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Claims, Evidence and Reasoning: A Framework for Evidence-Based Writing on the subject of Evolution

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CLAIMS, EVIDENCE, AND REASONING: A FRAMEWORK FOR EVIDENCE – BASED WRITING ON THE SUBJECT OF EVOLUTION

by

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Nothing in biology makes sense except in the light of evolution.

- Theodosius Dobzhansky, 1973

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INTRODUCTION

Informed Decisions

Informed decision-making is what this research is about. I wanted to know how students best learn to write in an evidence based manner – what the Next Generation Science Standards refer to as Claims, Evidence and Reasoning. In chapter one, I will talk about the path that led me to hold this skill so important. I will discuss my childhood, life in the woods, volunteer opportunities, go on to discuss time spent working with sea birds in Alaska, and finish with my teaching career. Each place changed me and made me a different person. I have become an educator with a commitment to constructive based pedagogy with a profound need to develop evidence based writing (and decision making) skills.

How did I get here?

I have always been at home in nature. As a child, my family and I spent many days out in the woods, finding treasures, building forts, walking the dogs, hunting birds, or just hiking at the area parks. One park stands out in my mind; one of the last remaining stands of the Big Woods on the Cannon River. I remember hiking and picnicking at our favorite spots, building forts, fishing, crossing the swinging bridge, getting lost one cold wintery night, and falling through the ice while fort building all in the same stand of woods. This area has remained the same for all these years. Most of my childhood was spent experiencing the outdoors first hand.

I started volunteering in late high school. First, as a wetland monitor with the Minnesota Pollution Control Agency for two years, then as a teaching assistant in a middle school earth science classroom. It was experiences like these that lead me to understand the complex balance of our ecosystem and the importance of teaching others about that balance. Looking for frogs that had deformities from the pesticides that we put on the fields and lawns with the Minnesota Pollution Control Agency taught me to think about the effects our actions have on the ecosystems around us. I began to understand why it is so important to make decisions based on information and evidence rather than doing so without any regard to the consequences.

I went to college to do the only thing I was passionate about at the time – to study natural science. The University of Minnesota – Morris taught me to think critically and question what I was learning about. Again, it became so important to me to do the work in classes rooted in factual based reasoning. I began to love to research journals, books, and interviews; they were the fuel that helped me answer difficult questions that I faced to topics like evolution, the use of stem cells, and climate change to name a few. This love and passion has continued on into my teaching career. I believe that it is so important to teach these same skills to students to equip them to make important decisions in their adult life. This paper will explore students' ability to provide appropriate rationale to a claim while working in a constructivist environment on the subject of evolution.

Alaska

In the fall of 2003, I was offered an internship in Seward, Alaska. I quickly took the position and relocated to the great frontier within two weeks. I began working with and researching reproduction in endangered sea birds. It was during this stay that I managed the captive population of seabirds, interacted with the public on a daily basis, and created educational panels on the endangered birds housed at the Sealife Center. To create these panels, I used our research, that of scientists in South Africa, and creative skills while creating permanent installations educating the public on the decline of the seabirds like puffins, eiders, and murres. From the art and education on the panels, people learned about the effect of climate change on native species. In the beautiful landscape where the mountains met the sea, I fell in love with nature and the natural world in a different way, coming to know the serenity that this wilderness offered but also the wonder that it could inspire. Entire days were spent walking along the water in the company of Stellar sea lions and sea otters, mucking through the rocks and sand during low tide looking for treasures, snowboarding down tucked away hills, and hiking Mount Marathon beneath the watchful eyes of bald eagles. I was filled with awe and wonder, but I was not too naïve to think critically about the scenario. The entire situation was made possible by an environmental disaster. The funding for the Alaska Sealife Center came from the settlement and clean up after the Exxon Valdez Oil Spill. Again, I was witnessing another example of how our decisions made a huge impact on our environment. I began to feel that as a society we needed to start making more careful and calculated decisions, look at both sides of the coin, weigh our options, and make decisions based off sound evidence.

The Real World

Then I moved to Texas – life isn't always so idyllic and magical in the real world! I worked at a decrepit animal rehabilitation facility that was running out of money while facing a high rate of abandoned, injured, or displaced animals. The site housed large exotic cats that had been illegally shipped in for "canned hunts," lab monkeys that wouldn't come out of their cages in fear of the grass they'd never before seen, and thousands of native animals that simply were displaced. It was unbearable to see the destruction that humans could cause, I came to understand that this was not the way to create change in the minds of society. I soon left and moved to New Orleans where I taught science classes at a nature center to elementary students. In a revolutionary way, these students took their science classes immersed in nature at the nature center. It worked – we taught them everything that was taught in the regular science classroom but in a sensory based and hands–on manner. The students from the ninth ward of New Orleans were engaged. The classroom was student-centered instead of teacher-centered. Pre and Post test scores showed significant differences. It changed everything for me. It showed me that there was a different way for children to learn.

Then Hurricane Katrina Hit, changing much of society in New Orleans. Displaced, my husband and I moved to Florida where I worked at an aquarium until I decided to teach high school science. After seeing how much damage we can do to our environment, it became a passion of mine to work on conservation and preservation. I realized that due to my constructivist - like roots in environmental education, I was an effective teacher and I could reach more students and families if I was teaching in a high school setting rather than at a nature center or through working directly with animals. I decided to work on preventing the problem rather than treating the symptoms. I brought those environmental teaching strategies that I had learned along the way to the traditional classroom. Environmental education focuses on cooperation between students, experiences for students, and application by students. To that end, the National Environmental Education Foundation states,

> Environmental education emphasizes cooperative learning (i.e., working in teams or with partners), critical thinking and discussion, hands-on activities, and a focus on action strategies with real-world applications. As a result, students who study EE develop and practice the following leadership skills: working in teams, listening to and accepting

diverse opinions, solving real-world problems, taking the long-term view, promoting actions that serve the larger good, connecting with the community, [and] making a difference in the world. (nd)

It worked. Students loved science and learned in and outside the classroom. It was here that I met one of my mentors, Leon Mays. He was a similar teacher to me, an old environmental educator working in the Florida school system. Together, he and I taught classes like urban forestry, took field trips, and built an outdoor classroom with our students. He brought me to conferences, introduced me to Project Learning Tree, and was my biggest cheerleader. He was one of my best friends and favorite colleagues.

After two years in Florida, my husband and I moved back home. I found a job at a charter school that seemed to fit me well; I've been here for nine years.

The Person I Have Become

While working at a Midwestern, urban, Montessori charter school, I've changed significantly. I have acquired many skills to inspire that same awe and wonder in students that I experienced in Alaska. But I've also learned how to give children experiences toward understanding why conservation and preservation matter. I teach regular classes like biology, but also classes like beekeeping, sustainable cooking, urban farming, case studies on climate change and fracking, pond studies and many others. When I started, I didn't really know how to cook – but I learned because I could see the connection between eating local, whole foods, and cutting down on our energy use. And naturally, those new cooking skills worked their way into my home. I began gardening at home with my daughter, to show her the connection between growing food in your garden and climate change. I saw the connection to the land and the ability to captivate students that bees have, so I learned how to keep bees. When we are in the bee yard, the students listen like there is nothing else going on and I'm their favorite band singing a personal concert for them, they are truly captivated. This school enables me to offer experiences to children that enable them to think critically about situations and make decisions based off their own experiences and facts. It was really the situation that I'd been searching for.

It was at this Montessori school that I began to understand how important the self-construction of the student is. To me, there is no other way to teach than through inquiry-based methods; this way works so well and can be much more meaningful to students. Over time my teaching technique has unintentionally morphed into a well-developed constructivist approach. The constructivist approach encompasses how students learn and not about how teachers teach. It is student – centered and focused on the student constructing their own knowledge from experiences that educators prepare and guide them through. "Constructivism is premised on the ideas that knowledge is 'constructed' by thinking individuals and that knowledge is self regulated and self mediated on the basis of a person's prior experiences" (Llewellyn, 2007, p 86). This pedagogy began to really resonate with me and become a natural part of the way I structured my classes. As time went on, students began to feel empowered in science classes, they remarked that they felt good at science, and liked learning about the subject material.

One challenge to delivering the biology curriculum in a constructivist manner was the topic of evolution. I set the goal to develop good evolution curriculum - I just wasn't satisfied with how the students were experiencing the content. I wanted students to be able to form their own opinions and theories about the topic based on facts, essentially, to be able to participate in a society in an informed way. Evolution education is a topic that many teachers avoid. It is a sensitive subject for many fueled by religious, cultural, and scientific opinions and facts. (Wei, 2012). The subject of evolution turns out to be a great tool to teach evidence based writing and it could equip students with the tools to make their own decisions about the subject

Then, in 2012, an opportunity to write curriculum on the topic of the evolution of multicellularity presented itself. This curriculum offers the opportunity for students to experience evolution of a model organism. During this lab, the students can see evolution happening in the classroom, they can take data on their work, and it involves real organisms. Because of this, the curriculum has the capacity to spark that same awe and wonder that I experienced when learning new topics or being immersed in the natural world. In collaboration with Dr. William Ratcliff working at the University of Minnesota and Nicholas Beerman, a teacher at McDowell Montessori School in Milwaukee, WI, we developed a curriculum where high school and undergraduate students could evolve baker's yeast (*Saccharomyces cerevisiae).* Using a protocol design by Ratcliff et al. (2012, 2014), we set out to create a curriculum geared towards teaching evolution effectively to high school and undergraduate students. This lab – based curriculum incorporated the use of a model organism, baker's yeast, to make the transition from a single celled organism to a multicellular organism in six weeks. Through the use of simple lab techniques, high school students are able to see this transition and thereby experience evolution giving them concrete experiences from which to draw their own conclusions upon.

Students need critical thinking skills. They are living in a more demanding society today. As they live and work in our society, they must know how to make informed decisions. The topic of evolution provides effective subject matter to make a theory and be able to support that theory with sound reasons and evidence. This is helpful to the student when making personal decisions about evolution but also the use of stem cells, climate change, and genetic engineering. We as educators must prepare students with the ability to make these decisions.

Research Question

The goal of this qualitative research was to explore to what extent students present reasoned arguments supported by evidence and reasoning, what educators refer to as evidence – based writing, after receiving scaffolded instruction? Students will do this work within an evolution unit based in constructivist pedagogy. It explores the theory that inquiry-based learning with authentic lab techniques can enable students to form their own opinions on the theory of evolution and support with scientific reasoning. Ninth grade students at a charter school in a Midwestern urban Montessori setting will complete a six-week unit on evolution while focusing on developing strong reasoning skills with targeted activities. Through the use of student lab reports and interviews, this research will explore inquiry-based, constructive methods when teaching about evolution.

Chapter 2:

REVIEW OF LITERATURE

Introduction

Writing is one of the most important skills that educators can teach in the high school classroom today (Srougi et al., 2014). Wheeler–Topin (2012) writes that writing stretches across almost all professions, plays a vital role in communication, and is present in everyday life. In the classroom, writing forces students to organize their thoughts and find relationships. In the fast paced world, writing also holds ideas long enough for students to think about them, evaluate them, and assess them (Wheeler –Topin, 2012). Compared to discussions, writing enables all students to participate. Written responses also help teachers discover misconceptions and what prior knowledge students are bringing to the classroom (Wheeler –Topin, 2012). The goal of this qualitative research was to explore to what extent students present reasoned arguments supported by evidence and reasoning, what educators refer to as evidence – based writing, after receiving scaffolded instruction? In this chapter, I discuss evidence-based writing, constructivist pedagogy, and give an introduction to evolution of multicellularity. I aim to examine the use of constructivist based learning as a best practice in order to teach evidence based writing skills more effectively in introductory biology courses. This research also introduces the reader to the evolution of simple multicellularity. This research will focus on the transition from single celled organisms to mutli-celled organisms and a hands – on lab so students can experience this type of evolution in the classroom in a realistic scenario.

Evidence Based Writing

I believe for students to be scientifically literate citizens, they need to be able to articulate their opinions and that their opinions are rooted in credible evidence. Students need to be able to form opinions based off facts and to discern fact from fiction to be engaged citizens. This capacity enables students to make informed decisions about issues that they will face in their adult lives like evolution, stem cells, antibiotic resistance, energy resources and climate change. Students also need have to have a stronger understanding of the content area to be able to explain their thoughts and the scientific principles of the phenomena and being able to make a sound argument is crucial to that process (Nelson, C. 2007; Venville and Dawson, 2010,;Wei et al., 2012). But perhaps, Driver et al., (1997) says it best.

> If we intend to show the socially constructed nature of scientific knowledge, we must give a much higher priority than is currently the case to discursive practices in general and to argument in particular. Being able to present coherent arguments and evaluate others, particularly those reported in the media, is important if students are to understand the basis of the knowledge claims with which they are confronted. Also, in our contemporary, democratic society it is critical that young people receive an education that helps them to both construct and analyze arguments relating to the social applications and implications of science. (p 297)

Claim, Evidence, and Reasoning

Claim, evidence and reasoning is an effective writing strategy that targets evidence–based writing. Students should be able to voice well - informed opinions based on a deep understanding of the scientific concepts, demonstrate reasoning, and support their argument with evidence (Srougi et al., 2014). Reasoning is used to answer open-ended problems with no definitive, right answers that have many resources from which to draw support from (Kuhn, 1991). To underscore the importance of developing reasoning skills, a growing body of researchers concludes that these critical reasoning skills are more important for high school and college students than specific science content knowledge (Heller and Hallabaugh, 1992; Heller, Keith, and Anderson, 1992; University of Minnesota Physics Education Research and Development, nd). Fenci (2010) conducted a study in a general education course comparing the development of critical reasoning skills in a class that explicitly developed these versus a control class. The class that developed those skills showed significant gains in reasoning and were better able to give a sound argument rooted in evidence after reading a scientific article.

