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Designing and Assessing New Educational Pedagogies in Biology and Health Promotion

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ABSTRACT

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Recent developments in educational research raise important questions about the design of learning environments—questions that suggest the value of rethinking what is taught, how it is taught, and how is it assessed. During the past few decades, STEM disciplines began formally recognizing and integrating discipline-based education research (DBER) into their research programs to improve STEM education. One of the less literature-affluent areas of DBER addresses curriculum order and design appertaining to concept types and the order in which we teach those concepts. As educational researchers, we pose the question: does content order matter? In this project we designed, implemented and analyzed a concrete-to-abstract curriculum as a way of teaching and learning that not only builds off what students already know but how their intellect develops throughout the learning process. This semester-long curriculum design is scientifically supported and provides a learning environment aimed to not only building a student's declarative knowledge of the subject but procedural knowledge as well and a way of developing scientific reasoning skills. This design also aimed at enhancing a student's ability to make connections between biological concepts despite being classified as different biological concept types (e.g. descriptive, hypothetical, and theoretical concepts) as described by Lawson et al (2000). The reasoning behind and development of this project was based from Jean Piaget's proposed stages of intellectual development, which supports the concrete-to-abstract theory. We found that, when compared to a traditional biology course (abstract-to-concrete in terms of content order), a concrete-to-abstract order of content resulted in significantly higher biological declarative knowledge and ability to make concept connections. While we failed to detect a significant difference between the two courses in terms of how quickly scientific reasoning skills are developed or how students' scores on scientific reasoning skill assessments, the concrete-to-abstract course did show significantly higher gains in reasoning between the start and end of the semester.

In addition to this project, a significant amount of time was also allocated to the design and evaluation of a health promotion and education program in Samoa. We developed a program which centered on a principal-run caregiver meeting as a means to expand health promotion and prevention efforts concerning Rheumatic Heart Disease, which is a significant cause of child morbidity and mortality in Samoa. We found that training principals on how to inform their student's caregivers was an effective way to increase RHD awareness and disseminate correct health information including what to do if their child presents with a sore throat.

Keywords: curriculum design, biology education, biological pedagogy, STEM education, biological concept type, concrete-to-abstract, scientific reasoning, health promotion, decision-tree, rheumatic heart disease prevention

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Introduction

Entering college students interest in STEM is increasing while the percentage of students who graduate in STEM is decreasing (Hurtado, Eagan & Hughes, 2012) with poor teaching, classroom climate and faculty pedagogy stated as some of the major factors contributing to whether or not students decide to pursue science majors (Seymour and Hewitt, 1997). Educational leaders across the nation recognize the need for implemented changes in the learning environments of undergraduate, introductory science courses. Learning environments should encourage, in addition to acquisition of content, the learning of higher order thinking strategies (Tennyson & Rasch, 1988). With this at the heart of its cause, the American Association for the Advancement of Science (AAAS) continually advocates for "a teaching approach that starts with questions about nature, engages students actively, concentrates on the collection and use of evidence, does not separate knowing from finding out, and de-emphasizes the memorization of technical vocabulary (1990)."

Progression in learning is usually from the concrete to the abstract. Humans develop creative and critical thinking skills and values by attempting to use them in "exploration and explanation of observations we see in the world around us" (Lawson, 2004).Therefore, we should be teaching science courses, especially undergraduate non-major courses, as science is practiced in the real world: a data-supported process of creative and critical inquiry that is based on how people actually learn. Course curricula should be designed in an order supported by research that suggests students learn best when they can relate new experiences and concepts to familiar ones (Project 2016 as cited by Lawson, 2004). The research is there to suggest that a concrete-to-abstract curriculum design may facilitate student's overall mastery of course content, influence their development of hypothetical-deductive reasoning skills, and impact their ability to make connection between concepts as well as descriptive, hypothetical and theoretical concept types.

Piaget's Stages of Intellectual Development:

Jean Piaget was one of the first psychologists to address intellectual development. Piaget proposed stages in the development of procedural knowledge (Inhelder & Piaget, 1958). The first stage is the *sensory-motor* stage. It lasts from the time we are born to around 18 months. During this stage, we acquire practical knowledge, such as object permanence (just because an object is out of view does not mean it is not there). The second stage, which last until children are around seven, is called the *preoperational stage*. Children in this stage are acquiescing language and using words and images to represent their experiences and observations. Pretend play also becomes a defining phenomena of this phase but a child still has an egocentric view of the world and cannot demonstrate conservation reasoning. While an understanding of these two initial stages are important to fully understand the progression in intellectual development, we can assume that students in our introductory biology courses have successfully advanced into the two proceeding stages (Lawson, 2002).

The next stage is called the *concrete operational* stage. Piaget termed concrete operations as "mentally internalized and reversible systems of thought based on manipulation of classes, relations, and quantities of objects" (Inhelder & Piaget, 1958). Otherwise known as the empirical-inductive stage, children ages 7-10 begin to assimilate data from experiences and mentally arrange and rearrange them in a logical manner. Progression into this stage provides greater mobility and ability to directly relate to objects. However, objects are still object-bound in mental operations.

The *formal operational* stage of intellectual development begins sometime between 11-15 years of age and continues through adulthood. Piaget believed this stage constituted the highest level attainable in the development of thinking patterns. Once an individual has reached this stage they can think beyond the present but begin to understand and relate to hypothetical scenarios and form theories. Thoughts and thought processes no longer need to be initiated by what is directly observable but can come about by non-observable, imagined, abstract and potentially possible (as cited in Lawson, 2002).

In other words, intellectual development begins with physical experiences with objects in one’s environment. From these experiences, individuals start to develop intuitive understanding and eventually their intuitions are transformed into a conscious, internally mediated problem-solving ability. According to Piaget, every student in an introductory biology course has the potential to be formal operators and, therefore, be able to apply hypothetical-deductive reasoning skills, make connections between concepts (see below), and come away with more than a novice level of acquired biological knowledge. However, development is necessary but not sufficient for progression through these stages. Without experience in using formal operational skills, many students fail to develop expertise in using them and may not always use the skills associated with their presumed level of intellectual development when placed in a new learning environment. This is important to consider when teaching introductory science courses to students, who have the ability to be formal reasoners, who may revert to concrete operational thought when facing unfamiliar subject material (Bodner, 1986). The objective then would be to create a curriculum that helps students utilize their intellect.

Keeping the proposed stages of intellectual development in mind, we believe using Paiget's proposed Theory of Concept Development (Piaget, 1952 & Piaget, 1954), and his associated theory of concept constructivism, to design a curriculum that would be a beneficial way to help our students reach their potential within this last stage of intellectual development. It could be important to begin with concrete, familiar concepts and allow students the ability to develop and implement these formal operational reasoning patterns so that they are equipped to deal with more unfamiliar and abstract concept types and thought processes later in the semester (see below).

Concept Types and Intellectual Development

Any educational study testing the idea of teaching undergraduate biology in a concrete-to-abstract curriculum order should acknowledge the Constructivist Theory when designing their curriculum. The Constructivist Theory claims that learning is an active process whereby students participate in the building of their own knowledge through a process of assimilation or accommodation with what is previously known (Cobb, 1994). In order to correctly implement curricula in support of this theory, there is a need to understand concepts in a scientific manner and be able to create classroom activities and discussions based on the hierarchy of learning.

So, what is a concept? People have ideas about how the world around them works. We can classify these ideas into meaningful systems where related ideas are grouped together and groups are arranged in a hierarchical structure (Piaget, 1952 & Piaget, 1954). We call these meaningful systems concepts. Early researchers to the field of concept constructivism refer to the following notion when defining the term concept: "a concept has been formed whenever two or more distinguishable objects, events, or situations have been grouped or classified together and set apart from other objects, events, or situations on the basis of some common feature, form, or properties of both" (Lawson book; Bourne, 1966). In Layman's terms, a concept refers to some pattern or regularity to which terms have been applied and, depending on the meaning of the pattern or regularity, those terms fall into different types of concept groups.

Our understanding of the world around us comes through internal sensory impressions, direct external experiences, classifying observable phenomena, inferences we make from our experiences, and assumptions about things we cannot directly observe. When we are born, our initial intellectual development is based on our internal sensory impressions such as painful, hot, cold, hard, soft, bright, and dark. The theory of concept constructivism distinguishes these impressions made from our internal and external environments as concepts by apprehension. They really only take some initial exposure for our brains to classify them all by itself and we learn to put a term to our sensory reactions as soon as we begin to speak. We can assume students already innately mastered this concept early in life.

Once we can immediately apprehend the world around us on an internal sensory level, we begin to make connections through our direct observations. A descriptive concept covers what is formed through our direct observation of objects, events, or situations as well as our associated perceived relations to them such as chair, table, boy, girl, happy, sad, taller, and shorter. We mentally construct order from environmental encounters. Scientifically we consider directly observable concepts to include environmental factors, food chains, populations, nocturnal, carnivore, community, etc. to fit under this descriptive classification (Lawson, A.E., Alkhoury, S., Benford, R., Clark, B. R., Falconer, K. A., 2000). Because these concepts are directly observable, we often have ample evidence to support their postulated existence in our lives. We consider these concrete concepts. Observations of one chair aid one in making inferential connections to other chairs even if they are not the same size, shape, or color. The same can be said of the examples we would see of concrete, descriptive concepts in introductory biology courses. Because the entities and processes upon which descriptive concepts are based can be directly observed, acquiring understanding of descriptive concepts is relatively easy and concrete. We would expect students to not only come to class with a greater previous knowledge of these concepts but to learn them more quickly throughout the semester (Lawson et al, 2000).

Science spans more than what is directly observable, however, and another concept system focuses on providing explanations for events that need causes but for which no observable cause can be directly or immediately perceived. We call these theoretical concepts. Theoretical concepts' defining attributes are only indirectly testable. Lawson et al (2000) states descriptive concepts as being "everything from ghosts and angels to atoms, electrons, and genes." We use analogical reasoning to invent unseen objects and interactions to explain events in more relatable or perceptible terms. Because these concepts are more or less imagined and unobservable, they can be given whatever properties necessary in terms of whatever theory they are a part of. It can be argued through the advancement of technology, that concepts once classified as theoretical have become descriptive, such as observing atoms under more powerful microscopes (Harre, 1986). Others believe that it is premature to rely on instrument resolution only to reclassify concepts. Seeing little balls under a microscope may or may not turn out to be actual atoms in the future with further instrument development and hypothesis testing. However, the central cognitive issue when determining if a concept is descriptive or theoretical focuses on interpretation of observations and not the direct observations themselves (Lawson et al, 2000).

