 to 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 assets required 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 assets required 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.

Anticipated Significance

The description of extinct species is fundamental to the science of taxonomy and functional morphology which has applications within 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 (Haug, Briggs, & Haug, 2012). The study of newly identified specimens also 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 ROM's new *Dawn of Life* gallery 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). Making these learning tools available in a museum setting can also help to improve scientific literacy in the general public by providing exposure to the scientific method and nature of science (NOS), which is considered a primary goal of science education (Meisel, 2010). Although multimedia learning tools tend to present information as absolute truth or the only definitive interpretation, this technology can instead be used as a means of presenting alternative views and admitting doubts and uncertainties when they exist (Economou, 1998). This includes the uncertainty and competing hypotheses presented for the phylogenetic relationship of extinct species from the Burgess Shale.

Furthermore, 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 and diverse target audience. The results of this project will contribute to the growing understanding of how to engage the public with exploring scientific content in an informal learning environment.

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