The framework of claim, evidence and reasoning is an instructional approach to writing a scientific argument. It includes three components: a claim, evidence, and reasoning (Venville and Dawson, 2010). "The claim makes an assertion or conclusion that addresses the original question or problem about a phenomenon. The evidence supports the student's claim using scientific data (McNeill, and Krajcik, 2008b, p 123)." McNeill and Krajcik go on to say, "The reasoning links the claim and evidence and shows why the data count as evidence to support the claim" and adds that the reasoning nearly always explains a scientific principle (2008b, p 102).

Next Generation Science Standards

The United States has seen the need to bolster its existing science, technology, engineering and math curriculum to produce graduates that can solve complex problems, defend their thoughts, examine claims made in the media, and work collaboratively in groups. In response, the Next Generation Science Standards (NGSS) were created. The NGSS emphasize

Science and Engineering Practices (Table 1) as key skills that should be developed throughout the child's educational history. Upon examination of those practices, it becomes apparent that evidence-based writing is a key part to educating the current students (NGSS Lead States, 2013).

Table 1. Scientific and Engineering Practices in the Next Generation Science Standards. (Next Generation Science Standards, 2013)

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. *Constructing explanations* (for science) and *designing solutions* (for engineering)
7. *Engaging in argument from evidence*
8. Obtaining, evaluating, and *communicating information*

Delving further, the Science and Engineering Practices that are highlighted under the topic of Natural Science and Engineering are the latter three: constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information (NGSS Lead States, 2013). The NGSS outline:

> **Constructing Explanations and Designing Solutions**
>
> Constructing explanations and designing solutions in 9-12 builds on K-8 experiences and progresses to explanation and designs that are supported by multiple and independent student-generated sources of evidences consistent with scientific ideas, principles and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigation, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Engaging in Argument from Evidence

Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current or historical episodes in the science.

- Evaluate the evidence behind currently accepted explanation or solutions to determine the merits of arguments.

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in the 9-12 builds on K-8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific information (e.g., about phenomena and /or the process of development and the design and performance of a proposed process or system (in multiple formats (including orally, graphically, textually, and mathematically.)

(NGSS Lead States, 2013, p 268)

If the need for citizens that are thinking critically about issues isn't enough, the NGSS clearly stresses the importance. The need for students to be able to make a claim and support it with evidence and reasoning is mentioned throughout the Next Generation Science Standards (NGSS Lead States, 2013). These skills involve students introducing a claim that they've ideally identified within a group, being able to discern that claim from counterclaims, and creating clear relationships to the claim, the counterclaims, evidence, and reasoning. The claims and counterclaims should also supply data and evidence collected, ideally by the student, while stating the strengths and weaknesses of both. In other words, the claim needs to be justified (Krajcick, 2012, January).

Teaching the Skills of Evidence – Based Writing

To teach the skills of evidence - based writing, Rupp – Fulwiler (2007) outlines a four-step sequence (Table 2). It includes first engaging the students using questioning and brainstorming to engage their prior knowledge. Then moving the students toward their own active investigation, they will write a question that they will investigate, discuss variables, make predictions, create data tables, and model observations. In the investigation stage, students will work with concrete materials to collect data and record it into their science notebooks. In addition, scientific thinking is modeled by the instructor and students are encouraged to practice that thinking through work with cooperative groups. The next step incorporates the use of whole class discussions. Students discuss the data, observations, graphs, and the concrete materials. During this time, the class begins to reflect on what occurred in the investigations and how the data supports the explanations that are beginning to emerge. The last step is application; students think about how this applies in the real world (Toulman 1958; 2003).

Table 2: The Teaching – Learning Sequence (Rupp – Fulwiler, 2007, p 14)

Stages	**1. Engagement**	**2. Active Investigation**	**3. Shared Reflection**	**4. Application**
Teacher	Models making tables, notes, data entries, illustrations, diagrams	Works with groups: asks questions, models language and thinking, addresses misconceptions	Models making tables, graphs of class data, graphic organizers. Introduces new words to word bank. Models language, thinking.	Leads discussion to connect lesson with real world or further investigations
Student	Write: date, investigation questions, prediction with reasoning, table.	Record Data. Take notes. Make illustrations, diagrams	Use notebooks to provide data for class results, evidence for own reasoning, explanations, conclusions.	May use notebooks to provide ideas, questions.

To structure the evidence based writing process further, McNeill and Martin (2011) recommend the following steps to help students with the claim, evidence and reasoning process. First, students make a simple claim about the general question "How was your weekend?" using a claim, evidence and reasoning graphic organizer. To model how to use the graphic organizer, it should be projected and gone through together as a class. The topic sentence is on the board using words from the question that is either developed by groups or given to the class. When modeling how to write the claim, the authors recommend using the words "for example" and to use their own data to finish the sentence. Finally, the concluding statement should also be modeled and should use the words "therefore". The final sentence should begin with "I think this is because" (McNeill and Martin, 2011, p 53 - 54).

Evolution as an Opportunity

With the former criteria outlined by the NGSS in mind, the topic of evolution lends itself nicely to provide an opportunity where students can meet the required criteria outlined in the Science and Engineering Practices while writing evidence–based material. It enables students to actively form ideas off their own work in the lab, gather data, construct explanations as to what they are seeing, and evaluate and communicate that information in various ways. It is also a highly debated and controversial topic that lends itself so easily to evidence-based writing (Venville and Dawson, 2010).

Constructivist Learning

A secondary task of this research is to help students discover evolution through their own work, not through someone else's or by reading about it in a book. Constructivism is a best practice that is commonly used to achieve those results. With roots reaching back to Dewey, Piaget, and Vygotsky, constructivism can be described as a theory of how children learn, not how teachers teach. Student learning should be an active process where they construct their own knowledge through inquiry based methods, work cooperatively with others, and discuss their learning with their peers (Brooks and Brooks, 1993; 1999; Burrowes, 2003, Christianson and Fisher, 2010; Llewellyn, 2014, Lord, 1998; Piaget, 1958; Roth, 1994; Vygotsky, 1978). Vygotsky (1978) states,

> The level of actual development is the level of development that the learner has already reached, and is the level at which the learner is capable of solving problems independently. The level of potential development (the "zone of proximal development") is the level of development that the learner is capable of reaching under the guidance of teachers or in collaboration with peers. The learner is capable of solving problems and understanding

> material at this level that they are not capable of solving or understanding at their level of actual development; the level of potential development is the level at which learning takes place. It comprises cognitive structures that are still in the process of maturing, but which can only mature under the guidance of or in collaboration with others. (p 85)

Constructivism in the Classroom – Cooperative Learning

Constructivism is student centered. Instead of classes where information flows from the teacher to the students, the students construct their own learning from experiences guided by the teacher (Brooks and Brooks, 1993; 1999; Bruner, 1960). Within constructivist pedagogy, there is a strong emphasis put on cooperative learning as students become active participants in the learning process (Bruner, 1960; Llewellyn, 2014; Piaget, 1958; Roth, 1994). There are many benefits to using cooperative learning and can be grouped into three categories, "efforts to achieve, positive relationships, and psychological health" (Johnson, Johnson, and Holubec, 2013). Students in cooperative groups achieve higher marks, are more productive, retain information on a long - term basis, are more motivated, achieve higher level thinking skills, and think critically about the concepts covered. In addition, strong, caring bonds are formed between the members of the cooperative groups through the personal and academic support they give to each other, the importance of diversity, and cohesion that is promoted through the structures of these groups. Students in cooperative learning groups also have greater psychological health due to their ability to help others in the groups, receive support, and the strong caring relationships previously mentioned (Johnson, Johnson, and Holubec, 2013).

Constructivism in the Classroom – Prior knowledge

Constructivism begins the learning process by accessing prior knowledge and identifying misconceptions.

> Constructivists hold that learning is an interpretive process, as new information is given meaning in terms of the student's prior knowledge. From a constructivist point of view, each learner actively constructs and reconstructs his or her understanding rather than receiving it from a more authoritative source such as a teacher or a textbook. (Roth, 1994, p 198)

New knowledge is built upon previous knowledge, previous knowledge affects how the learner interprets the new material. Prior knowledge has a profound impact on how students can take in, interpret, and make sense of the information that they are learning during the exercise. When teachers are aware of the prior knowledge that students have and the misconceptions that students hold, they can be better equipped to address those misconceptions in the classroom and access connection points with prior knowledge (Brooks and Brooks, 1993; 1999; Burrowes, 2003; Christianson and Fisher, 2010; Llewellyn, 2014; Lord, 1998; Roth, 1994). Some misconceptions as presented by the University of California at Berkeley about evolution are: evolution is a theory about the origin of life, evolutionary theory implies that life evolved (and continually evolve) randomly or by chance, because evolution is slow, humans cannot influence it, and evolution only occurs slowly and gradually. These are just a few examples, but as stated previously, once an educator knows and can recognize the misconceptions their students have, they can better present lessons and activities that help address them. (Misconceptions about Evolution. Understanding Evolution, 2015).

Constructivism in the Classroom – Role of Assessment

Constructivism works best when students can work together in groups to share their prior knowledge and then test those understandings. (Brooks and Brooks, 1993; 1999; Llewellyn, 2014; Lord, 1998) Through "discussions, cooperative group work, and inquiry – based investigations…It's all about how we come to know what we know. It is founded on the premise that we search for and construct meaning from the world around us " (Llewellyn, 2014, p 87). Emphasis is put on the learner understanding the material, being able to make sense of the material and being able to reproduce the material in collaboration with others (Brooks and Brooks, 1993; 1999; Christianson and Fisher, 1999; Lord, 1998; Roth, 1994; Tynjålå, 1999). Writing assessments should be included; studies have shown that many formative assessments such as, learning journals, extended essays, and reflective statements produce higher long term learning results than only one summative lab report at the end of the unit. Writing assessments could include application of knowledge, criticism of a particular reading, reflection of what they've learned based on their previous knowledge, new theories based off of newly acquired knowledge, application of those new theories to new situations, preparation and participation in a group discussion or seminar, and application to real world situations (Brooks and Brooks, 1993; 1999; Christianson and Fisher, 1999; Lord, 1998; Tynjålå, 1999). Rather than a significant summative test being taken at the end of a unit that measures how much a student has committed to memory throughout the course, the purpose of ongoing, formative assessments during the constructivist learning process is to "promote the learning process and to find out what kind of qualitative changes are taking place in students' knowledge" (Tynjålå, 1999).

Christianson and Fischer (1999) compared constructivist based and traditionally structured college classes based mostly off lecture and concluded that students in the constructivist-based classroom scored better on post test results with a chi squared value of 29.82, $p< 0.01$, a statistically significant result. More specifically those same students out performed their counterparts on three content items involving complex reasoning skills (p 692). These students "demonstrated a good understanding of the reasoning on most items" (p 694).

Comparatively, students in the two lecture courses did not perform as well on the content plus reasoning questions. Researchers attributed this ability to understand and apply the newly acquired knowledge to the constructivist process; the emphasis on prior knowledge, misconceptions, inquiry-based learning strategies, cooperative learning groups, discussion, and reflection.

In a study performed at the University of Jyvåskylå (1995), researchers found that 80% of students in an educational psychology course thought that constructivist based learning helped develop their thinking, whereas only 15% of students in the same course but delivered in a traditional manner felt that their thinking had been developed. One hundred percent of students in both groups felt that they had acquired knowledge. However, 73% of the constructive learning students felt that they had acquired skills, where only 54% of the control group felt the same (Tynjålå, 1999).

Constructivism in the Classroom - The Role of Discussion

To be a learner in a constructive classroom means to be an active learner, use experiments, solve problems, ask questions and explore, to acquire and evaluate new knowledge. Students and teachers reflect and evaluate on that learning, discussing and assessing how they are gaining knowledge and understanding. This continuous reflection strengthens ideas and they become increasingly complex. Students can apply new information better. (Brooks and Brooks, 1993; 1999; Christianson and Fisher, 1999; Llewellyn, 2014; Lord, 1998; Tynjålå, 1999) "Children come to understand and interpret their world through observing and inquiring with the help of their peers. Dialogue, discussion, and communication with peers during inquiry make the construction of knowledge a social experience" (Llewellyn, 2014). The teacher's role is to guide and facilitate this reflection and new acquisition of understanding. The classroom environment shifts from teacher centered to student centered where the teacher acts more as a guide, one who asks good questions, provides prompts when needed, and helps the students assess their learning. “Teaching is not transmitting of knowledge but helping students to actively construct knowledge by assigning them tasks that enhance this process” (Tynjålå, 1999, p 365). Discussion plays a large role in the constructivist classroom. It provides a forum where children and adolescents alike can share ideas, test beliefs, and reflect on what the learning process. Students can also ask questions and clarify their learning in a way that put them in charge of their learning and gives more intrinsic value to that learning (Brooks and Brooks, 1993; Christianson and Fisher, 1999). Table 3 compares a traditional classroom to a constructivist classroom and reflects the shift to a student – centered, inquiry - based classroom.

Table 3: Comparison of a traditional classroom and a constructivist classroom. (Thirteen ed online, 2015)

Traditional Classroom	Constructivist Classroom
Curriculum begins with the parts of the whole. Emphasizes basic skills.	Curriculum emphasizes big concepts, beginning with the whole and expanding to include the parts.
Strict adherence to fixed curriculum is highly valued.	Pursuit of student questions and interests is valued.
Materials are primarily textbooks and workbooks.	Materials include primary sources of material and manipulative materials.
Learning is based on repetition.	Learning is interactive, building on what the student already knows
Teachers disseminate information to students; students are recipients of knowledge.	Teachers have a dialogue with students, helping students construct their own knowledge.