The last concept system is based off of the notion that there are phenomena out there that could be observed if time were not an issue. We classify these as hypothetical concepts (Lawson et al, 2000). This intermediate class of concepts includes biological terms such as limiting factors, evolution, natural selection, fossilization, and convergent evolution. Direct observation of these events is not possible due to our lifespan, not our senses, as is the case with theoretical concepts. See Figure 1 for more examples.

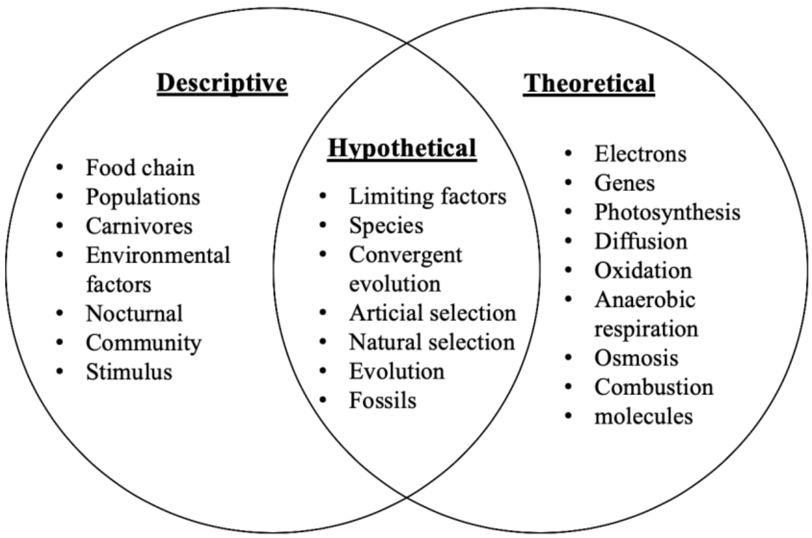


Figure 1. Examples of biological terms that fit under the three concept types: descriptive, hypothetical and theoretical concepts

The construction of all three types of concepts is linked to intellectual development because their construction depends on procedural knowledge, such as reasoning patterns, and prior declarative knowledge, both of which continue to develop with maturation and experience. In general, through the intellectual development process, descriptive concepts are constructed in childhood before theoretical concepts. You learn that a table is a table before you make the connection that the table is fundamentally made up of atoms. Theoretical concept construction continues through adolescence and adulthood (Lawson, 2002). One of the reasons, intellectually, that we can accept theoretical concepts is because of the foundation we built from previous association of descriptive concepts. This needs to be considered from a course curriculum standpoint as well. As adolescents and adults entering a new field of study, a descriptive conceptual foundation in relationship to that field of study must be partially in place before theoretical concepts are constructed in a meaningful way. Each student will enter the classroom with varying degrees of experience with and descriptive knowledge of the subject material and will benefit differently from a course aimed at teaching descriptive and theoretical concepts beginning at their level of previous understanding, supporting, once again, a concrete-to-abstract curriculum design.

In summary, three scientific concepts exist: descriptive, theoretical, and hypothetical. Descriptive concepts are constructed from experience and direct observation. They should be the easiest to construct. Hypothetical concepts are an intermediate concept with equally intermediate difficultly to construct because we may have to imagine the past and/or present in order to fully derive their meanings but the concept itself is descriptive in nature. Theoretical should be the most difficult because, regardless of how much time we have, we cannot directly observe them. We have to use analogical reasoning to understand them. Intellectual development proceeds from descriptive levels to theoretical levels (Lawson, 2000), the next building on the last just like in Piaget's concrete operations stages and formal operations stages.

A quasi-experiment, where we can compare the results of students in different curriculum treatment groups in the same semester with all other factors held constant, would help educational researchers understand the affects curriculum has on student's ability to master course learning objectives and biological knowledge, develop hypothetical-deductive reasoning skills, and to make connections between descriptive, hypothetical, and theoretical concepts. This project proposes such an investigation.

So, what do we know about the Theory of Concept Constructivism or Constructivist Theory? In general, the theory of concept constructivism is a learning theory found in psychology which explains how people might acquire knowledge and learn (Lawson, 2002). It therefore has direct application to education. The theory suggests that humans construct knowledge and meaning from their previous knowledge and experiences. Where the sequencing of subject matter is concerned, it is this constructivist viewpoint that supports the notion that any subject may be taught to anybody at any stage of intellectual development in some form (Duffy and Jonassen 1992). This means that instructors should first introduce the basic ideas that give life and form to any topic or subject area, and then revisit and build upon these repeatedly. This notion has been extensively used in the design of learning environments.

Several education models, including the active learning model, were designed around the foundations of constructivist theory (Dewey, 1938; O'Donnell et al., 2006). This is the idea that students are not empty buckets to be filled with knowledge, but rather that students must construct knowledge for themselves through a process of dynamic equilibration (Piaget, 1985; Lawson, 2002). The research never touches on using this same theory to develop a course curriculum where actual order of content matters for the success of students in education.

Curriculum Studies

Substantial research exists to support the justification for teaching introductory science courses in a concrete-to-abstract curriculum direction (Lawson, 2000; Lawson, 2002; Lawson, 2004). From a psychological and developmental perspective, we would expect a modified concrete-to-abstract curriculum order of how content is taught to provide a more effective learning environment for students in introductory biology when compared to students who take the course following the traditional abstract-to-concrete curriculum. An understanding of intellectual development and the importance of students taking away higher-order thinking and reasoning skills, along with content knowledge, supports a need for a future investigation of this modified concrete-to-abstract curriculum.

In 2000, Lawson et al, conducted a study to establish his three biological concept types in a semester-long undergraduate biology course through overturning the traditional introductory biology course—which starts with theoretical concepts (chemistry) before progressing to more concrete concepts (whole organisms). He reconfigured this traditional biology curriculum to begin with descriptive concepts and progress towards the hypothetical and then theoretical (Lawson et al, 2000). The purpose of the study was to emphasize that all science instructors should concern themselves with introducing new concepts by paying attention to which kinds of concepts, the order they introduce them in and how they are introduced. They concluded that this reversal could improve student understanding of biological concepts and promote intellectual development as well as help solve the widespread problem of college student attrition from the sciences (Lawson et al, 2000).

There are biology departments and individual professors across the nation who teach in a modified, concrete-to-abstract way. Most biologists will agree that "what we are doing now doesn't work" (Gwynne, 1997). Movements to implement a modified curriculum opposite of the traditional abstract-to-concrete curriculum among undergraduate biology courses has been made at several notable universities including Oregon State and Brown University (Gwynne, 1997). In addition, there are several textbooks available that have been designed in a "macro-to-micro" (common terminology for reversing the abstract-to-concrete, or "micro-to-macro" biology curriculum) fashion (Lawson, 2002; Gwynne, 1997). However, very little solid empirical evidence exists to support the effectiveness of implementing one order of curriculum over another.

Many researchers recognize the need for a change in instructional design. William Winn of the University of Washington reviewed the work of researchers across the nation to see what types of instructional design and curriculum reforms were out there (Winn, 1990). He found several professors trying to devise and implement instructional designs based on the analysis and the structure of knowledge, as well as the understanding of cognitive processes and learning theories. There were others that focused their instructional designs on the cognitive theory—how our thought processes work—and the application of cognitive [thought] operations. He cited a previously proposed instructional theory based upon how students acquire knowledge and skills (Winn, 1990). None of the instructional designs Winn (1990) reviewed addressed curriculum order of topics/content themselves. Few even compared curriculum designs in classrooms across an entire semester, none of which specifically address the stages of intellectual development and the theory of concept constructivism through the assessments used to collect data.

One study proposed an instructional design model that integrated cognitive learning theories and instructional prescriptions to achieve an effective learning environment that improves both knowledge acquisition and procedural understanding (Tennyson & Rasch, 1988). However, their proposal focused on the order of content and activities within individual lesson plans and not content order of an entire semester. Other proposed studies explore how "a macro-to-micro curriculum will address the issues surrounding the substantial increase in subject material introductory biology courses are required to teach in the past few decades" (Gywnne, 1997) as well as how "moving from concrete to abstract enhances student learning of biology content" (Lawson, 2004). None of the studies determined that the declarative and procedural knowledge we want our students to acquire in our classrooms can be conceptualized and taught in an order that utilizes how people actually learn.

Similar interests in curriculum design expand into other scientific subjects. Dr. Bodner of Purdue University has completely revised the way the chemistry department teaches their introductory courses based on Piaget's theory on intellectual development with significant success in learning (Bodner, 1986). Additional movements have been made in physics, mathematics and other science departments (as cited in Bodner, 1986). Another researcher's chemistry curriculum design starts with a concept/observation that already makes sense to the students and builds from their understanding towards that of the professor's, which has shown positive student gains throughout a semester (Herron, 1984).

When it comes to implementing similar changes into biological curricula, some biologists argue that teaching in the traditional and conventional abstract-to-concrete manner is actually supporting Piaget's stages of development because the courses start with the smallest part of biology and lay the foundation for the next system or level they are teaching (as cited in Lawson, 2004). However, this hierarchy of learning is misinterpreting Piaget's stages and how concepts and connections between concepts are essentially constructed from the concrete to the abstract.

Many biologists, including Dr. George Johnson of the University of St. Louis, object to the concrete-to-abstract approach because they believe it promotes learning based more on faith than empirical evidence (Gwynne, 1997). However, Lawson's concepts would state the opposite because there is more "faith" needed to teach the theoretical concepts students cannot see in an abstract-to-concrete design then the observable descriptive concepts students can clearly observe in a concrete-to-abstract" curriculum (Lawson, 2002). While disagreements among professors do exist on which way is the most effective way to teach biology, the important thing to consider here is the sufficient lack in studies effectively testing one curriculum to another, thereby discrediting any preferential or self-perceived advantages of teaching either way.