Teacher's role is directive, rooted in authority.	Teacher's role is interactive, rooted in negotiation.
Assessment is through testing, correct answers.	Assessment includes student works, observations, and points of view, as well as, tests. Process is as important as product.
Knowledge is seen as inert.	Knowledge is seen as dynamic, ever changing with experiences.
Students work primarily alone.	Students work primarily in groups.

Evolution Science

The modern intelligent design movement developed in the mid 1980's gained momentum after the *Edwards v. Aguillard* Supreme Court decision ruled that creation science should not be given equal treatment given as evolution science. Because public schools could not teach a religious creation curriculum, intelligent design began to increase in popularity. Intelligent design is the concept that life forms are too complex and advanced to have evolved from such simple forms, as with the process of evolution, and must have begun through an intelligent force. With a forty to fifty percent acceptance rate of the theory of evolution in the general public, scientists and science educators have worked to come up with better, more effective ways to teach evolution (Abraham et al., 2012). Abraham et al. completed a qualitative analysis of college aged students' acceptance level of the theory of evolution and found that "even short interventions that explicitly teach evidence for evolutionary theory may influence student acceptance" (p 162), highlighting the importance for effective evidence based evolution instruction. Nelson (2007) discussed the importance of understanding the evidence of evolution and being able to critically think about the evidence before asking students to make a claim or state an opinion on the theory of evolution. Chinsamy and Plagányi (2008), also show strong evidence for using experimental evidence whenever possible when teaching students the subject of evolution.

The life sciences community accepts the theory of evolution and the connections it brings to the diversity and history of life. Yet the study of evolution has long been an area in need of improvement in United States curricula. Wei et al. (2012) hypothesize that this is due to "many people not understanding the principles of evolution or the nature, processes, and limits of science more generally." Evolution is often taught as a singular topic in the biology curriculum or is left until the last topic of the year – resulting in shortened content because of time constraints, leading students to believe that evolution is a minor point of life science or could be left out of the course entirely (Wei, et al., 2012). In light of that information, while working in collaboration with Dr. William Ratcliff, Dr. Sehoya Cotner, and Nicholas Beerman, we identified the need for an effective model to teach evolution (Pentz et al., 2015; Ratcliff et al., 2014; Ratcliff et al., 2012).

Geologic Time

When one thinks about evolution, we must think about the vast expanse of time that has passed since Earth formed roughly 4.6 billion years ago (Figure 1). During the first few million years the earth cooled from it's molten state after formation. During this time, no life had arisen, volcanoes were erupting, and the earliest rocks were still forming.

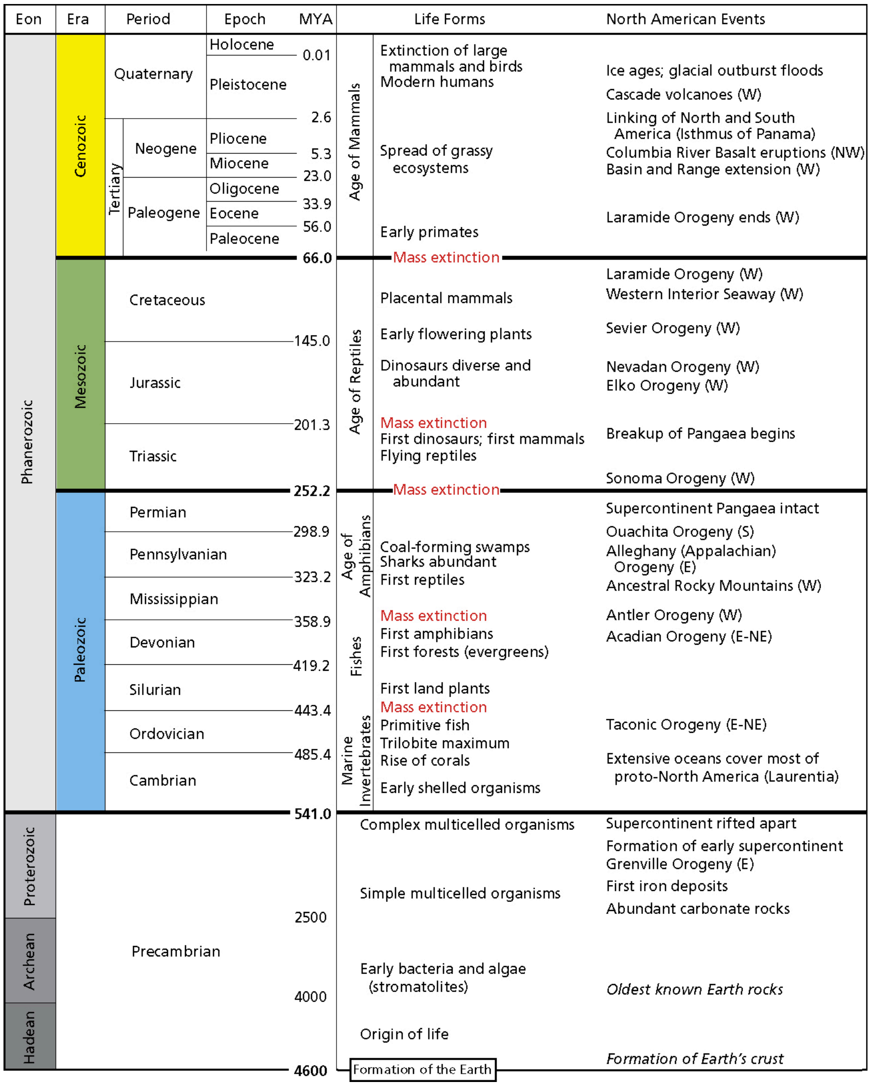


Figure 1: Geologic Time Scale. (National Park Service, 4.27.15)

The first cellular life to leave fossilized remains were unicellular prokaryotes (probably similar to modern day bacteria and archaea), which diversified into the early Precambrian oceans 3.4 billon years ago. Bacteria and other prokaryotic cells do not contain a nucleus that houses DNA or other plastids. Instead, the DNA is free floating inside the cell centralized in the nucleoid. Prokaryotes are mostly small, forming spheres (coccus), rods (bacillus), or corkscrews (spirochaete) shaped life forms. These life forms are typically single celled (unicellular).

The Evolution of Multicellularity

Around 2 to 2.5 billion years ago life made the jump from single celled organisms to filamentous and mat – forming cyanobacteria (Grosberg and Strathmann, 2007). These cyanobacteria colonies would form multi-celled structures called stromatolites documenting this time well in the fossil record.

Multicellularity is defined as an entity that contains multiple cells that show a division of labor. According to Grosberg and Strathmann, (2007) multicellularity evolved at least twenty five times from its unicellular ancestors. "Multicellularity appears to have originated once for the metazoa [animals], but multiple times (with secondary losses) in plants, fungi, and the eubacteria" (p 622). Figure 2 demonstrates the wide variety of life that has evolved among eukaryotic organisms (a monophyletic lineage of cellular life in in which cells have a nucleus and other plastids).

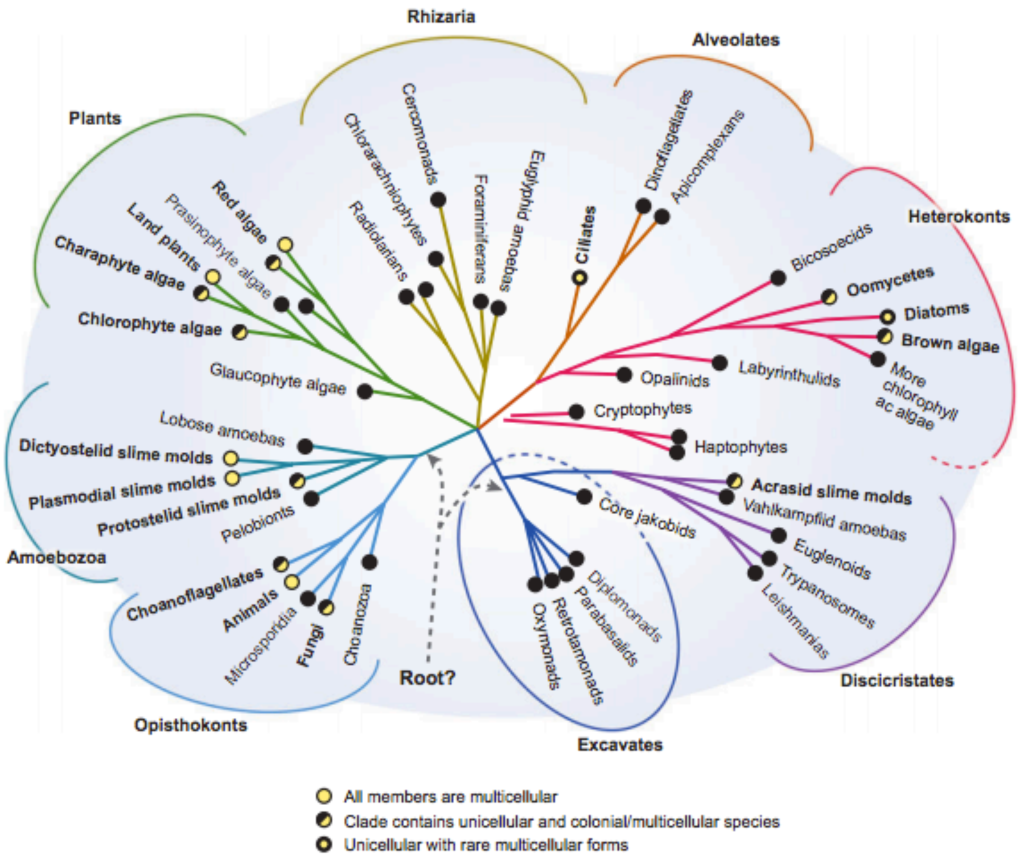


Figure 2: The Phylogenetic Distribution of Multicellularity among Eukaryotes. (Grosberg and Strathmann, 2007)

This transition from unicellularity to multicellularity seems to be "easy" (Grosberg and Strathmann, 2007, p 623). Grosberg and Strathmann state that this transition can be precipitated by factors present in the environment and that many single celled organisms will make the transition under certain conditions like predation or the ability to obtain resources more efficiently. Though relatively little is known about the evolutionary process underpinning the origin of multicellularity in nature, recent experimental work has shed light on how multicellularity may arise (Ratcliff et al., 2012). The first step to multicellularity was single celled organisms evolving to form multicellular clusters. Secondly, once cells adhere together, it must be advantageous for cells to live together. And thirdly, whole clusters must adapt as a group, for example through cellular differentiation.

Using baker's yeast (*Saccharomyces cerevisiae*) as a model organism, Ratcliff et al (2012) evolved simple multicellular entities that met the above criteria. The authors showed that daughter cells in *S. cerevisiae* adhere together to form multicellular clusters that exhibited a novel multicellular life cycle (characterized by cycles of growth and multicellular reproduction) (Figures 3 and 4). They accomplished this by selecting for fast settling through liquid medium, a simple experimental method of favoring large, fast sinking groups of cells (Ratcliff et al., 2012). The multicellular organisms also developed a division of labor. It was observed that the yeast clusters evolved apoptosis to create new budding sites to create smaller propagules to avoid the cell size limits of larger cells. This research has been modified for classroom use and forms the basis of the final analysis of students' ability to provide a rationale supported with evidence and reasoning (Pentz et al., 2015; Ratcliff et al., 2014).

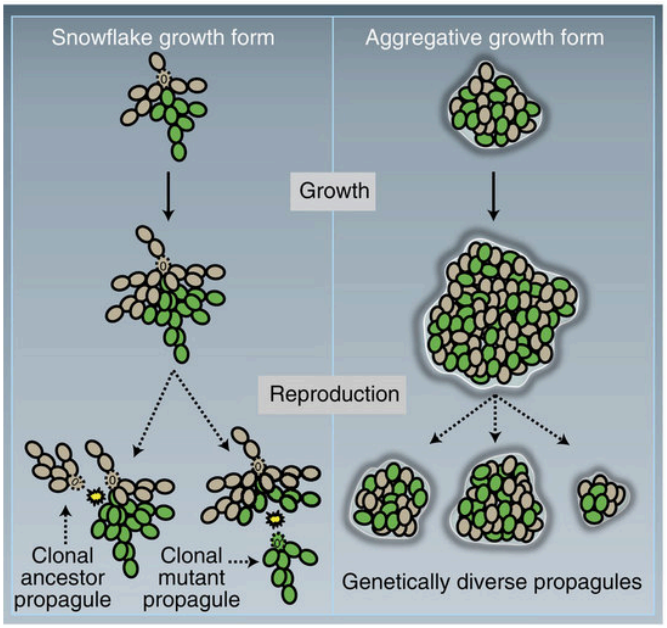


Figure 3: Snowflake yeast (*Saccharomyces cerevisiae) vs aggregate growth forms (Ratcliff et al., 2015)*

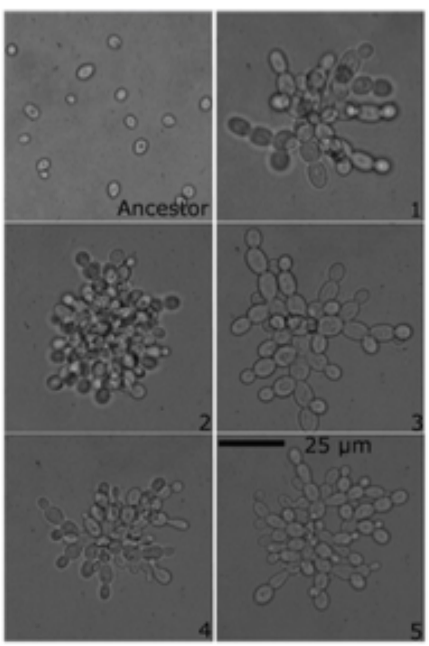


Figure 4: Rapid evolution of *Saccharomyces cerevisiae* after 400 generations of settling time in liquid growth medium. (reproduced with permission from Ratcliff et al., 2012)

Conclusion

Evidence–based writing has been shown to be a way to prepare students to make important decisions in their life. Constructivist pedagogy is an active way for students to become engaged in the learning process. The theory of evolution with its long debated nature provides a beautiful topic through which to employ both evidence based writing and constructivism. The goal of this qualitative research was to explore to what extent students present reasoned arguments supported by evidence and reasoning, what educators refer to as evidence – based writing, after receiving scaffolded instruction? The subject of study was evolution taught in constructivist – based pedagogy. Students were asked to keep a science notebook to document their evidence over the course of the investigation and were assessed on their ability to support their opinion of the experimental evolution in a culminating lab report. Through the use of student interviews I looked for trends in student knowledge and ability to verbally support their claims. Using the lab reports and student interviews, I was able to determine if students developed the ability to support their thoughts on evolution with evidence and deep understanding.

Chapter 3

METHODS

Introduction to Research Methods

The goal of this qualitative research was to explore to what extent students present reasoned arguments supported by evidence and reasoning, what educators refer to as evidence – based writing, after receiving scaffolded instruction? Qualitative research was used to gain a deep understanding of how the students experience the work of claim, evidence, and reasoning and their perspectives surrounding the work. Qualitative research was used to describe the individual experiences that my students were having, document detailed descriptions of the students' perception of instruction, integrate multiple perceptions of the process, explain relationships between their learning and the content presented, and to describe any variations that arose (Mack et al., 2005; Weiss, 1994). Qualitative research was effective when asking what and how questions. Qualitative data was appropriate for this study because the desired outcome was not a simple answer to a simple question, rather I sought the knowledge of the process of how students came to their end results (Silverman, 2011).

This exploration of how students present reasoned arguments supported by evidence and observations was scaffolded through a series of activities in an evolution unit based in constructivist pedagogy. Students began with a geologic time activity to grow accustomed to using their work to provide evidence to their own claims (evidence- based writing), to identify misconceptions, and to establish a baseline of student knowledge. Students then progressed to writing another evidence – based piece after receiving instruction on the three domains of life to have more depth from which to draw from while students develop their claims on the evolution of multicellularity. Finally, students moved on to a laboratory activity using yeast (*S. cerevisiae*) to collect their own data and make observations on evolution of multicellular life.

Demographics

Each section of biology contained twenty-eight students. Classes were held at 8:45 am and 9:45 am for 55 minutes each. Four hundred twenty three students attend in grades one through twelve at this Midwestern charter school with an 11% free and reduced lunch rate and 17% students of color. Twenty nine percent of students in the school tested in ninth or tenth grade earned a proficiency rating on the science MCA.

Analyzing Student Work

The work of twenty students was assessed using qualitative measures. I used quota sampling to select the twenty students (Mack et. al., 2005). (You may notice that student numbers exceed the number 20, this is due to originally collecting work from all students, numbering the work, and then taking out the 20 students that were selected to increase anonymity.) I sampled ten students from each section of biology, five males, five females. Of those twenty students, I included two special education or 504 students and one English Language Learner. To scaffold instruction, I used a claim, evidence, and reasoning graphic organizer (McNeill and Martin, 2011) (Table 4) and targeted strategies (McNeill and Krajcik, 2008b; McNeill, and Martin, 2011; Rupp Fulwiler, 2007). The graphic organizer helped students organize into evidence the data they observed and collected. It also helped organize student thoughts into a step-by-step form that makes claim evidence and reasoning more manageable. The graphic organizer explicitly asked for data that comes from the students' notebook or that they have gathered from papers, notes, or discussions.

Table 4. Claim, Evidence and Reasoning Graphic Organizer (Adapted From: McNeill, and Martin, 2011)

Claim, Evidence and Reasoning Graphic Organizer
1. **Big Question**: **How are organisms evolutionarily related?** (Hint: What question does your group have about the investigation?)
2. **Evidence:** What scientific data does your group have? What do your data show? Use evidence from your notebook including the position of organisms on the charts and characteristics that organisms share. Use specific details or numbers.
3. **Claim**: Write a sentence stating how organisms are evolutionarily related. (Use the evidence from step 2 to craft and support this claim.)
4. **Reasoning** (Claim and Evidence). Explain why your evidence supports your claim. Describe what it means to be evolutionarily related and why your evidence allowed you to determine the relationships.
5. **Explanation**: Use your evidence to fully explain the answer to the big question.

I used a rubric (Table 5) published by the National Science Teachers Association to help shape my thinking and to give feedback on students' attempts at evidence based writing.

Table 5: Base Explanation Rubric adapted from McNeill and Krajcik. (2008a, p 138)

Base Explanation Rubric				
Component	Level			
	Not Demonstrated	Developing	Proficient	Excelling
Claim- A conclusion that answers the original question.	Does not make a claim, or makes an inaccurate claim.	Makes and accurate but incomplete claim.	Makes and accurate and complete claim.	Ties claim into context of scientific claims.
Evidence - Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (evidence that does not support the claim).	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.	Gives specific data to support claim.
Reasoning - A justification that links the claim and evidence. It shows why the data count as evidence by using appropriate and sufficient scientific principles.	Does not provide reasoning, or only provides reasoning that does not link evidence to claim.	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some – but not sufficient - scientific principles.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.	Provides reasoning that links evidence to claim. Ties data and claim to specific scientific principles with clear demonstration of knowledge.

This rubric gave partial feedback to the students but my comments also informed the student on areas of growth and strengths. The feedback that I gave was not directly part of this study, instead a tool that I used to help students grow in their evidence – based writing skills. The lab reports included observations and data tables of student findings, which students used to support their writing. Trends in these data were analyzed. I looked for areas of strengths, challenges, students' ability to make connections between their data and claims, reasoning that connects to data given, and other trends that presented themselves. To do this, I coded the student's work using different colors to signify different themes. For example, blue coded for the presence of a claim, green for evidence, pink for reasoning. I also used a code on the side of each writing piece as a quick rubric to the student (Figure 5). The C corresponded to the claim, E to evidence, and R to reasoning. Each section (claim evidence or reasoning) received a "mark," ND for non -demonstrated, D for developing, P for proficient, and E for excelling. I read through student work first, taking care to notice themes that emerge, then read it a second time to confirm those themes, and again a third time to code the themes. The rubric helped shape my assessment in offering a consistent reference point.

Figure 5: Example of Coding on student work

Interviews

According to Mack et al. (2005) "The strength of qualitative research is its ability to provide complex textual descriptions of how people experience a given research issue. It provides information about the "human" side of an issue – that is, the often contradictory behaviors, beliefs, opinions, emotions, and relationships of individuals (p 1)." Silverman (2011) states that qualitative interview questions can sometimes be more valid and reliable than quantitative data when the desired outcome is an understanding of a process. Qualitative research consists of participant observation, interviews, and focus groups with field notes, audio or video recordings and transcripts being the principle types of data collected. I interviewed students at the middle and end of the unit. Each interview examined the learning process of the same twenty students whose written work was analyzed.

Interviews were conducted during independent work sessions. Students signed up for appointments on two Tuesday or Wednesday mornings. Students were asked to come to the interview with their notebooks that contained a previously written claim with evidence and reasoning on work specific to the particular interview. Interviews were held in the conference room at our school. These quick interviews were used to help students dialogue and process through the claim, evidence, and reasoning method, uncover individual experiences with the process, and identify themes common to the twenty students. Two interviews were used to provide mid term and final term data, track progress, identify areas of weakness and strength common to students, and direct one-on-one instruction. To ensure truthful answers no questions were asked about "opinions, attitudes, appraisals, evaluations, values, or beliefs" (Weiss, 1994, p 149). Questions were also of a concrete nature to ensure that they were answered from one perspective and were less likely to be modified (Weiss, 1994. p 150).

Poland (1995) cites the difficulty in transcribing interviews, the variability of subjects, pauses, grammar and speech patterns make it difficult. To that end, I digitally recorded the interviews with the app called Dragon Speech. This software recorded the interview and transcribed it into written transcripts. As a back up, I took notes during the interview and recorded the interview on my cell phone. I analyzed the interview data to determine:

- If students are able to verbally articulate what they have written in their journals
- Their ability to provide a rationale to a claim
- If their evidence connects with their claim with the appropriate scientific content
- Where students struggle and grow over time (McNeill and Krajeik, 2008b).

I listened to the recording several times to glean out prominent themes. I used a set of codes or colors to code for segments of text and sort the texts with similar content; then distilled out further into major themes (DiCiccio-Bloom and Crabtree, 2006). I used the general inductive approach to analyze the interviews. This process, outlined by Thomas (2006) includes a prep of raw data, close reading of texts, creation of categories using coding, finding overlapping coding and un-coded text, and coding revision and refinement of category system. This process yielded three to eight themes (Poland, 2005).

The following is a list of the interview questions that have been field tested with a group of tenth grade students, a group of teachers during the summer months, and submitted to the Human Subjects Review Board at Hamline University.

- What claim can you make about the evolutionary connections of the Kingdoms of Life?
- What are the data that you have collected to support this claim?
- Explain your thinking about your claim. Why do you think the way you do?
- What scientific principles can you help explain with these data?

Action Plan

Over the course of thirty days students went through an evolution unit rooted in the pedagogy of constructivism. While doing this, they were given direct instruction on evidence based writing within the framework of claims, evidence, and reasoning. Students were given four written and two verbal opportunities to make a claim and support it with evidence and reasoning. The first of the four written opportunities was an exercise with geologic time that enables the student to tap into their prior knowledge and demonstrate what skills they already possess. The second opportunity for the student to demonstrate evidence - based writing followed instruction on the evolutionary tree of life. Working in cooperative groups, students chose two organisms and made a claim stating how they are evolutionarily related. Students used research and examples from class materials to support their claim. Students then repeated this exercise on an exam (though this section was not for points) to determine if students could do this without the support of their group. After this third written assessment, I conducted a one on one interview with the students. Students then conducted an investigation on the evolution of a single-celled yeast to a multicellular yeast. Using experimental data, the opinions they gathered and strengthened from discussions, and the research they conducted, students stated a claim based on the evolution of multicellularity and support it with evidence and reasoning in a final lab report. Students then finished the unit with a final interview.

Summary

In summary, the goal of this qualitative research was to explore to what extent students present reasoned arguments supported by evidence and reasoning after receiving scaffolded instruction? Through the use of two interviews and four written student responses, I aimed to delve deeper in student learning. Using coding strategies, I analyzed data and looked for trends.

Chapter 4:

RESULTS

Overview

In Chapter one of this research, I explained my personal connection to this work and presented the research question: How do students present reasoned arguments supported by evidence and reasoning after receiving scaffolded instruction? In chapter two, I reviewed significant literature that pertains to this topic. In chapter three, I presented the methodology I took to investigate the topic of evidence - based writing. In chapter four, I document how the results relate to that research question and describe three major themes that emerged.

Results

After an introductory activity where students placed major events of evolutionary history on a timeline, I asked students to pick one of the events and hypothesize the corresponding geological time period, why they placed it in there, and why that placement made sense to them. I used this to gauge prior knowledge and discover misconceptions. We then spent time examining the tree of life and the evolutionary relationships it depicts. A graphic organizer (Table 4, p 44) and in class modeling was used to help students organize their ideas about evolutionary relations into the claim, evidence, and reasoning format. I collected this graphic organizer and gave written and verbal feedback on where students could improve. I then gave a formative assessment exam on the same skills. Following the assessment, I analyzed the work for major themes and areas of improvement and challenges for the students. Interviews were conducted with all students.

When following through with the interviews, I found that DragonSpeech or Google's Text to Speech application did not translate accurately from voice to speech. Alternatively, a LiveScribe (a smartpen that records voice and when paired with dot paper corresponds to written notes, www.livescribe.com) worked so effectively that I found I did not need to transcribe the interviews as the vocal recordings were sufficient. Notes were taken and analyzed looking for major themes and trends (refer to Chapter 3, page 46).

Following the first round of interviews, I noticed that student ability to verbalize their response was far greater than their ability to write it. Based on that, I identified that students needed more modeling, so I created a lesson explicitly modeling the skills. I presented a slideshow that clearly separated out each piece of evidence – based writing (claim, evidence, and reasoning) and explicitly taught concepts again, but in a different format, on how to complete each part of the writing.

Students then participated in a lab on the predation of single celled and multicellular yeast by rotifers to determine if rotifers preferred one over the other (Rotifer Predation Lab). We used this lab to practice writing another evidence-based writing piece. I analyzed the student responses, again looking for themes and areas of improvements. Interviews were then conducted with all students. After these interviews, the interviews morphed into more of a consultation than an interview as students became more comfortable and began to ask specific questions about their work and how they could improve. Figure 6 is a timeline of these major events.

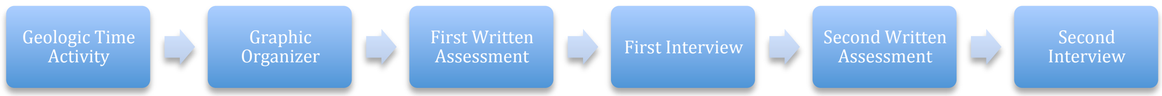


Figure 6. Timeline of Evidence - Based Writing Instruction and Assessment.