Lawson predicted using a concrete-to-abstract curriculum design to solve college departments' attrition problems (Lawson et al, 2000). Studies conducted among university students show that two major factors contribute to why students decide whether or not to pursue science majors—classroom climate and faculty pedagogy. These studies show that among the top factors determining student attrition rates from science majors, over-packed and unorganized curricula is close to the top (Seymour & Hewitt, 1997). In response to these studies, it is obvious that we need our teaching styles, instructional selections, and pedagogical approaches to be differentiated in a way that will reach more students, appeal to a variety of learning styles, and retain a broader range of students interested in science (Tanner and Allen, 2004). Dr. Paul L. Farber and several of his colleagues at the Oregon State University found that the number of students who withdrew from introductory biology courses throughout the semester decreases significantly in those courses taught using a concrete-to-abstract approach (Gwynne, 1997). Research professors, including Dr. Ken Miller, who is nationally known for his attempts to publish a "macro-to-micro" order textbook, at Brown University, where a concrete-to-abstract curriculum standard has been implemented for several decades, have noticed that the number of students who declare their major in biology as well as the number of degrees awarded to students in biology had more than doubled (Gwynne, 1997).

Despite these intriguing outcomes and the rationale for teaching science courses in a concrete-to-abstract curriculum order, most introductory biology courses and textbooks still begin with the atom, a theoretical and abstract concept and proceed through the molecular, cellular, organismal, population and ecosystem levels. A survey of several popular majors and non-majors' textbooks reveal the same pattern (see Table 1). The support of other professors is hard to come by, the funding is never there to move on to the next step of the research and the conclusion is usually made that biology professors do not want to take the time and energy required to make the switch.

Table 1. Curricular order of several popular biology textbooks for major and non-major courses

Textbook	Chemistry	Genetics	Evolution	Organismal (physiology)	Ecology
Majors					
Campbell Biology by Reece et al.	Ch2	Ch13	Ch22	Ch40	Ch52
Biological Science by Freeman	Ch2	Ch13	Ch24	Ch41	Ch50
Biology How Life Works by Morris et al.	Ch2	Ch15	Ch21	Ch35	Ch46
Principles of Life by Hillis	Ch2	Ch8	Ch15	Ch29	Ch42
Non-majors					
Biology for a Changing World by Shuster et al.	Ch2	Ch11	Ch13	n/a	Ch20
Biology Science for Life by Belk & Maier	Ch2	Ch8	Ch11	n/a	Ch15
Campbell Essential Biology by Simon et al.	Ch2	Ch9	Ch13	n/a	Ch19
What is Life? A Guide to Biology by Phelan	Ch2	Ch9	Ch12	n/a	Ch16

Lawson has developed, tested and published several proposed curriculum designs for undergraduate introductory biology. One of these curricula was developed using the "learning cycle approach." This approach is an inquiry-based approach derived from constructivist ideas of the nature of science, and the developmental theory of Jean Piaget (Piaget, 1970). The learning cycle approach as a recognized instructional strategy can be traced to the Science Curriculum Improvement Study (SCIS), an elementary school science curriculum project initiated during the late 1950's to establish a distinct instructional strategy for widespread implementation (Atkin &

Karplus, 1962). The Science Curriculum Improvement Study was the first program to explicitly use the learning cycle approach to instruction and curriculum design (Karplus, 1964). The model divides the activities of instruction into phases. Students are given an experience, such as a laboratory experiment, with a specific concept they need to develop in the exploration phase of this instructional approach. This is followed by a phase called the conceptual invention phase, where the student and/or teacher derives the concept from the data, usually during a classroom discussion. The final phase, the application phase, gives the student the opportunity to explore the usefulness and application of the concept (Lawson, 1995). Lawson traditionally follows a concrete-to-abstract curriculum order (Lawson, 2002; Lawson, 2004) and both of these instructional methods are based on Paiget's theories regarding intellectual development and should help aid student learning and acquisition of higher-order thinking strategies.

Another curriculum designed and tested by Lawson et al (2001) was devised to promote the development of students' creative and critical thinking skills as they participated in a series of biological inquires throughout the semester. The overview of the curriculum attempted to follow the natural historical paths of inquiry in biological sciences. It starts at the concrete organismic level and extends into abstracts concepts and topics and then returns to familiar concrete level at the end. Lawson found that this curriculum approach showed that students did obtain gains in creative and critical thinking skills (Lawson, 2001). This curriculum comes closer to showing the benefit of a specific curriculum order over another in that concepts were presented from familiar and concrete to unfamiliar and abstract in each lesson plan.

Another interesting advancement in the importance of curriculum order within biology courses is the reform of the Advanced Placement (AP) Biology curriculum (2009). For decades, instructors and members of the college boards realized there were some major flaws to the curriculum and in 2009 the first draft of the new AP curriculum was introduced (College Board, 2009). The new curriculum and exam were first distributed in 2013 and focuses on four “big ideas” in the following order (College Board, 2009):

1. Evolution as the basis for both the diversity and the unity of life
2. Biological systems and their properties, including energy use, molecular components, growth, reproduction, and homeostasis
3. Information: how organisms store it, retrieve and use it, transmit, and respond to it
4. Interaction of systems components and the emergent properties of the resulting entities, from DNA molecules to cells to organisms to ecosystems

While the curriculum as a whole does not follow a complete concrete-to-abstract design, the collaborating researchers did agree on introducing evolution first as a way of connecting all concepts throughout the course back to this one hypothetical concept (College Board, 2009). However, they use the same theoretical rationale for their new curriculum design as a modified concrete-to-abstract design. The official referenced research to support the new AP Biology curriculum and exam comes from the National Research Council and their publication *How People Learn: Brain, Mind, Experience, and School* (2000)—which reviews topics of novice-to-expert and concept construction among other educational models and theories.

Conclusion

In the field of science education, many advancements have been made to create pedagogies that focus on questions about nature, student engagement, and the collection and use of evidence, and de-emphasizes the memorization of technical vocabulary. Examples include the implementation of backwards design, flipped verses non-flipped classrooms, inquiry-based teaching or individual learning theories (Kyriakides, Christoforou & Charalambous, 2013). These studies are producing promising results. The next step is to take those literature-supported instructional methods and incorporate the best curriculum to implement them in—a curriculum based on how people actually learn. The order in which content is presented, according to research, could have a substantial impact on learning and development of higher-order reasoning skills among students enrolled in STEM courses (Lawson, 2004). There are limited studies to date that compare or directly assess the benefits of one curriculum design over another, none of which test the order of learning on an entire course for an entire semester as the experiment's environment. There have been social movements among professors and universities to switch to modified curriculum designs with various positive results, few of which have been empirically tested or authenticated in publications (Gwynne, 1997). However, substantial research exists to support the justification for teaching introductory biology in a concrete-to-abstract order.

CHAPTER TWO: CONCRETE TO ABSTRACT: A CURRICULUM DESIGN THAT UTILIZES HOW PEOPLE LEARN

Abstract: What is the role content order plays in student development and learning within a subject area? Most introductory biology courses and textbooks start small, at the atomic level, and move up through molecular, cellular, organism, population and ecosystem levels in terms of their curricular order. However, does this curriculum content order aid in creative and critical inquiry that is based on how people actually learn? In this classroom-based, quasi-experimental study, we predicted that biological learning and development of scientific reasoning is best done from the concrete descriptive concepts to the abstract theoretical concepts, when compared to learning that takes place in a traditional ground-up, hierarchical format (abstract to concrete). Results show that when compared to the traditional format, a modified, concrete-to-abstract order of content resulted in significantly higher biological declarative knowledge and ability to make concept connections. While we failed to detect a significant difference between the two courses in terms of how quickly scientific reasoning skills are developed or how students' score on scientific reasoning skill assessments, the concrete-to-abstract course did show significantly higher gains in reasoning between the start and end of the semester.

Introduction

The Higher Education Research Institute (Hurtado, Eagan & Hughes, 2012) reported that entering college students' interest in STEM (Science, Technology, Engineering, Mathematics) is increasing; however, the percentage of students who actually graduate in STEM is decreasing. According to the 2012 PCAST report, only 40% of students who enter college with the intent to pursue a STEM degree actually do so. Furthermore, in a large-scale study of college students nationwide, 90% of students stated they left STEM due to poor teaching as one of the primary reasons for their departure (Seymour and Hewitt, 1997). In addition to perceived teaching quality, studies have found that retention in STEM is highly correlated with both a student's performance in introductory courses (Suresh, 2006) and their analytical and quantitative reasoning ability (Astin & Astin, 1992; Eris et al., 2010; Heilbronner, 2011). There is a strong correlation between these reasoning skills and academic performance, especially in STEM subjects (Bransford et al., 2000; Cohen, Hillman, & Agne, 1978; Kuhn, 2005; Lawson, 1980, 1982; Zeineddin & Abd-El-Khalick, 2010; Zimmerman, 2007), and academic performance in introductory STEM courses is directly related to retention (Suresh, 2006). Thus, we should be designing our courses to maximize both the development of reasoning skills and the performance of students so that self-efficacy increases, and retention rates rise.

Previous studies conducted among university students show that two major factors contribute to whether or not students decide whether or not to pursue science majors: classroom climate and faculty pedagogy (Seymour & Hewitt, 1997). These studies show that among the principal factors determining student attrition rates from science majors, over-packed and unorganized curricula is close to the top. In response to these studies, Tanner and Allen concluded that we need our teaching styles, instructional selections, and pedagogical approaches to be differentiated in a way that will reach more students, appeal to a variety of learning styles, and retain a broader range of students interested in science (Tanner and Allen, 2004). One way of doing this would be through curriculum reform.

This leads to the salient question for this research study: Does the order of the curriculum play a critical role in student development and learning within a subject area? We would argue that the answer to this question is unequivocally affirmative. Most introductory biology courses and textbooks start small, at the atomic level, and move up through molecular, cellular, organism, population and ecosystem levels in terms of their curricular order. A survey of several popular majors and non-majors' textbooks reveal the same pattern (see Table 2).