My analysis of the data resulted in three themes:

1. Students showed a steady trend of intellectual growth over time, resulting in an improvement of their evidence based writing skills.
2. Students benefitted from the constructivist based pedagogy.
3. Students had the greatest struggle with reasoning through writing and connecting it to broad scientific concepts

Theme One: Students showed a steady trend of intellectual growth over time, resulting in an improvement of their evidence-based writing skills

During this investigation, students were given four written and two verbal opportunities to demonstrate their knowledge of the subject of evolution. Throughout the course of the investigation, students continued to demonstrate steady growth of varying levels on each opportunity. Figure 7 depicts the steady progression of skills over the course of the investigation (as assessed by the Base Explanation Rubric, Table 5, page 41) with the majority of students demonstrating proficient or excelling skills by the second interview.

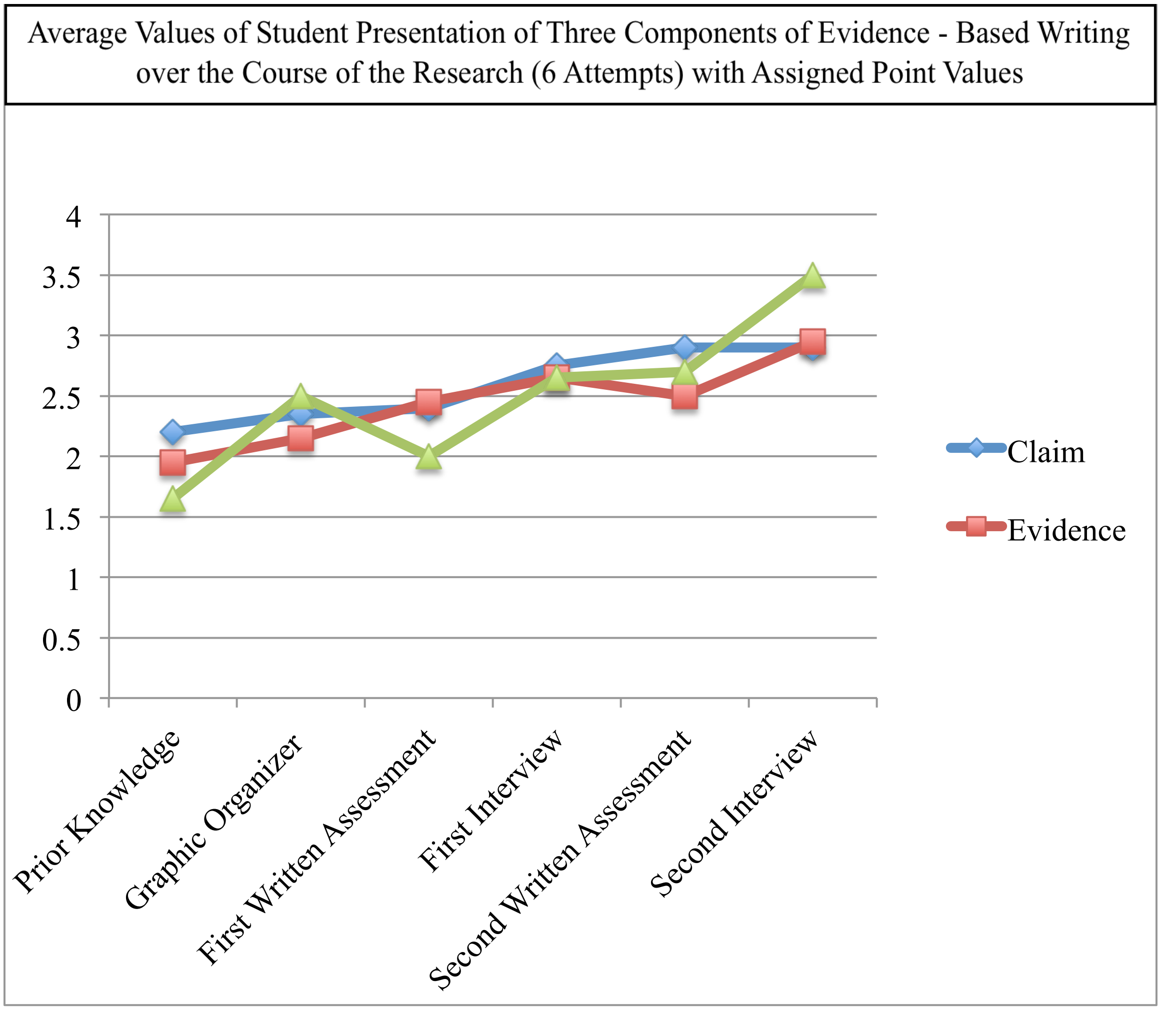


Figure 7: Average Values of Student Presentation of Three Components of Evidence - Based Writing over the Course of the Research (6 Attempts) with Assigned Point Values

To determine these levels, I gave a number to each of the different levels, number one for non-demonstrated, two for developing and so on. I looked at the student progression of evidence-based writing skills over the six exercises and looked to find the numbers of students that increased one line in the Base Explanation Rubric (Table 5, page 41). Then, I assigned each of the values in each level a point value and multiplied the number of students by the point value and found the average values for each section of evidence –based writing (claim, evidence, reasoning) for each of the six attempts (Table 6).

Table 6: Average Values of Student Presentation of Three Components of Evidence - Based Writing over the Course of the Research (Six Attempts) with Assigned Point Values

Component	Assessment					
	Prior Knowledge	Graphic Organizer	First Written Assessment	First Interview	Second Written Assessment	Second Interview
Claim	2.2	2.35	2.4	2.75	2.9	2.9
Evidence	1.95	2.15	2.45	2.65	2.5	2.95
Reasoning	1.65	2.5	2	2.65	2.7	3.5

These data show overall student growth from the first prior knowledge assessment to the final verbal assessment. Students showed a progression of skills after preliminary direct instruction. For example, at the time of the prior knowledge pre –assessment, the claim writing average score was 2.2. The final interview presented an average score of 2.9 for claim writing. Students showed the largest margin of growth when writing the reasoning component. Student cumulative scores began with a score of 1.65 and ended with a score of 3.5. As shown in Figure 7, student scores also showed less of an increase in performance from the first interview to the second written assessment (Rotifer Predation Lab). During the second interview, students again showed an increase in proficiency on the evidence and reasoning portion and remaining the same on the claim portion. The second interview showed students progressing in their writing ability, going from twelve percent of responses demonstrating excellence on the second written assessment to fifty two percent in the final interview. Interviews seemed to be helpful for this particular group of students while they were acquiring the skills of evidence-based writing.

As expected, students became more proficient with skills as they receive direct instruction and feedback (Figure 7, p 49). Students in this investigation began to demonstrate more proficiency and excellence in their final written and verbal assessment. Similarly, in a study conducted by Fenci in 2010, students showed significant gains when using hands on methods coupled with writing instruction. In the study, one set of college students was given daily physics practice problems and instruction on reasoning throughout the course of the semester. Another set was only given the practice problems. Predictably, the two groups did not differ in performance at the beginning of the investigation, but with continued and direct instruction the former group showed statistically significant gains between pre and post-tests. The students in the study "showed the ability to apply [reasoning skills] to straightforward but unfamiliar situations (2010, page 61)." Fenci concluded that "in this study, the use of carefully crafted activities requiring students to explore physics content through experiment, graphs, and written and verbal discussion did, indeed, have a significant effect on students' scientific reasoning skills (2010, page 61)." Fenci also suggests,

> Guided practice in reasoning skills appears to be a key component. Explorations that, if viewed superficially, appear content focused can be successfully used for the additional purpose of approaching reasoning skills if practice and use of those skills are built in intentionally. That intentionality must include both consciousness of the skills to be addressed and consciousness of the guidance or direction students need in order to do the activity. (2010, page 61)

I found that this guided practice was important to student progression of evidence – based writing skills. Students needed several attempts with and without the support of their cooperative group, direct and specific feedback, and one on one conversation as shown in Figure 7 (p 49). Steady student growth is what we as educators expect when we design a curriculum. Most educators take care to plan lessons and activities and give feedback to promote growth over time so this trend was expected. Additionally, I gave students immediate and specific feedback in their interviews, which enabled them to use that feedback promptly, promoting growth over time (Jones, 2005). During interviews, students would listen to my reasoning behind the mark that they received based on the rubric, and immediately restated their response (as will be discussed in Chapter 5). This enabled immediate change and improvement.

During the second round of interviews, Student 13 was given feedback that he/she did not connect his/her reasoning to a larger scientific concept. He/she was then able to pause, gather his/her thoughts and use examples from class to tie the broad concept of evolution into his/her claim. He/she explained,

> Like in the big cat example from class, it is not advantageous to bigger because you have to find more food or hunt in packs. But in [the case of the rotifers it] is advantageous to be bigger because you can escape predation.
>
> Student 13 Personal Interview, 3.1.16

Theme Two: Students benefitted from the constructivist based pedagogy

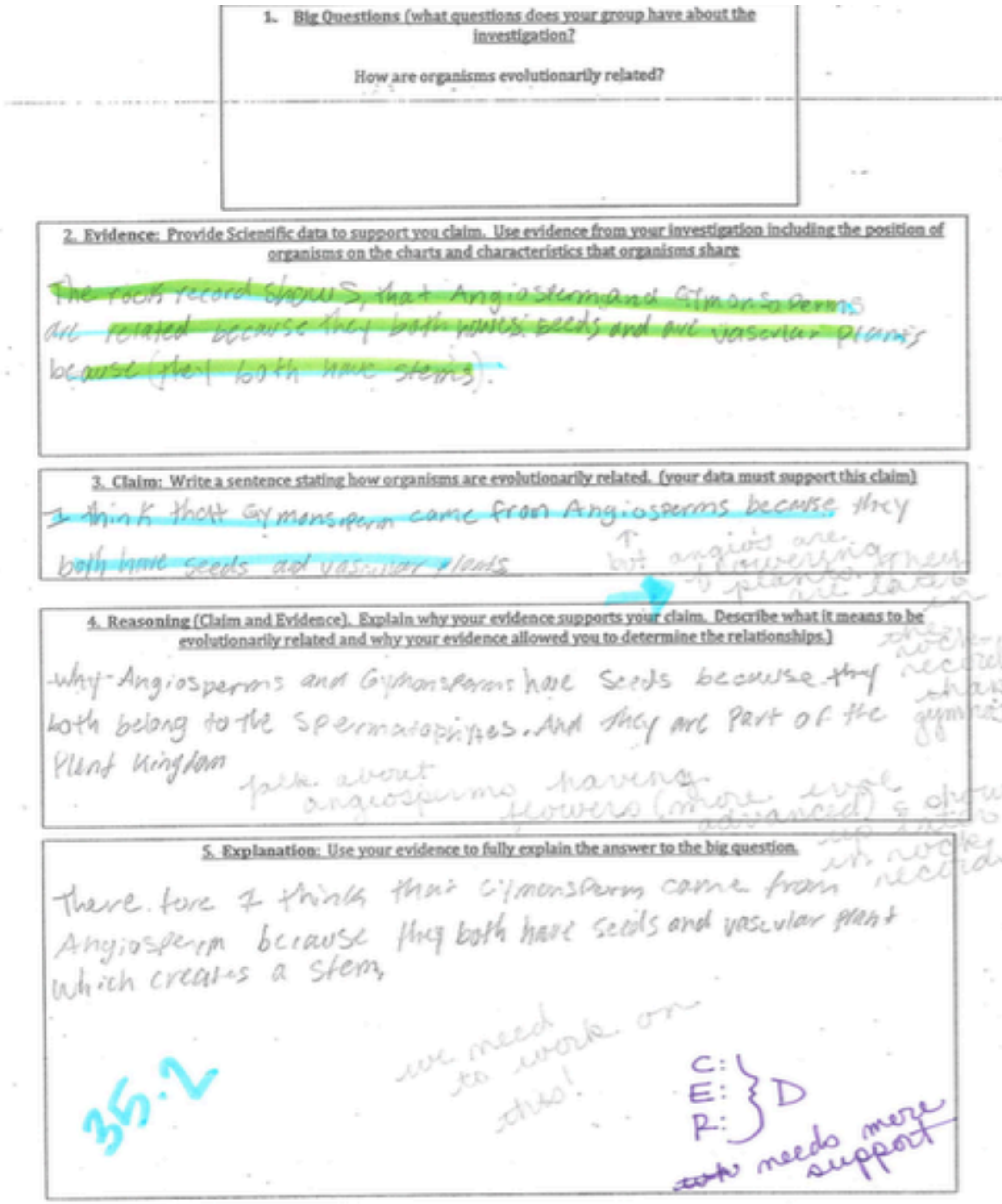
As stated in chapter two, constructivist pedagogy improves student learning through accessing prior knowledge, the student building his or her own knowledge through experiences, and cooperative learning that increases student engagement. During the course of this research I observed that cooperative learning groups helped struggling students. When struggling students worked with another student, they were able to write responses to the prompts or questions following the rubric that they would not have been able to formulate on their own. After reviewing the graphic organizer, I observed that students 22, 23, 32, and 35 had identical written responses to their partners and demonstrated more advanced thinking and vocabulary than on previous work. During the first round of interviews with these students, it was evident that these students could not verbalize their learning. Due to these observations, I concluded that these students relied heavily on their partners while writing the graphic organizer. When working alone, these students often disengage, record little in their journals, and minimally engage in the academic work. These students did show that they were able to gain skills throughout the investigation as demonstrated in Table 7 below.