Table 2. Curricular order of several popular biology textbooks for major and non-major courses

Textbook	**Chemistry**	**Genetics**	**Evolution**	**Organismal (physiology)**	**Ecology**
Majors					
Campbell Biology by Reece et al.	Ch2	Ch13	Ch22	Ch40	Ch52
Biological Science by Freeman	Ch2	Ch13	Ch24	Ch41	Ch50
Biology How Life Works by Morris et al.	Ch2	Ch15	Ch21	Ch35	Ch46
Principles of Life by Hillis	Ch2	Ch8	Ch15	Ch29	Ch42
Non-majors					
Biology for a Changing World by Shuster et al.	Ch2	Ch11	Ch13	n/a	Ch20
Biology Science for Life by Belk & Maier	Ch2	Ch8	Ch11	n/a	Ch15
Campbell Essential Biology by Simon et al.	Ch2	Ch9	Ch13	n/a	Ch19
What is Life? A Guide to Biology by Phelan	Ch2	Ch9	Ch12	n/a	Ch16

According to the American Association for the Advancement of Science (AAAS), "Progression in learning is usually from the concrete to the abstract" (1989, p. 199). Learning takes place by connecting new experiences to things we already know. Theoretically, students learn best when they are presented with something familiar first. This allows them to make connections between new information and information already retained in long-term memory. Called "meaningful learning", research has shown it to be more effective than rote learning (Ausubel et al., 1978; Bransford & Johnson, 1972; Mayer, 1996). Thus, it is understandably difficult to make connections with abstract or theoretical topics where concrete experience is impossible or has yet to be gained. Thus, with unfamiliar concepts, students will default to rote memorization (e.g., the energy from high-energy electrons is used to shuttle hydrogen-ions across the cristae membrane in a mitochondrion) and not have opportunities for meaningful learning.

Lawson et al. (2000) has demonstrated that three types of concepts indeed exist: descriptive, hypothetical, and theoretical. Descriptive concepts are ones that are observable (i.e., concrete, e.g. *predator* or *organism*). Theoretical concepts are those in which the causal agent is indirectly testable (e.g., *atom* or *gene*). Hypothetical concepts are intermediary concepts that hypothetically could be observed, but due to limits of normal observation time, cannot be (e.g., *natural selection* or *subduction*). These concept types are acquired sequentially in the development of the intellect (see Figure 2 for more examples). Likewise, as an adult begins to construct concepts in a new field (i.e., Biology), descriptive concepts will form the foundation upon which hypothetical and theoretical concepts can be built (Lawson et al., 2000). This makes sense in light of the constructivist theory that claims that learning is an active process whereby students participate in the building of their own knowledge through a process of assimilation or accommodation with what is previously known (see Cobb, 1994). Lawson et al. (2000) and others (see Baddeley, 1999, for a review) have also shown that these concepts (descriptive, theoretical, and hypothetical) are sequentially harder to acquire and require increasingly greater intellectual development to obtain.

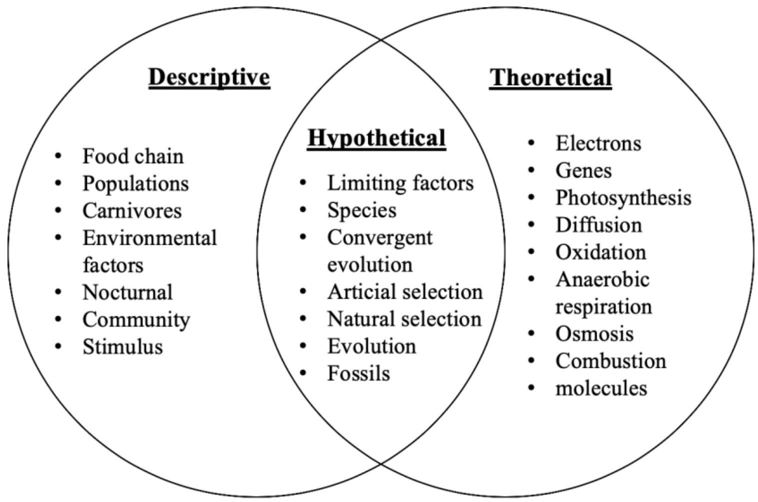


Figure 2. Examples of biological terms that fit under the three concept types: descriptive, hypothetical and theoretical concepts

Armed with the knowledge of the way in which conceptual understanding is formed, it is surprising that most biology textbooks, and subsequent curricula, are designed to begin with theoretical concepts, i.e., atomic, molecular, and cellular structure. It is intuitive for scientists to teach in a structurally organized fashion, either bottom-up (atoms to ecosystems) or top-down (ecosystems to atoms), as this is the way in which our knowledge is organized, i.e. hierarchically (Baddeley, 1999). But, being experts, professional scientists and educators have forgotten the way in which our knowledge was initially obtained and are often unaware of the challenges faced by beginners in the field (Bransford et al., 2000). Thus, instructors unknowingly often begin with the most difficult concepts to construct (atoms, molecules, energy transfer) and often end with the most concrete (organisms, body systems, variation).

Substantial research in intellectual development and constructivism support the justification for teaching introductory science courses in a concrete-to-abstract curriculum order. More specific publications support the idea that curriculum order does matter and has the potential to greatly influence student performance if, throughout the semester, content is presented in an “concrete to abstract” manner (Lawson et al, 2000; Lawson, 2002; Lawson, 2004). Humans develop creative and critical thinking skills and values by attempting to use them in exploration and explanation of observations we see in the world around us (Lawson, 2004; Inhelder & Piaget, 1958). Therefore, we should be teaching science, especially undergraduate, non-major courses in the way intellectual development is practiced in the real world: a data-supported process of creative and critical inquiry that is based on how people actually learn.

According to developmental psychologists, students in their undergraduate degree years should be operating in a high developmental level of thought and operation (Piaget, 1952; Inhelder & Piaget, 1958) and should therefore be able to apply their higher-order reasoning skills to new experiences. However, development is necessary but not sufficient for progression through stages of intellectual development. As adolescents and adults entering a new field of study, a descriptive conceptual foundation in relationship to that field of study must be partially in place before theoretical concepts are constructed. Without experience in using formal operational skills, many students fail to develop expertise in using them. Students do not always use the skills associated with their presumed level of intellectual development when placed in a new learning environment. For example, students, who are presumably formal reasoners, will revert to less operational means of thought in unfamiliar learning conditions (Bodner, 1986). This is why it is important to start with concrete, descriptive topics to allow students the ability to develop these formal operational reasoning patterns so that they are equipped to deal with more theoretical biological concepts later in the semester.

Some biologists argue that teaching in the traditional and conventional abstract-to-concrete custom is actually supporting intellectual development because the courses start small and lay the foundation for the next system or level they are teaching (as cited in Lawson, 2004).

However, this is misinterpreting Piaget's stages of intellectual development (Piaget, 1952; Inhelder & Piaget, 1958) and how concepts and connections between concepts are actually constructed. Many biologists object to the concrete-to-abstract approach because they believe it promotes learning based more on faith than empirical evidence (Gwynne, 1997). We would argue the opposite, emphasizing the differences between the abstract introduction of traditional biology courses, which requires educators to teach students about unobservable phenomena to the concrete introduction of a modified concrete-to-abstract. Claims that teaching the traditional method is best for students dismiss an important gap we see in educational studies when it comes to curriculum content order and the effect the order of content can have on students.

While there have been social movements among professors and universities to switch to a modified biology curriculum design with various positive, though unquantified results (Gwynne, 1997), most introductory biology courses still begin with the atom, a theoretical concept. While some universities have noted trends of decreased withdraw rates within concrete-to-abstract structured biology courses or an increase in the number of students who declare biology majors (Gwynne, 1997), there is no definitive existing research that supports the use of one curriculum over the other when it comes to improvement in student learning. Until substantial empirical evidence exists to demonstrate an actual change in content order of how material is presented to the students as a determining factor in that success, no large-scale switches to this modified curriculum will be made. There are limited studies that truly compare curriculum designs in classrooms across an entire semester and none of them specifically address the stages of intellectual development and the theory of concept constructivism through the assessments used to collect data.

Based on these learning theories we put forth the hypothesis that the learning of biological concepts proceeds most easily from concrete to abstract. Given this hypothesis, we predicted that a curriculum that begins at the organismal level and proceeds to the cellular/molecular/atomic level and also in the opposite direction to the population and ecosystem level will result in greater conceptual understanding than one that proceeds in the traditional format (bottom-up, abstract-to-concrete). In addition, it has been shown that the process of learning concepts through the proposal and testing of alternative theoretical possibilities leads to greater scientific reasoning skills (see Lawson et al., 2000 and Metz, 1995 for discussions). Thus, an additional prediction follows that if theoretical conceptual understanding is greater in a reversed curriculum, then greater gains in scientific reasoning ability should be seen.

A concrete-to-abstract curriculum design encompasses more than simply turning the conventional micro-to-macro curriculum upside-down and teaching it in the opposite order. It is a way of teaching and learning that not only builds off what students already know but how their intellect develops throughout the learning process. This approach is designed to provide learning experiences aimed at doing more than just building a student's declarative knowledge of the subject but developing hypothetical-deductive reasoning skills and enhancing a student's ability to make connections between biological concepts.

Methods

Ethics Statement

The Institutional Review Board for Human Subjects at the first author's institution approved this research and granted permission for human subjects use in this study; written consent was obtained from all participants.

Subjects

This study was run at a large (approx. 35,000 students) private doctoral-granting university in the Western US. The university is highly selective with an average incoming freshman ACT score of 28 and GPA of 3.82, making students highly motivated. It is a private religious institution with a highly homogeneous population both religiously and culturally.

Students in this study were non-majors enrolled in a General Education Biology course. They range from freshmen to seniors and ranged in majors across all non-life science disciplines. The classes had approximately 65 students each. The course met three times per week for 50-minute time periods.

Data was only included in the analysis for students who signed written consent and completed the course with a passing grade. This was done to exclude students who stopped attending the course midway through the semester and/or turned in less than 50% of course assignments and exams. Both sections had an equal fail rate of approximately 2%. Thus, 55 students in the traditional condition and 60 students in the modified condition were included in the final analysis.