Table 7: Student Progression of Skills (Not Demonstrating, Developing, Proficient, or Excelling) over the Course of Research

	Pre Assessment (0.1)			**Interview 2**		
Student	**Claim**	**Evidence**	**Reasoning**	**Claim**	**Evidence**	**Reasoning**
22	D	D	ND	ND	P	P
23	ND	ND	ND	P	E	E
32	ND	ND	ND	P	D	D
35	ND	ND	ND	P	P	D

.

Specifically, student 32 was one student that used the support of his/her group to his/her benefit. His/Her cooperative group would collaborate on activities through discussion and writing. It was apparent in student 32's writing that he/she and his/her group were working together closely as the student's writing is exactly the same as the more proficient peers in the group on the student's graphic organizer. Student 32 also did not demonstrate proficiency on the first written assessment (Figures 8 and 9). Student 32 was able to gain skills throughout the investigation, becoming proficient in writing a claim and demonstrating developing skills in supporting the claim with evidence and reasoning.



1. Big Questions (what questions does your group have about the investigation?

How are organisms evolutionarily related?

2. Evidence: Provide Scientific data to support you claim. Use evidence from your investigation including the position of organisms on the charts and characteristics that organisms share

The rock record shows, that Angiosperm and Gymnosperms are related because they both have seeds and are vascular plants because they both have stems).

3. Claim: Write a sentence stating how organisms are evolutionarily related. (your data must support this claim)

I think that Gymnosperm came from Angiosperms because they both have seeds and vascular plants

4. Reasoning (Claim and Evidence). Explain why your evidence supports your claim. Describe what it means to be evolutionarily related and why your evidence allowed you to determine the relationships.)

why- Angiosperms and Gymnosperms have seeds because they both belong to the spermatophytes. And they are part of the Plant kingdom

5. Explanation: Use your evidence to fully explain the answer to the big question.

there.fore I think that Gymnosperm came from Angiosperm because they both have seeds and vascular plant which creates a stem,

35.2

C:
E:
R:
D
needs more support

Figure 8: Student 32 Response from the Graphic Organizer

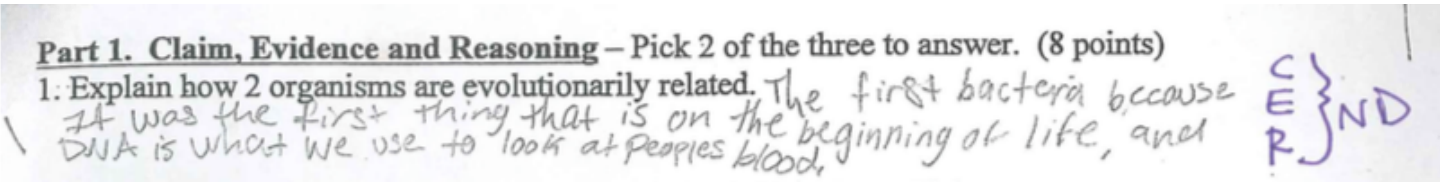


Figure 9: Student 32 Response from First Written Assessment

Similarly, during the first interview, Student 35 demonstrated developing skills. This student was able to state a claim without specifics and give some reasoning but not able to tie it into the greater topic of evolution. In the second written assessment (Figure 10), the student continued to demonstrate growth but still needed to add specific evidence and tie her reasoning into a broader scientific concept.

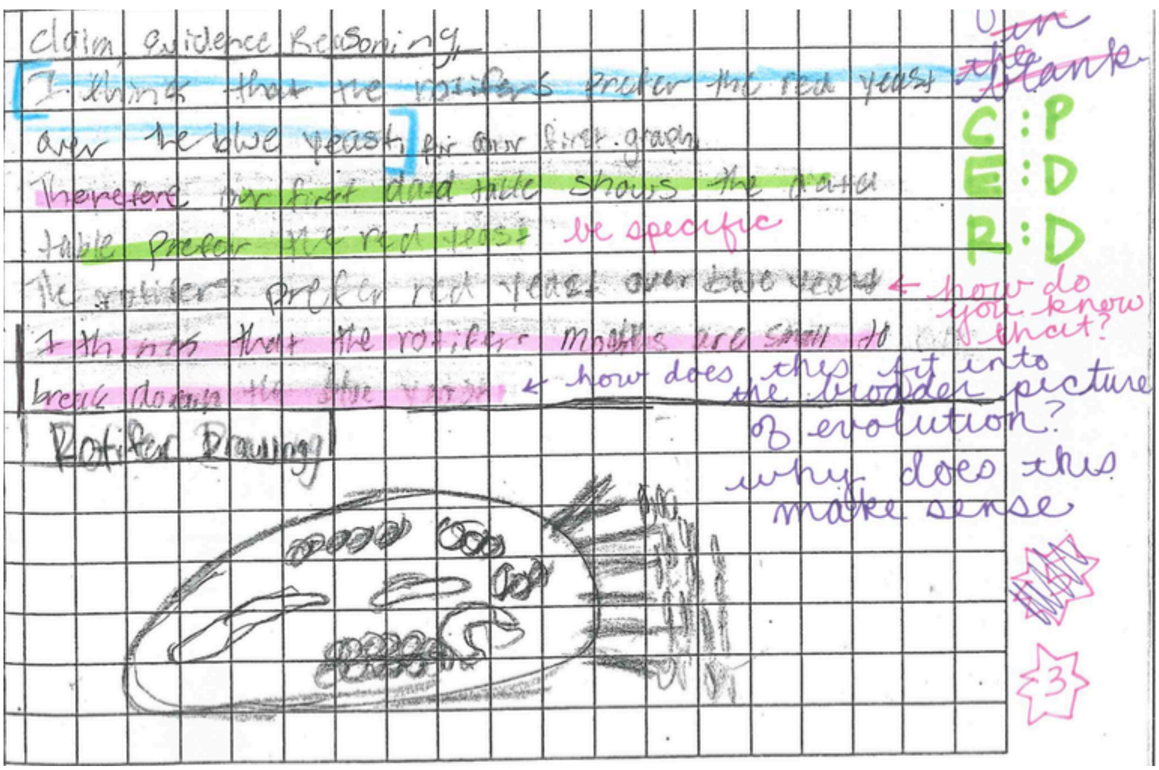


Figure 10: Student 35 Response from the Second Written Assessment

Throughout the investigation, this student demonstrated the strength of working with a cooperative group and the constructivist process. This student, as mentioned previously, had identical written work on the graphic organizer as their group member and could not reproduce his/her thoughts during the one on one consultation. However throughout the process of the hands on activities, readings, and group collaboration, student 35 was able to make gains as shown below in Table 8. During the first interview, this student was able to make a claim, but it was inaccurate and did not provide specific data to support her claim. The student also asked questions that indicated that he/she did not understand the concepts of the evolution. After a three-minute explanation, the student was able to correctly repeat the information I gave him/her. The students' skills continued to improve when he/she worked through the rotifer lab. The hands-on experiences made it easier for him/her to see the concept of evolution and gave the student specific examples to attach learning to. When the student was interviewed for the second time, he/she had demonstrated growth in terms of knowing the content of evolution and the ability to support an argument with evidence and reasoning. This student was able to give specific data to support his/her claim, "I think the rotifers will eat more of the blue yeast cells because there were more blue than red cells in the guts of the rotifers." (Personal Interview, 3.1.16) The student was not able to tie the learning back to the general concept of evolution in any of her written or verbal attempts (Figure 11), but did show growth over time (Table 8). Interviews that truly morphed into a one on one consultation with this student were a really powerful learning tool as well. The interviews enabled the student direct access without interruptions for him/her to relearn and practice the concepts.

Table 8: Student 35 Data Demonstrating Growth Throughout the Investigation			
	Claim	Evidence	Reasoning
Pre Assessment	ND	ND	ND
Graphic Organizer	D	D	D
First Written Assessment	ND	ND	ND
First Interview	D	D	D
Second Written Assessment	P	D	D
Second Interview	P	P	D

Throughout the course of the investigation, students were given six opportunities to write or articulate their learning about evidence-based writing. After three opportunities, fifty seven percent of the students in the study group were earning proficient ratings on the individual components of claim, evidence, or reasoning portions of the rubric (Table 9, labeled yellow). It seemed apparent that the combination of group work and hands-on, experiments helped the students articulate their thoughts more concretely. After completion of the Rotifer Predation Lab (Second Summative Assessment), I again interviewed the students. At that time, fifty-two percent of the individual portions of claims, evidence, or reasoning were earning excellent marks and thirty seven percent were proficient (Table 9, labeled blue). Comparatively, no students were able to demonstrate excellence on the first interview and only thirty-seven were able to demonstrate proficiency. By the time students were writing about the Rotifer Predation Lab (second written assessment) and articulating their thoughts in the second interview, they had already had three opportunities to practice the skills of evidence - based writing. As a result, they had gotten considerably better at these skills.

Table 9: Percentage of students demonstrating excellence, proficiency, developing or not demonstrating the skills of Evidence - Based Writing throughout the investigation

	Not Demonstrated	Developing	Proficient	Excelling
Prior Knowledge	39%	33%	27%	0%
Graphic Organizer	5%	48%	46%	0%
First Summative	28%	15%	57%	0%
Interview 1	1%	18%	78%	0%
Second Summative	0.05%	41%	53%	36%
Interview 2	1%	8%	37%	52%

Additionally, when students were actively engaged with constructing their understanding, the interviews lengthened in duration. As the students engaged more with the work, they had much more to discuss. Most interviews during the first round ranged anywhere from 1 minute, twenty nine seconds to three minutes, five seconds. In the second round of interviews, no interview was shorter than three minutes, fifty-four seconds with the majority of interviews lasting between six to seven minutes. During this time, students were able to more fluently describe their learning. During the interviews eleven students were able to give specific data (evidence) to support their claims when prompted. Only two students did this on the second written summative assessment, despite being given explicit instruction through modeling and practicing it in class. It seemed that the verbal reminder and practice during the interview coupled with the constructivist process helped to cement the skills of evidence – based writing.

For example, student 23 did not give any specific data in the second written assessment (Figure 11). This student did have specific observational data that were recorded in his/her student lab notebook. However, during the second round of interviews, Student 23 was able to give specific data. He/she stated, “Rotifer 32 ate the most red cells which has 255 cells inside and no blue cells inside” (Personal Interview, 3.1.16).

Figure 11: Student 23 Response from the Second Written Assessment. Student color coding signifies the different components of evidence – based writing. Students coded the claim blue, the evidence green, and the and reasoning red

It is interesting to note that during interviews with this student, I was able to prompt him/her and ask questions in different ways so that he/she could articulate his/her understanding. It became very clear throughout the course of this investigation that this student had a good understanding of the topic, but did not have the writing skills to articulate them on paper. In line with the constructivist pedagogy, this student is an English Language Learner and is paired with another student in a cooperative group who speaks the same native language as well as fluent English. As the constructivist model predicts, student 23 benefited from working in a cooperative learning group. The more proficient student was able to help student 23 understand the meanings of terms, compose sentences, spell words, and help her articulate her thoughts and observations during the lab exercises. The more proficient student would model how to take notes, record lab data, and help understand directions during lab exercises. The social acceptance and modeling that the more proficient student showed helped student 23 open up more during classes and, as a result, ask more questions and be able to engage in the learning more fully. Throughout the progression of the unit and assessments, student 23 acquired more knowledge and was able to demonstrate that through her one-on-one interviews (Table 10).

Table 10: Student 23 Data Demonstrating Growth Throughout the Investigation

	Claim	Evidence	Reasoning
Pre- assessment	ND	ND	ND
Graphic Organizer	D	D	D

First Written Assessment	D	D	ND
First Interview	P	P	P
Second Written Assessment	P	D	D
Second Interview	P	E	E

Another student used the hands-on realistic scenario of the Rotifer Predation lab to understand evolution. Very quickly, student 12 was able to describe natural selection, something that has taken me weeks in previous years to teach in a lecture based setting. Student 12 stated the following when I asked why their data made sense to them,

> Well, sort of. When we were talking about the rotifers, they are eating the single celled stuff. Eventually, they could become endangered. Then the rotifers will have to evolve somehow to fit the circumstances. They're going to have to be able to eat multicellular yeast or else they will become extinct. So it is like they are forced to evolve.
>
> Student 12 Personal Interview, 3.1.16

These findings support the theme that students benefitted when they constructed their own learning. As students built their own knowledge through activities, lectures, readings and cooperative group work, their knowledge base grew and they were better able to articulate themselves and tie their thoughts back to broad scientific concepts.

Theme Three: Students had the greatest struggle with reasoning through writing and connecting it to broad scientific concepts

Reasoning was the most difficult concept for the students to understand. McNeill and Martin (2011) suggested that this would be the case and recommended using strong and weak examples to teach students how to reason. Comparatively, on the first written assessment only eight of the twenty students were able to demonstrate proficiency through written reasoning and by the second interview all but four were able to develop proficiency or excellence (Figure 12).