Study Design

A comparative quasi-experimental design was used. Two sections of the introductory biology course were used in a test-control situation. Significant effort was put forth to ensure as much group equivalence as possible, i.e., the same instructor taught both sections, the same textbook, course materials and assessments were used, the same lectures and course content was presented through the semester (see description below), and the same two teaching assistants were present in both sections. Additionally, group equivalence was tested using several pre-tests (see *Appendix A and Appendix B*). Due to a scheduling conflict outside of the research team's control, the sections were not taught back-to-back in the same classroom as originally planned but were, instead, taught at the same time across two consecutive semesters. The traditional condition was taught the first semester and the modified condition was taught the second semester.

Traditional and modified classrooms

The nature of our hypothesis, that the order of concepts taught is the main causal factor of improvements in student learning in the macro-to-micro modified condition, necessitated that all other factors be tightly controlled. Thus, both conditions were exposed to the same course content and active learning instructional materials, just in a different order and at different points in the semester as described in Figure 3 below.

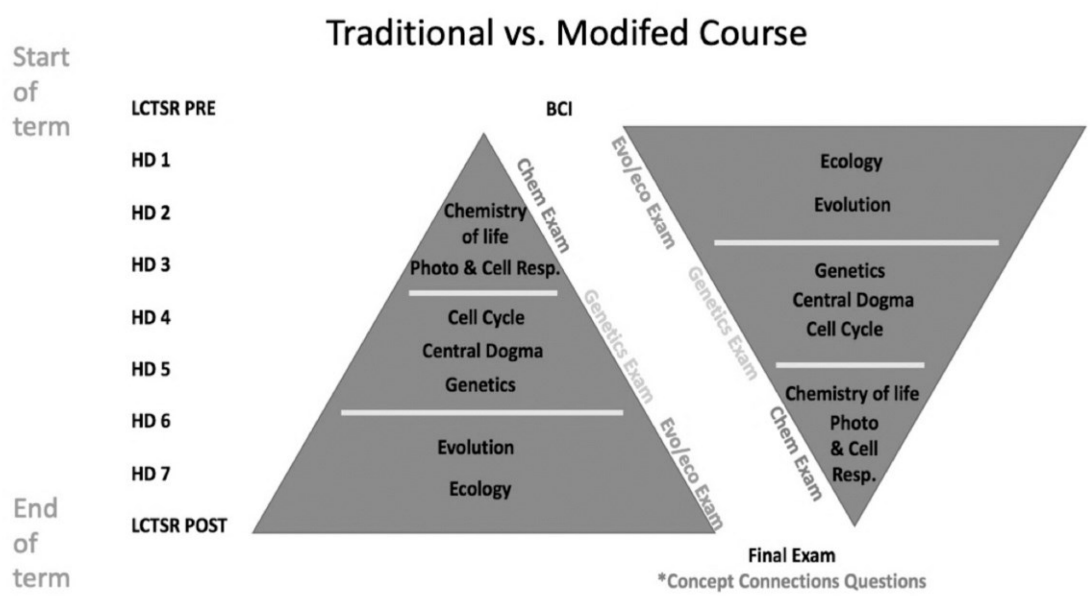


Figure 3. Outline and comparison of course curriculum in both the traditional and modified sections

Each section covered three general units of material throughout the semester. We refer to the three units as chemistry, genetics, and evolution/ecology. Each unit lasted an average of three weeks and covered three to four subunits. The chemistry (Figure 3. chem) unit covered the chemistry, nutrition and macromolecules, cells, and photosynthesis and cellular respiration subunits. The genetics unit covered the cell cycle, central dogma and DNA replication, and genetics subunits. The evolution/ecology (Figure 3. eco/evo) unit covered the evolution, ecology, and stewardship and conservation subunits.

The first several lectures for both conditions were spent exploring the nature of science, hypothesis testing, statistical measures and an overall introduction to the scientific thought process before beginning the first unit of instruction. During this time, students sent in their research consent forms and measures of group equivalence was collected (see measures of group equivalence below). Throughout the semester, students were given short hypothetical deductive (HD)-reasoning quizzes to track development and application of reasoning skills. At the end of the semester, students took a final exam in the university testing center during the university's mandated finals week.

Traditional condition. In the traditional condition, the first unit covered chemistry, nutrition and macromolecules, cells, and photosynthesis and cellular respiration in that order. The second unit covered the cell cycle, central dogma and DNA replication, and genetics. The third unit covered evolution, ecology, and stewardship and conservation. At the end of each unit, a 100-point exam unit exam was administered in the university testing center. Points were totaled from a combination of multiple-choice, matching, short answer and free-response (often problem solving or diagramming) questions.

Modified Condition. In the modified condition, all units, lectures and exams were identical to the traditional condition, units were simply flipped, and subunits rearranged to fit our concrete-to-abstract hypothesis. The first unit covered ecology, stewardship and conservation, and evolution. The second unit covered the cell cycle, central dogma and DNA replication, and genetics. The third unit covered cells, macromolecules and nutrition, chemistry, and photosynthesis and cellular respiration. At the end of each unit, a 100-point exam was administered in the university testing center. Points were totaled from a combination of multiple-choice, matching, short answer and free-response (often problem solving or diagramming) questions.

Measures of Group Equivalence

Both students' prior knowledge of biology and students' scientific reasoning skills were assessed at the start of the semester to determine group equivalence and to be used as potential covariates if groups appeared to be non-equivalent. Students' prior biology knowledge was assessed using the *Biology Concept Inventory* (BCI), an instrument designed by researchers to assess basic biology understanding (Garvin-Doxas, Klymkowsky, & Elrod, 2007). Reliability of the instrument was low (Spearman-Brown Coefficient = 0.51), thus it was only used to establish a baseline level to assess group equivalence. It was not used in a pre-test/post-test design to determine student learning. Students' scientific reasoning ability was measured using the *Lawson Classroom Test of Scientific Reasoning* (LCTSR; Lawson, 1978, ver. 2000). The LCTSR is a content-independent test of basic formal reasoning skills including correlational, combinatorial, probabilistic, proportional, and hypothetical-deductive reasoning as well as identifying and controlling variables. The LCTSR has been shown to be highly correlated with performance in science classes (Johnson & Lawson, 1998). Validity and reliability have been well established (see Lawson *et al.*, 2000). Thus, it was used both to assess group equivalence and to determine student gains in a pre-test/post-test design.

Data Collection

Unit exams. To assess incremental learning throughout the semester, three identical, 100-point unit exams were administered in both the traditional and modified conditions. The three exams (eco/evo, gen, and chem) were given at different times during the semester to match when the material was taught in class (see Figure 3). Points were totaled from a combination of multiple-choice, matching, short answer and free-response (often problem solving or diagramming) questions and exams ranged from 35-45 questions. Questions were designed using Bloom's Taxonomy (Blooms, Krathwohl & Masia, 1984) with a focus on high-level Bloom's design. Both conditions were also administered a comprehensive, multiple choice final exam at the end of the semester. All exams were administered at the University Testing Center. Student scores were calculated as total percent correct. Thus, neither section was exposed to more content material, more application practice, or more assessment than the other.

HD reasoning quizzes. Identical HD reasoning quizzes were administered starting the second week of the semester with one every week on average throughout the remainder of the semester. Each quiz contained three HD questions unrelated to the current course material pulled from a bank of HD scientific reasoning questions created by the research team. In the first semester, one of the quiz images failed to download, making it impossible for students to answer the questions, this same test with the same errors was administered the second semester to assume as much equivalence as possible between the two conditions. Student scores were calculated as total percent correct on each quiz so that HD development could be tracked throughout the semester (see appendix C for an example HD quiz questions).

Final exam scores. An identical comprehensive final exam was administered to both the traditional and modified conditions in the University Testing Center. The exam consisted of 124 multiple-choice questions including the 24-question LCTSR (to assess reasoning gains, the change in LCTSR was calculated by subtracting pre-LCTSR scores from post-LCTSR scores). Questions were designed using Bloom's Taxonomy (Blooms BS, 1984) with a focus on high-level Bloom's design. In addition, 10 free response Concept Connection Questions (see below) were included. The final exam was worth 200 points, or approximately 15% of their final grade.

Concept Connection Questions. As a part of their final exam, students were asked ten free response questions specifically designed to determine their ability to think about and make connections between concepts in different units/subunits throughout the semester. Unbeknownst to students, concept connection points did not contribute to their final exam score. This page was removed from each final exam and deidentified. Three members of the research team were trained to code each students' responses. Papers were chosen at random, and ideas, themes, and answers were organized by each team member individually until nothing new came up in student responses. From there, the research team created a code based on themes collected to assign each question an individual score from 0-2 (0 = the connection was not made, 1 = a partial connection was made, and 2 = the connection was made). Ten papers were chosen at random and each team member read each paper and individually coded and scored each answer. Each team member's scores were compared and evaluated until all team members agreed on a score assigned to each question. This was repeated twice more, each with ten new random papers, until no discrepancies were found between the researchers' scores. At this point, researchers coded and scored the remaining papers with random checks by the other two researchers. A total score for the ten concept connection questions was calculated for each student. To see a copy of the concept connection questions, see Appendix D.

Statistics

All comparisons between sections were done using independent samples t-tests or univariate analysis of variance (ANOVA) in the SPSS statistical package (2019, version 26). Where appropriate, findings were confirmed using univariate analysis of covariance (ANCOVA) using the LCTSR and BCI scores as covariates.

Results

Group Equivalence

Scores on the BCI were compared using an independent samples *t* test to evaluate the equivalence of the sections on prior biology knowledge at the beginning of the course. The BCI was scored as a raw percentage correct. We failed to detect a significant difference between sections signifying that sections were equally matched in prior biology knowledge. ($M_{modified}$ = 11.09, $M_{traditional}$ = 11.58, $t(111) = -.775$, $p = 0.44$). See Figure 4.

Scores on the Pre-LCTSR were compared using an independent samples *t* test to evaluate the equivalence of the sections on reasoning ability at the beginning of the course. The LCTSR is scored out of 24 points. We failed to detect a significant difference between sections signifying that sections were equally matched in reasoning ability (Mmodified = 17.83, Mtraditional = 18.61, $t(108) = -1.103$, $p = 0.273$). See Figure 6.

Both tests confirm that the groups were statistically equivalent in prior knowledge and scientific reasoning skills. However, since both prior knowledge and scientific reasoning ability could potentially affect student performance on high-level exams, analyses were run with these as covariates to confirm the findings of the analyses without covariates included.

Unit Exams

Unit exam scores were compiled for all students in each condition. Unit exams were scored as a raw percentage correct. An ANOVA was conducted wherein each unit exam was compared between the modified and traditional conditions. An ANCOVA using students' Pre-LCTSR and BCI as covariates confirmed the results. For the evolution/ecology exam student scores we failed to detect a significant difference between sections ($M_{modified} = 89.98$, $M_{traditional} = 89.91$, $t(112) = 0.051$, $p = 0.96$) with Pre-LCTSR being a significant predictor ($F(1,103) = 11.395$, $p = 0.001$).

For the genetics exam, the modified treatment scores were significantly higher ($M_{modified} = 88.034$, $M_{traditional} = 81.673$, $t(112) = 2.931$, $p = 0.004$) with Pre-LCTSR being a significant predictor ($F(1,103) = 15.443$, $p = 0.000154$).

For the chemistry exam, the modified treatment's scores were significantly higher ($M_{modified} = 83.644$, $M_{traditional} = 78.655$, $t(112) = 2.057$, $p = 0.042$) with Pre-LCTSR being a significant predictor ($F(1,103) = 9.953$, $p = .002$). See Figure 4.

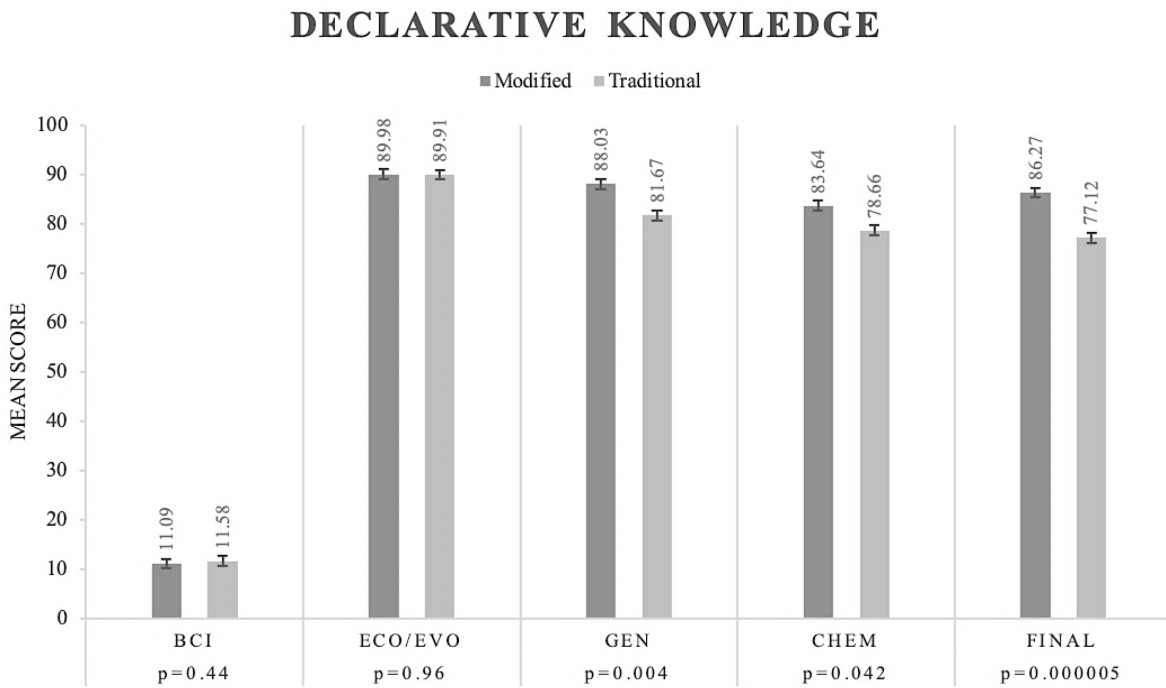


Figure 4. Mean score and significance of declarative knowledge measures

Final Exam

The overall total score on the final exam was evaluated using ANOVA between the modified and traditional conditions. An ANCOVA using students' Pre-LCTSR and BCI as covariates confirmed the results. Results indicated that the modified treatment scores were significantly higher ($M_{modified}$ = 86.267, $M_{traditional}$ = 77.146, $t(113) = 4.783$, $p = 0.000005$) with Pre-LCTSR being a significant predictor ($F(1,104) = 6.411$, $p = .013$). See Figure 4.

HD Reasoning Assessments

HD Reasoning Assessments taken throughout the semester were compared using a repeated measure factorial ANOVA. A comparison of the main effects failed to detect a differential change over time according to group condition ($F(6,342) = 1.355$, $p = 0.232$). See Figure 5.

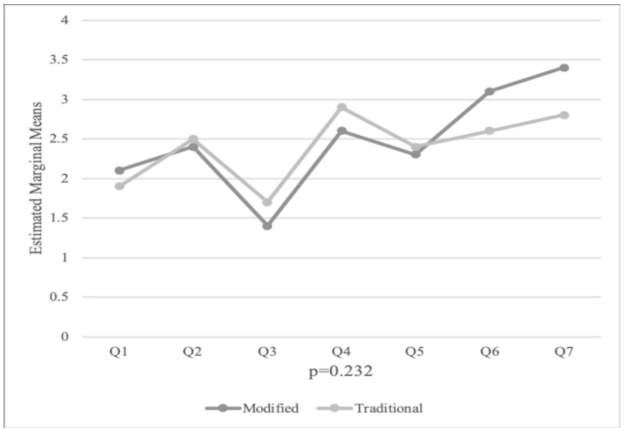


Figure 5. Estimated marginal means of HD reasoning assessments (1= $M_{modified}$, 2=$M_{traditional}$)

Scores on the Post-LCTSR were compared using an independent samples *t* test to evaluate the equivalence of the sections on reasoning ability at the beginning of the course. The LCTSR is scored out of 24 points. The comparison failed to detect a significant difference between the two sections ($M_{modified}$ = 20.034, $M_{traditional}$ = 19.667, $t(111) = 0.511$, $p = 0.611$). The average change in LCTSR scores from pre-test to post-test was compared between the two sections. Results of the paired samples *t* test showed the students in the modified treatment experience significantly higher gains ($M_{modified}$ = 2.396, $M_{traditional}$ = 1.358, $t(107) = 2.27$, p = 0.025). See Figure 6.

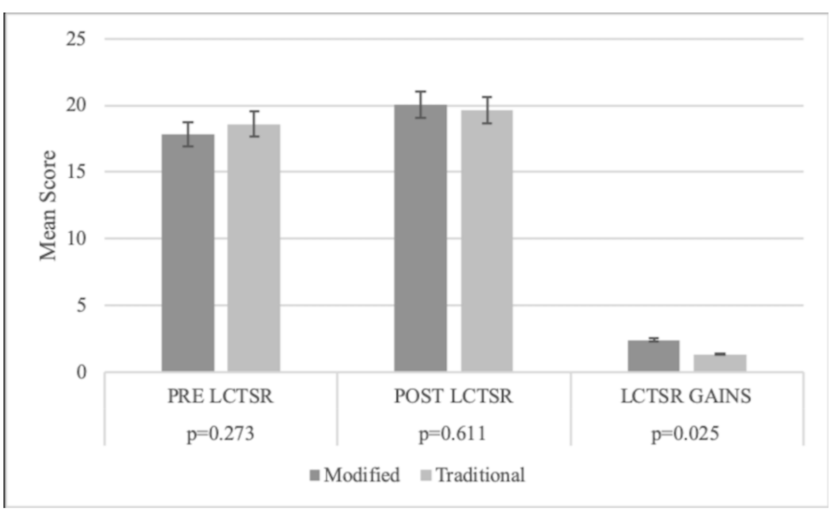


Figure 6. LCTSR pre/post comparisons with gains analyzed

Concept Connections

The overall concept connection score was evaluated using ANOVA between the modified and traditional conditions. Results indicated that the modified treatment scores were significantly higher ($M_{modified}$ = 12.9107, $M_{traditional}$ = 10.8596, $t(111) = -3.034$, $p = 0.003$). ANCOVA using pre-LCTSR and BCI as covariates confirmed these results ($p = 0.001$). See Figure 7.

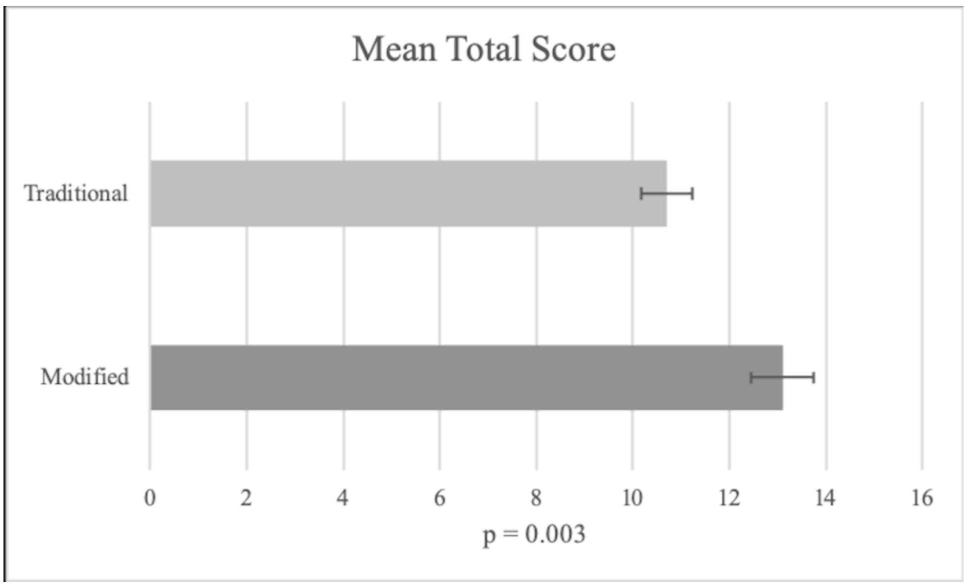


Figure 7. Mean total score on concept connection questions

Individual concept connection questions were analyzed using independent samples t tests. Results found that the modified condition did significantly better than the traditional course on four out of the ten questions. There were six questions where we did not find a significant difference. The traditional condition did not do significantly better on any question when compared to the modified condition. See Table 3.