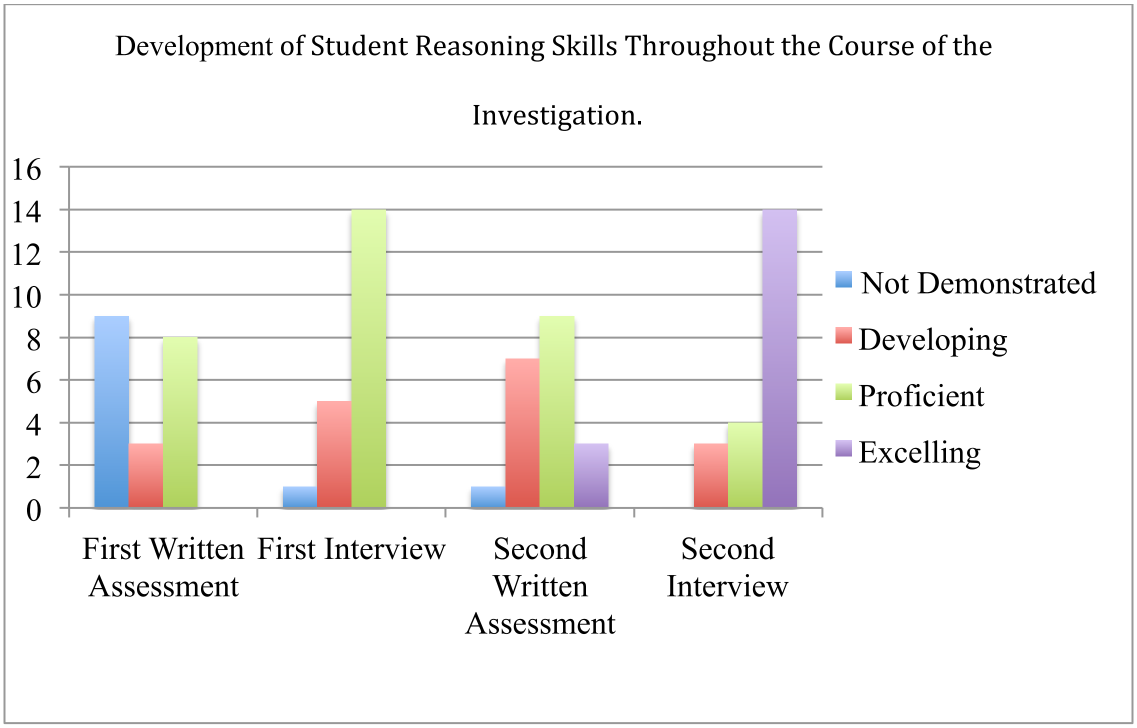


Figure 12: Development of Student Reasoning Skills Throughout the Course of the Investigation

As Figure 12 depicts, reasoning was the skill that was last acquired by the students. During the first interview, students remarked that they were having trouble understanding how reasoning is defined, leading me to change the fourth interview question from "What scientific principles can you explain with these data?" to "How could a scientist use your information to explain a broader claim within the context of evolution?" During the interviews, I also noticed that students needed more specific and direct instruction on how to write responses using the evidence – based writing format. One student remarked, "I don't know, I mean I guess I know but it is hard to explain. I feel like I understand the concepts but it is hard to explain" (Personal Interview, Student 20, 2.24.16). Students who were able to demonstrate proficiency in their written work (students 8 and 33) used the word "generalization" in their responses to question four during the interviews. I concluded that this was a word that students could use to demonstrate their understanding of the content. To give additional direct instruction, I explicitly modeled the skills of evidence-based writing using sentence scaffolding and prompts. Students practiced using a different set of data and performed the writing in their cooperative groups for support. I was sure to use the word generalization during this instruction. As a result, student responses improved. One student wrote,

> Therefore rotifers prefer to eat red unicellular yeast to blue multicellular yeast. We know this because rotifers are observed and depicted to have eaten much more red yeast to blue yeast. This is evident in all of our data, and proven again in our Chi squared statistics. Thus, rotifers may have to evolve to eat multicellular yeast in the future if the unicellular yeast all dies out and their mouths must evolve to become bigger to eat multicellular yeast.
>
> - Student Journal 26

Another student writes,

> Therefore a rotifer will be more probable to consume red unicellular yeast to blue multicellular unless they evolve. Because their mouths are smaller and the yeast cells are multicellular which means they clump together therefore the rotifer's mouths will evolve to become bigger to consume the multicellular yeast.
>
> - Student Journal 8

Reasoning was the most difficult piece of the evidence-based writing process for students to grasp and demonstrate proficiency. I believe that students at this school have not been asked to write about reasoning in an academic context enough. They are often asked to reason verbally during seminars and discussion, which explains Student 20's comment, but are in the acquisition stage of writing their thoughts down. When students were given direct instruction, as discussed previously, they were able to show growth. This phenomena is supported by this study. Figure 12 (page 68) shows that in both interviews, students demonstrated better reasoning skills than when they wrote responses. As previously noted, the interviews enabled students to verbally process what they were thinking rather than writing it down first.

Summation

After five opportunities to practice the skills of evidence-based writing, students demonstrated growth when written and verbal responses were assessed with a rubric. After analyzing the data, three major themes became apparent:

- Students showed a steady trend of intellectual growth over time, resulting in an improvement of their evidence based writing skills.
- Students benefitted from the constructivist based pedagogy.
- Students had the greatest struggle with reasoning through writing and connecting it to broad scientific concepts.

Students were able to acquire many of the skills of evidence-based writing. Many students excelled or became proficient with the skills, but there is still additional instruction needed for others.

Chapter 5:

CONCLUSION

Summary

It was my intention, through qualitative research, to explore how students present reasoned arguments supported by evidence and reasoning after receiving scaffolded instruction. After researching, I discovered best practices to effectively teach and assess the acquisition of evidence – based writing skills. I scaffolded curriculum, conducted three summative assessments, and interviewed students twice. Through the course of this investigation, I identified three major themes in the acquisition of evidence – based writing skills:

1. Students showed a steady trend of intellectual growth over time, resulting in an improvement of their evidence-based writing skills.
2. Students benefitted from the constructivist based pedagogy.
3. Students had the greatest struggle with reasoning through writing and connecting it to broad scientific concepts.

After engaging in this capstone and the analysis of its outcomes, I have found, that pairing constructivist-based pedagogy with one-on-one interviews was an effective way to teach evidence-based writing. In the future, I think that these interviews will be thought of as consultations. The one-on-one communication gave students immediate feedback that helped them rethink and refine their responses and how they understood the structure of evidence -

based writing. The one-on-one communication impacted each of the three identified themes as discussed in detail in Chapter Four. Consequentially, over the course of the school year I would like to meet with different selections of students. It is very time consuming but very effective for the students and class instruction. Additionally, I would like to continue using the constructivist-based practices outlined in this study, as it is clear that it fostered engaged and active learners.

Literature Review

Constructivist pedagogy was very effective as a means to help students understand the concept of evolution and the skills of evidence - based writing. In this research, student learning was an active process where students learned through inquiry based methods while working cooperatively with peers. Additionally, because students were assessed on a rubric with a number scale, traditional grades were not attached to it and students did not see this as an assignment that they quickly finished. It was seen more as a skill to practice. This meant that the majority of the students were engaged and looking to improve on their skills. Group work also supported student learning and growth as discussed in chapter four. Constructivist pedagogy, as discussed in chapter two supports student learning from many different angles and keeps the curriculum student centered. This method of learning enabled much student growth in the skills of evidence–based writing.

As discussed in chapter two, developing sound reasoning skills is far more important for high school and college students than specific content knowledge. (Heller and Hallabaugh, 1992; Heller, Keith, and Anderson, 1992; University of Minnesota Physics Education Research and Development, nd). This investigation demonstrated that reasoning is a difficult skill to acquire which McNeill and Krajcik (2008a) also found.

This research could impact the teaching practices of many in the field as it brought to life how hard it is to teach evidence – based writing skills and that students need explicit and direct instruction that is continued through much of the school year. Furthermore, this research is evidence that the constructivist model activates and engages students, enabling them to learn. This student-centered practice mirrors Montessori education, the mission at the charter school where I am a teacher, and is being implemented throughout. As our nation's educational philosophies continue to evolve and change, based on my findings, it is imperative that we evolve from a teacher-centered model to a student-centered one. We need to have more studies published stating the effects of student-centered pedagogy and create effective policies to enact that change.

Limitations

The study was limited by the number of opportunities students had to demonstrate their learning. This study suggests that students need more practice than just three written attempts and two opportunities for verbal feedback. Student 13 (3.1.16) remarked

> I think that at the time that I wrote this (my entry) I believe that I had forgotten to tie it into the central idea of evolution and how that helped. I think I just explained how it helped in this case. But I think that was a my bad on my part because I did explain that later (in the interview). I'm not sure why I didn't put it in there….I don't think there is something to improve with your teaching I think that I could use more practice writing this because it's kind of hard.

This is clear evidence that students needed more time to learn this skill. I think that this is one of those skills that can be taught explicitly in a unit like this but the skills need to be continued throughout the course of the semester or year to offer more opportunities for practice.

This study was also limited by the small number of students from which to draw data from. Due to the limitations of time, I could only work with twenty students. Within this sample set I was able to identify many different learning patterns, idiosyncrasies, and develop closer working relationships with my students. Forty other students did not have this opportunity. One way to overcome this limitation would be to have these interviews or consultations be part of my teaching practice and feedback process during all of first semester and rotate students each unit to enable more face time with more students.

Human subjectivity was also another limitation. I did use a rubric but there is always room for subjectivity when assessing written work. The rubric was descriptive and easy to follow for both students and myself, however there are words like appropriate, sufficient, and incomplete. These words are open to various interpretations by students or myself. In hindsight, I would test the rubric out with actual students during the academic school year rather than testing the rubric with other teachers and students during the summer break.

That being said, I do think that there was sufficient consistency offered with the rubric between the back and forth of the written and oral assessments but there is an aspect of human emotion that is present during an personal interview that is not present when assessing and giving feedback written work. When interviewing students, I know that I am more compassionate and forgiving than I present through grading written work. Perhaps students pick up on that during the interviews and become more comfortable and willing to explain. Conversely, students could also be intimidated or nervous about the interviews and rush through them without fully explaining themselves. This was definitely the case for at least two students, one needing support from a friend during the interview and another avoiding the interview for four days. While the interviews helped many students during this investigation, it could have also hindered some.

A potential limitation of this study could have been the subject of evolution. There were two students in the study who commented that they did not believe in the theory of evolution because of religious reasons. Rather than force them to write about evolution I suggested that they write about how the organisms could change over time. These students were still able to participate in the work and find meaning through the work but were not blocked from it through the use of the word evolution. While I would like every student to understand evolution and be able to support it with reasoning, I understand that if I were to force students to use the word evolution it would present a barrier to their education. One of these students (who was not part of the study) could clearly support her claim of change over time evidence and reasoning. He/she was interested in the topic, saying that he/she wanted to know what others' thought so that he/she could understand their point of view. Consequently, he/she learned the material and concepts using a more vague term than evolution, if I had made her use the word evolution her parents would have pulled her out of the class and she would not have learned the concepts.

Future Work

I will continue to teach in this constructivist-based manner. Evidence supports the steady growth that these students experienced through constructing their own learning. Through the use of readings, projects, group work, and hands – on activity students were able to construct a rich knowledge of the subject of evolution. I also like how students received support from their peers and that made a more welcoming, inclusive classroom.

I will continue to use the Rotifer Predation Lab (Second Summative Assessment). Student engagement was high – they loved seeing the rotifers "chow down" on the yeast. They loved the comparison of the slide to the African savannah that I used with big predators and different kinds of prey present. This lab made evolution real in the minds of students and something they could see happening. This lab also offered quantitative and qualitative data for students to experience and work with in a concrete manner. They were exposed to the Chi-Squared analysis offering an answer to the age-old question of "Why do I need to know this?" while preparing them for future math and science work. This lab was really fun for students and gave a realistic scenario for evolution that they can easily see in the lab and was pretty inexpensive.

I would like to continue the one-on-one interviews with students. At the beginning of this study students were struggling with the interviews. Students were nervous and intimidated to sit and chat with me one on one. One student even wanted his/her friend in the interview for moral support. As time passed, these interviews shifted to one on one consultations with the students. Students grew to like these consultations; it became more about the one on one work and giving each other feedback. Students that were not involved in this study signed up for these meeting because their friends would tell them how beneficial they were. I also learned so much about the students during these consultations, I actually got to talk to these students, look at their faces, notice the physical development they were going through, and develop real relationships with the students. Interviews also made very obvious those who could convey knowledge through written and verbal means and those who could not. In two cases, this work made it easy to identify learning disabilities and recommend those students for the testing of the need for special education services or improved special education services.

I enjoyed this investigation. It reminded me that six years ago I made a goal to improve my evolution curriculum, to make it memorable for the students and to give them accurate examples and explanations of evolution. I wanted to not just teach about Darwin but also teach about the mechanisms of how evolution happens so that the students can make their own decisions. I feel like I finally got what I was striving for with this unit. It teaching the concepts of evolution, particular parts of the scientific method like variables, qualitative and quantitative data, creating data tables and graphs, data analysis, and of course, evidence-based writing all in a constructivist based manner. I will continue to implement it.

Communication of Work

If the opportunity arises I would like to present this work under the topic of feedback to my colleagues. The tools of written and verbal feedback in a timely fashion, immediate in the case of the interviews, were very powerful in changing how the students responded to the prompts. This immediate feedback that was honest but positive enabled lasting changes in the students writing much more than other forms of feedback that I've given them in the past.

I would also like to present this work at larger conferences in conjunction with the Rotifer Lab as it is part of a larger curriculum with similar pedagogy.

Myself as a Scholar

I have always loved to research and learn more about science but this study heightened my abilities. This study has refined my research skills, enabled me to acquire proper interviewing techniques, and made completely apparent the need for data collection and analysis in the teaching profession. Because of this work, I can speak with students about the importance of learning effective research techniques, citing their work, and data collection while they are performing their investigation. I feel that I am a much better writer having practiced the skills of formal writing for many months.