Table 3. Determining how each condition performed on individual concept connection questions

Question	Higher Scoring Condition	p-value
1	Modified	$p = 0.003$
2	Modified	$p = 0.273$
3	Modified	$p = 0.019$
4	Modified	$p = 0.823$
5	Modified	$p < 0.001$
6	Traditional	$p = 0.077$
7	Modified	$p = 0.097$
8	Modified	$p = 0.555$
9	Modified	$p < 0.001$
10	Modified	$p = 0.518$

Discussion

The results of this study provide evidences in support of our hypothesis that a modified concrete-to-abstract course curriculum results in greater student gains in declarative knowledge, scientific reasoning skills, and in a student's ability to make concept connections compared to a traditional abstract-to-concrete curriculum.

We predicted that students in a modified concrete-to-abstract curriculum would have a greater conceptual understanding of biological content than one that proceeds in the traditional abstract-to-concrete curriculum both on unit and final exams. Our results showed that students performed equally well on the ecology/evolution unit exam, which was expected as this was the most concrete exam in terms of subject material. However, the modified treatment performed higher on the two other unit exams (genetics and chemistry), which covered more abstract concepts.

Students who covered concrete concepts first should have a conceptual foundation to build upon. This process of "meaningful learning" allows them to make connections between new information and information already retained in long-term memory instead of relying on rote memorization (Ausubel et al., 1978; Bransford & Johnson, 1972; Mayer, 1996). Because exams were designed to focus on higher level Bloom's (Blooms BS, 1984), we predicted that the students who are able to build their declarative knowledge from a concrete understanding can perform better on questions that ask them to formulate, evaluate, and experiment with the material they have learned and not just generate rote, memorized, fact-based answers. These results were solidified again in the comprehensive final exam when students in the modified treatment scored significantly higher than the traditional treatment students on the comprehensive final exam.

We predicted that students in the concrete-to-abstract curriculum would develop greater scientific reasoning skills and would apply these skills sooner than students in the traditional abstract-to-concrete curriculum. Students performed equally as well on the Pre-LCTSR, which determined equivalence between the two treatments and was expected. Students also performed equally as well on the Post-LCTSR. We would have expected students in the modified curriculum to score higher, however, it is important to note that students in both sections scored high on the Pre-LCTSR, which left less room to measure drastic improvements.

Our results do support that overall gains between pre and post LCTSR test scores (gains in scientific reasoning) was significantly higher for the concrete-to-abstract students. We measured this by taking a student's Post-LCTSR score and subtracting their Pre-LCTSR score and giving each student a "gains score" for their point difference. Mean gains scores were significantly higher for the students in the concrete-to-abstract curriculum, which supports our original hypothesis.

Another way we tracked scientific reasoning ability was through HD quizzes. Students performed equally as well on all the HD quizzes throughout the semester although some interesting trends emerged. We begin to see a divide in scores between the two sections after quiz five (see Figure 5). that may suggest the modified students begin to perform better. If more time in the semester were permitted, it would have been interesting to see if the trend continued. The trend matches our hypothesized expectation that our concrete-to-abstract students would develop and apply their scientific reasoning skills earlier in the semester.

We predicted that students in the modified treatment would be able to make more accurate concept connections. Our results supported our hypothesis. Students in the modified treatment scored significantly higher on the concept connection questions, which were designed to pull materials from different concepts covered throughout the semester and tie them together. When individual questions were analyzed, there were four questions specifically that the modified condition scored significantly higher on. The traditional condition did not score significantly higher on any of the concept connection questions. Students who have a concrete foundation from them to build abstract concepts on are more likely to correctly make connections that relate between concept types.

While not a part of our initial research, additional observations were made by the research team which made us consider that students in the concrete-to-abstract curriculum were more likely to recognize the connections they were making throughout the semester and, overall, enjoy the course more. Class attendance was higher and fewer students withdrew from the concrete-to-abstract course. We predict that if we had measured student attitudes towards the course, our concrete-to-abstract students would have scored higher. The following unprompted email from a student in the concrete-to-abstract course exemplifies multiple student responses to the course:

> *"I just wanted to let you know I really enjoyed taking BIO 100 this semester. It was my third time taking BIO 100 and I finally passed! The organization of what you taught really helped me connect everything we were learning. Starting big with ecology and going small to atoms made things clear to me.*

I learned more than I had previously and was excited about what I was learning."

This study addresses an overlooked issue within biology education research: the impact that understanding concept types and curricular order in introductory biology. A theoretical rationale of a concrete-to-abstract curriculum order has been documented (Lawson, 2000; Lawson, 2002; Lawson, 2004), but not compared to the traditional abstract-to-concrete course curriculum. Nevertheless, research exists to support the justification for teaching introductory sciences courses in a concrete-to-abstract curriculum order (Lawson, 2000; Lawson, 2002; Lawson, 2004). Our current comparison suggests that the modified concrete-to-abstract curriculum offers many benefits to student gains over a traditional learning approach. This is the first step our institution has made to establish the effect of the mechanisms of this new methodology.

Based on the results of this research, we can establish a set of recommendations for the use of the concrete-to-abstract curriculum design. In order to justify the investments of institutions and educators in the implementation of this modified curriculum we need the convincing nature of scientifically based studies examining effectiveness of any educational-based proposal. Policymakers overseeing research funding for educational innovations rely heavily on research findings to justify expenditures (Feuer, Towne & Shavelson, 2002; Ringstaff & Kelley, 2002). Future research should involve implementing and testing these same curricula at other institutions to confirm our results are transferrable to a wider variety of classrooms and student bodies. These data have been gathered within a specific context and from a narrow demographic. Thus, we recommend and encourage the implementation of this same research design on varying student bodies in a variety of academic settings (e.g., small versus large class sizes, lower versus upper division, majors versus non-majors, different learning outcomes) in order to better define the degree and extent of transferability of these results.

It has been hypothesized that reversing the traditional curriculum order in introductory biology courses could improve student understanding of biological concepts and promote intellectual development as well as help solve the widespread problem of college student attrition from the sciences (Lawson et al, 2000). Similar, successful education research within physics, chemistry and mathematics over the past few decades has shown great success in modifying curricula to more accurately mirror student intellectual development and decrease student attrition in these majors (Bodner, 1986; Gwynne, 1997). As educational professionals, we should be designing our courses to maximize the development of reasoning skills and the performance of students so that self-efficacy increases, and retention rates rise. Retention in STEM is highly correlated with both a student's performance in introductory courses (Suresh, 2006) and their analytical and quantitative reasoning ability (Astin & Astin, 1992; Eris et al., 2010; Heilbronner, 2011). There is a strong correlation between these reasoning skills and academic performance, especially in STEM subjects (Bransford et al., 2000; Cohen, Hillman, & Agne, 1978; Kuhn, 2005; Lawson, 1980, 1982; Zeineddin & Abd-El-Khalick, 2010; Zimmerman, 2007), and academic performance in introductory STEM courses is directly related to retention (Suresh, 2006). It is our hope that as more data-supportive research is disseminated on a concrete-to-abstract curriculum, we can contribute to the establishment of a more effective and enjoyable curriculum in introductory biology courses and increase overall retention as well.

CHAPTER THREE: PRIMARY SCHOOL PRINCIPAL-RUN RHEUMATIC HEART DISEASE PREVENTION PROGRAM IN SAMOA

Introduction

Rheumatic heart disease (RHD) is a serious yet preventable disease which affects over 30 million individuals world-wide (World Health Organization, 2018). Developing countries, such as the island nation of Samoa, specifically exhibit high prevalence and incidence rates of RHD (Faller & Allen, 2009; Carapetis et al. 2013; Kumar & Tandon, 2013). Rheumatic Relief, a multi-disciplinary public health and research program, provides and promotes educational and clinical RHD prevention in Samoa. Continued efforts on behalf of the Rheumatic Relief team attempt to evolve and implement new and innovative prevention studies and techniques with the goal to alleviate the burden of RHD in Samoa and influence similar practices in other vulnerable areas of the world.

Public health programs often involve collaborative efforts between health professionals, community members, and primary researchers in order to find effective and sustainable solutions to health issues found in local and global communities. Global public health efforts often include a combination of indigenous and nonindigenous expertise for program planning, implementation, and evaluation (Zühlke & Engel, 2013). In the case of the Rheumatic Relief program, public health efforts between the Samoan Ministry of Health (MOH) and trained professionals in the United States have provided vital information and assistance to Samoan education administrators, caregivers, and children to curtail the burden of RHD.

To date, Rheumatic Relief has focused on the at-risk population of children ages 5-15 years old with a hope that these intrapersonal initiatives in Samoa are beneficial for a child's direct involvement in the instruction of and decision-making regarding their own health (Allen et al, 2017). Similar studies have shown the effectiveness and necessity to allow children to be agents in their own health care. One study conducted in Spain analyzed health discourse among primary school children ages 8-12 years, finding the majority of children were generally very aware of the role they played in their own health (Davó-Blanes & La Parra, 2013). Another study conducted in rural Kenya strongly supported the significant and positive impacts when children and adolescents play a role or have primary control over decision-making when it comes to health research (Marsh et al, 2019). However, children are often dependent upon caregivers and other adult influences to implement choices related to the health of dependent children. Despite a potential disconnect between informed children and under-informed caregivers, intuitively caregivers would desire to be actively involved in their children's' health and learn more from health care professionals about the issues pertinent to their children (Ford et al, 2016). Such a disconnect could be problematic for the Rheumatic Relief team's efforts to relieve the burden of RHD in Samoa, which motivates an expansion to the program's focus to include caregivers.

Samoa is a nation of defined villages with concomitant leadership. Primary school principals are not only heavily involved in village educational decisions, but they also have frequent and ongoing contact with their students and their caregivers. This relationship offers principals a unique position of trust and influence within their communities. Other studies support the idea that principals of primary school-aged children play a fluid role in the changes made within their schools with many potential outreaching effects. One study conducted in Canada found that when principals took responsibility for heading new school-based health promotion initiatives, changes were easily adopted in the school communities. In this study as well, the personal responsibility each principal felt heading the project made them more likely to advocate for changes inside and outside of the school which lead to greater caregiver involvement and community support (Roberts et al, 2016).