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Appendix A:

Predator escape: an ecologically realistic scenario for the evolutionary origins of multicellularity
Student handout

William C. Ratcliff, Nicholas Beerman and Tami Limberg

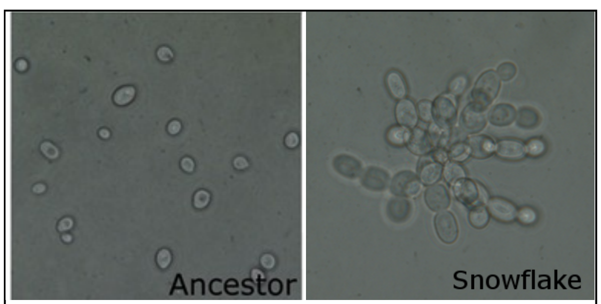
Introduction. The evolution of multicellularity was one of a few events in the history of life that allowed for increases in biological complexity. The first step in this transition is the evolution of multicellular clusters. Once clusters have evolved, there is a shift in the level of natural selection- from single-cells to whole clusters. Over many generations, cluster-level adaptation results in the evolution of increased multicellular complexity (e.g., cellular division of labor, the evolution of developmental programs, etc). This process is described in the movie entitled 'Video overview of the yeast experiment'.

Here we will examine the very first step of this process- the evolution of cellular clusters. In the lab, scientists have shown that simply selecting for fast settling through liquid media can result in the evolution of cluster-forming 'snowflake' yeast. Gravity (imposed by Ratcliff et al (2012)[1] with a centrifuge) is a simple way to select for cluster formation, because clusters of cells fall through liquid media faster than single cells. As a result, if a random mutation arises that results in cluster formation, these will have a *huge* competitive advantage over the ancestral unicellular yeast.

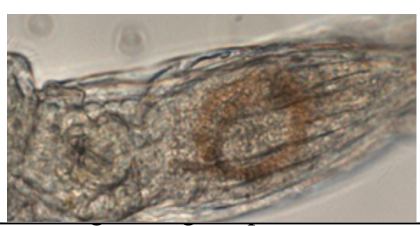
While these experiments are easy to do and give researchers a lot of experimental control, they aren't a very good model for types of selection that unicellular organisms face in nature. After all, there aren't any centrifuges in nature. In this lab, students will use unicellular and snowflake yeast to test a key hypothesis about this transition[2]: that predation by small-mouthed organisms can select for cluster formation.

Goals. Give rotifers (small animals that prey on single-celled organisms) unicellular and multicellular yeast. Observe rotifer predation, and then calculate the relative survival of uni and multicellular yeast during predation. Perform a statistical analysis on this result.

The actors



The prey. Unicellular yeast (strain Y55) on the left. Multicellular yeast (strain C1W3) on the right.



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resulted from a single mutation that knocked out a gene required for mother-daughter cell

separation after mitosis. This experiment was important because it showed that simple multicellularity can evolve rapidly, but it does not use a very ecologically-realistic selective agent.

Rotifers are microscopic animals that prey upon single-celled organisms like algae and bacteria. For a long time, scientists have hypothesized that predation could provide a similar selective environment to settling through liquid- namely that predators would be capable of eating (and killing) small, single-celled organisms, resulting in selection for multicellular clusters too large to be eaten. Rotifers live in aquatic environments, like ponds, marshes, and wet moss. They eat food by creating a vortex with the cilia on their head, which funnels microbes into their mouth. Their bodies are largely transparent and they move slowly, which makes them ideal for this lab. We will give hungry rotifers uni and multicellular yeast, then examine their ability to eat each growth form.

Task 1: Observing rotifer predation.

This experiment utilizes two yeast strains: strain Y55 was isolated from a vineyard in France, and is a regular, unicellular yeast. Multicellular strain C1W3 was derived from Y55 after three weeks of selecting for rapid settling through liquid media. We have labeled the unicellular yeast (strain Y55) red, and the multicellular yeast (strain C1W3) blue. Ask your instructor if you are interested in how this was done. Here you will mount rotifers on the microscope, and observe their predation by the rotifers.

Mounting live rotifers for microscopic examination.

Materials

·Yeast (both strains Y55 and C1W3) fixed and stained with Congo red and methylene blue (supplied in kit). **Be sure to wear gloves and protective eye glasses. These stains are toxic.**

· (2) Glass depression slide (alternative: plastic depression slide)

· (2) 22mm x 22mm coverslips

·Micropipette capable of pipetting 100 µL of liquid

·Micropipette capable of pipetting 1 mL of liquid (alternative: plastic pipettes)

·Corresponding micropipette tips

·Rotifers

Procedure

1. Add 100 µL of predator to depression slide.

   Hint: Get rotifers from the bottom of the container

2. Add 5 µL of blue stained C1W3 multicellular yeast (shake vigorously with cap on prior to using)
3. Add 5 µL of red stained Y55 unicellular yeast (shake vigorously with cap on prior to using)
4. Add coverslip and immediately view on microscope

Observations

You must observe at least 25 rotifers (a larger sample size is encouraged if time permits) and make a determination on which yeast is the predominant yeast in the stomach of a given rotifer. Note the behaviors of the rotifers. How do they eat? Can you observe any yeast being consumed? How long does it take them to fill their stomach? Record this information in a table.

On a blank sheet of paper, draw a picture of a rotifer eating yeast. Use arrows to indicate the movement of water around the rotifer head.

Task 2: Quantifying rotifer predation.

In this experiment, you will quantify the number of each type of yeast cell in rotifer stomachs. In comparison to the previous exercise, you will actually quantify predatory selection, and will analyze your results statistically. This approach is more rigorous- it will not only allow us to calculate the relative fitness of multi:unicellular yeast, but it will also allow us to determine if this result is statistically robust.

Both red and blue yeast are visible in the stomach.

Imaging flattened rotifers. If the school has a microscope with a digital camera: students can take images of flattened rotifers (photos at right) for counting the number of red and blue yeast inside their stomachs. To do this, follow the protocol above, but let the yeast and rotifer mix stand for ~3 minutes prior to pipetting onto a microscope slide. Rather than using the concavity slide, transfer 10 μL of the yeast-rotifer mixture onto a standard slide and flatten by placing a coverslip on top. Otherwise, use the images provided with the lab. You should see images like those to the right.

If the lab does not have a microscope camera, your instructor will provide you with electronic or printed images of rotifers that we imaged using the above protocol.

In either case, each student will obtain an image of a flattened rotifer. Each student will record the number of yeast of each color in their rotifer and then the number in the rotifers of their group members. Each circle in the stomach of a rotifer is one yeast cell (lower right).

Each of the dark circles above is a yeast cell in the stomach of a rotifer. These are all red unis.

Data Collection

In the table below, count the number of red unicellular and blue multicellular yeast found in your rotifer stomach. Include the number of each yeast strain your group-mates find in their rotifers. Finally, sum the total number of uni and multicellular yeast your group found across all of your rotifers, and put this in the 'total' box

	Rotifer 1	Rotifer 2	Rotifer 3	Rotifer 4	Rotifer 5	Total
Number of red unicellular yeast						
Number of blue multicellular yeast						

Relative survival during predation
Now we will calculate the relative survival of multi to unicellular yeast during rotifer predation. This is a key element in their Darwinian fitness, because yeast that are eaten by predators are killed and cannot pass their genes on to future generations. First, calculate the proportion of killed yeast that are multicellular:

$$\text{Proportion multicellular consumed} = \frac{\#\ blue\ multicellular\ yeast}{\#\ blue\ multicellular\ yeast + \#\ red\ unicellular\ yeast}$$

Statistical analysis
To determine if the above difference is significant, we will perform a statistical analysis. In essence, this analysis determines the probability that the difference in predation between uni and multicellular yeast would have been observed by chance. For example, if you flip a coin 100 times and you get 53 heads and 47 tails, this difference isn't large enough that we're could say with much confidence that the coin was biased towards heads. As the results get more divergent from our expectation of 50:50, the chance that the coin really is fair goes down. We're going to use the same principles here to determine if the differences we see in yeast death by rotifers is significant.

We will use a chi-square test, which compares the observed frequencies of uni and multi cells to expected frequencies. To generate the expected frequency of red vs blue cells, assume that both uni and multicellular yeast stock solutions were at the same cell density (cells / mL). Assuming there was no rotifer preference for either yeast strain, we expect that half the total number of yeast counted should be multicellular, and half should be unicellular. Therefore, to calculate the 'expected' number of multis and unis (for use below), divide the total number of counted cells by two.

The chi squared statistic (denoted χ^2 because χ is the Greek letter 'chi') is calculated by summing the squared difference between the observed and expected number of multicellular yeast in the rotifer stomachs, and the unicellular yeast in rotifer stomachs.

$$\chi^2 = \sum \frac{(\#\ Obs - \#\ Exp)^2}{\#\ Exp}$$

For example, say I counted 200 yeast cells in total, so I expect there to be 100 multi and 100 uni cells in the rotifer stomach. But, when we counted them, I found there were 50 multi cells and 150 uni cells. The χ^2 statistic is calculated as:

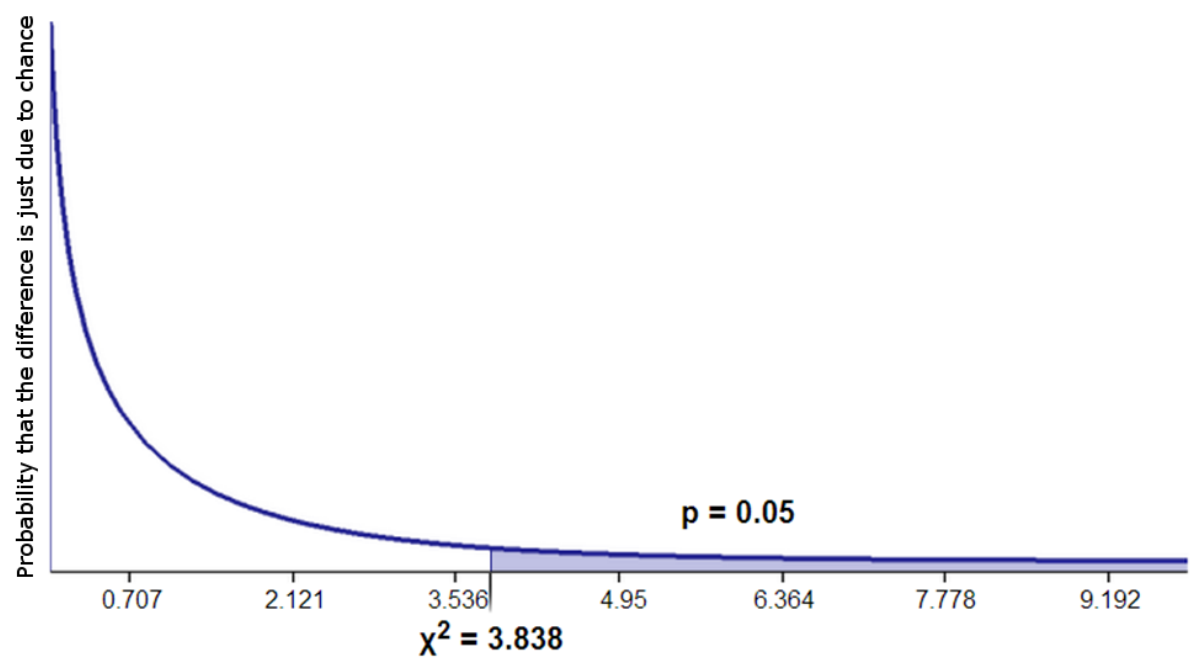
$$\chi^2 = \frac{(50-100)^2}{100}\ [this\ is\ the\ multi\ expectation] + \frac{(150-100)^2}{100}\ [the\ uni\ expectation] = 50$$

Fill out the following table with the information necessary to conduct a chi-square analysis.

Number of observed multis consumed (# Obs)	Number of expected multis consumed (# Exp)	$\frac{(\# Obs - \# Exp)^2}{\# Exp}$ for multis	Number of observed unis consumed (# Obs)	Number of expected unis consumed (# Exp)	$\frac{(\# Obs - \# Exp)^2}{\# Exp}$ for unis

What is your chi squared statistic? Make sure to show your work (either here or in the boxes above).

Finally, we need to use the chi squared statistic to determine the probability that we got the difference between uni and multi predation simply by chance if rotifers really have no preference. As you can see on the distribution below, if your χ^2 statistic is greater than 3.9, then there is a less than 5% chance that your results were caused by chance alone. At that point, we're pretty confident that the rotifers really do have a preference. If your χ^2 statistic is greater than 3.9, the difference in predation you observed is statistically significant at a level generally



Chi squared distribution. When the chi squared test statistic is above 3.84, then the chance that the difference in rotifer predation was due just to chance is below 5%. At that threshold, we are pretty sure the rotifers have a preference!

accepted by scientists to be robust. If this was your result- congratulations, most scientists will now believe that your result is real!

Discussion
Depending on instructor preference, students will answer discussion questions in their lab notebooks or discuss these questions as a class. At the culmination of this lab, you will be asked to incorporate your thoughts and write up a full lab report.

References
1. Ratcliff, William C., R. Ford Denison, Mark Borrello, and Michael Travisano. "Experimental evolution of multicellularity." Proceedings of the National Academy of Sciences 109, no. 5 (2012): 1595-1600.

2. Grosberg, Richard K., and Richard R. Strathmann. "The evolution of multicellularity: a minor major transition?" Annu. Rev. Ecol. Evol. Syst. 38 (2007): 621-654.