Another study conducted among school principals in Taiwan found that principals are greatly interested in and highly willing to get involved in health-promoting programs and activities but may not always know the appropriate way to make connections between the schools and the community, including to their students' caregivers (Liu et al, 2019). Another study conducted by Liu & Chang (2015) has shown that implementation of good school-caregiver and community communication and collaboration can effectively promote and enhance efficiency of school-based health programs. Research also shows that caregivers are open to learning about the health issues facing their children and are looking for opportunities to learn how to be more informed when it comes to their children's health and school leadership plays a large role in helping caregivers achieve that goal (Ford et al, 2016).

The purpose of this study was to further investigate and utilize the potential influence a principal can have on their students' caregivers through the development of principal-run caregiver meetings and the immediate efficacy of the material presented in this meeting in caregivers. Previous studies conducted in similar settings have shown that health promotion and prevention efforts were more successful under these circumstances because they exist as part of the socio-ecological model where key positions within the socio-ecological environment, such as principals, can more successfully assist in the organization and implementation of health promotion initiatives (Langille & Rodgers, 2010; Perelini, Blair, Wilson, Farrell, & Aitken, 2015). Programs that are integrated into an existing health system through policy support are more successful at overcoming barriers unique to underdeveloped areas, such as Samoa, and instilling an organized advocacy, education and treatment cycle in communities (Langille & Rodgers, 2010; Dougherty et al, 2018). Successful program implementation can benefit from the strategic use of health promotion methods across multiple socio-ecological levels, and comprehensive evaluation within focus indigenous communities (Zühlke & Engel, 2013).

Methods

The development and evaluation of the principal-run RHD educational presentation was based on constructs of the Social-Ecological Model (SEM) of health. This health behavior research model has been applied to studies with similar purposes of influencing child health behaviors (Langille & Rodgers, 2010; Wold & Mittelmark, 2018). The SEM provides a meaningful framework for the study of social contextual factors that influence how policy, community, and organizational levels interact and influence opportunities for health behaviors in a specific organizational setting (Langille & Rodgers, 2010). The first construct of the SEM focuses on the individual. Factors from higher interpersonal and intrapersonal constructs have the potential to influence the children's health behaviors. Previous Rheumatic Relief efforts have focused on this first SEM construct: in this case, the children. This study was designed to validate the expansion of health promotion and prevention efforts using effective circles of influence (principals) into the second interpersonal construct: the children's personal relationships (family/caregivers). In order to determine the effectiveness of using principals to reach our target audience, a three-part study was implemented during three separate visits to Samoa over the course of two years (2018-2019). Each visit focused on collecting data on one of the three research aims.

Research Aim 1) Initial perception of caregivers, principals, and government workers towards the influence of principals among their students' caregivers

Conducted as a pilot study to support and guide the larger program in Aims 2 and 3, initial data was collected in February 2018 from caregivers and principals of primary-aged children on the two main islands of Savai'i and Upolu, as well as from officials working for the MOH within the Samoan sector. Participants were selected by randomly reaching out to individuals within our three criteria groups who agreed to participate. Each participant was asked to complete a six-item assessment with questions designed specifically to target which group their answers represented (principal, caregiver or MOH). Surveys included multiple choice and open-ended questions. The surveys provided the prompts/questions and the response options in both English and Samoan. Survey responses written in Samoan were translated into English.

The survey designed for members of the MOH (Figure 8) asked the participant what he/she believed the status of primary school principals to be in their villages/communities, as well as how influential they perceived principals are among their students' caregivers. Participants were also asked if the MOH has utilized principals in the past, and if so, how? Data on position within the MOH was also noted.

Government Questionnaire (02.2018) MOH

Status of primary school principals in villages?

Not important | Somewhat important | Very important

Influence of primary school principals among parents/caregivers of students?

No influence | Some influence | Very influential

Have primary school principals been utilized by the MOH in the past?

Yes: If so, how? ______________________ No

Figure 8. Example MOH Questionnaire

The survey designed for principals (Figure 9) asked participants how influential they believed the status of primary school principals to be, whether or not they organize caregiver meetings and how often, and if they knew where to go for medical assistance. Data on years they have worked as a principal as well as number of students enrolled in their school was also collected.

Principal Questionnaire (02.2018)

Years as primary school principal? _________

Approximate number of students in their school: _____________

Influence of primary school principals among parents/caregivers of students?
No influence   Some influence   Very influential

Do you organize regular parent/caregiver meetings?
Yes   No
If so, how often?

Do you know where to go for medical assistance?
Yes   No

Figure 9. Example Principal Questionnaire

The survey designed for the caregivers of primary school-aged children currently living and attending school in Samoa (Figure 10) asked participants if they had attended an informational meeting held at their dependent's school in the past and whether or not they would be willing to attend such a meeting in the future. They were also asked how frequently they are contacted by the school's principal, a teacher, or another staff member. Information on gender and whether or not they work was also collected.

Parent/Caregiver Questionnaire (02.2018)

Have you ever attended a school information meeting?
Yes No

Would you attend a meeting organized by the primary school principal?
Yes No

Do you have frequent contact with schoolteachers, principals, or staff?
Yes. Frequency: _________ No

Do you work?
Yes. No

Figure 10. Example Caregiver Questionnaire

It is important to note that these results were analyzed on insignificant sample sizes, especially of the principals, and that the principals we contacted were affiliated with private schools on the islands. Our research team arrived in Samoa the day after hurricane Gita hit the islands. All public schools were closed while the principals were undergoing the country's emergency protocol and were unavailable for us to survey. The rest of our respondents (MOH staff and caregivers), answered questions based on public school principals. The data was used to better understand their attitude towards principal influence, whether or not principal-run meetings were perceived as an effective way of disseminating information to caregivers, as well as to map the general relationships between principals, caregivers, and local village leaders. Data that was statistically analyzed using independent sample t-tests.

Research Aim 2) Baseline caregiver understanding of basic RHD concepts and willingness to participate in any principal-run RHD educational presentation to show the potential benefit of such interventions

The second step we took to assess the effectiveness of a principal-run caregiver meeting was to establish a baseline understanding about RHD among caregivers, as well as their willingness to participate in a principal-run meeting at their child's school. Implementation and evaluation of this part of the study was conducted in 19 schools randomly assigned by the Samoan Ministry of Education, Sport, and Culture (MESC) in May of 2018 over the course of two weeks. Meeting materials were designed and prepared in the Samoan language by the Rheumatic Relief team. Participants comprised caregivers of primary school-aged children that were living and attending school in Samoa. The principal of each school was contacted about our team's visit one month ahead of time so they could organize the meeting. Once our team arrived at a school, the principal was taken aside by a member of the research team, as well as a translator, to review the structure of the caregiver meeting, explain the concepts included in the presentation and associated materials, and the process of conducting a pre- post-presentation survey with participants. The principals were taught the basic behavior of RHD prevention using a poster-based decision tree (Figure 11) which detailed the possible outcomes of a child who is or is not properly treated at the first sign of a sore throat, promoting a visit to the local medical facility to allow for diagnosis and treatment if a pharyngeal streptococcus infection is implicated. Principals were allowed to ask questions about the information we needed them to relay to the caregivers, and then we asked them to teach us the information back in preparation for the meeting. This principal preparation took approximately 10 minutes due to the simplicity of the concepts contained in the presentation.

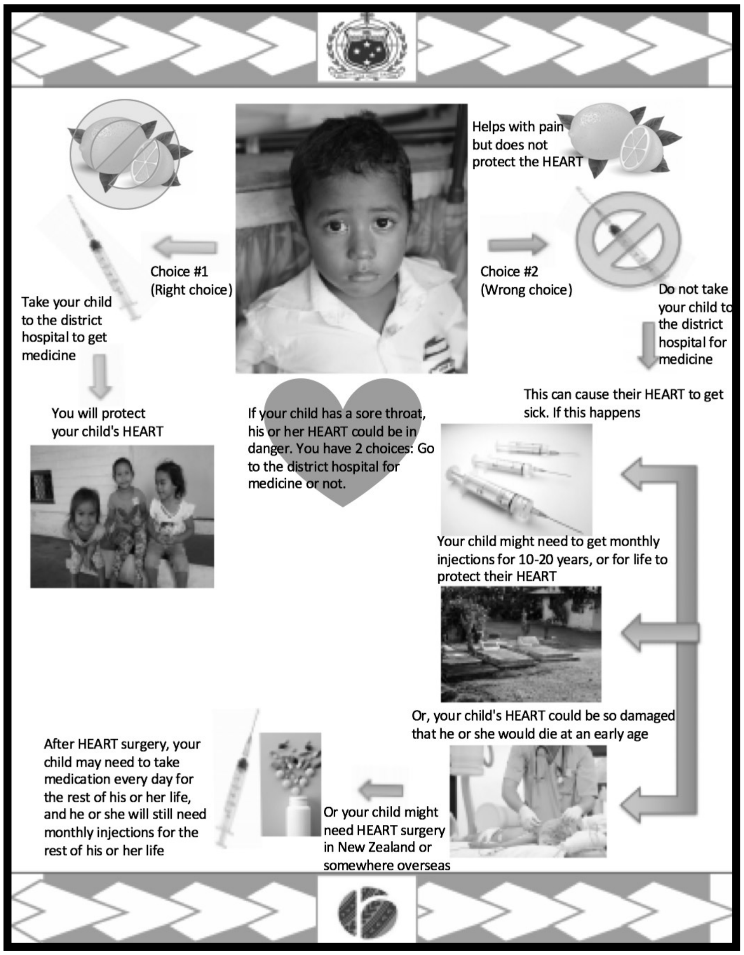


Figure 11. Decision tree used during Principal meetings with English Translation

While the principal was briefed, caregivers were given an eight-item pre-survey to be filled out and collected before the presentation began (Figure 12). Survey answers were anonymous, and participation was optional. The purpose of the assessment was to keep track of the school/island/village of each participant and to collect some demographic data and baseline knowledge of RHD. Surveys included multiple choice and open-ended questions. The surveys provided the prompts/questions and the response options in both English and Samoan. Survey responses written in Samoan were translated into English. A translator was available to each individual taking the survey to assist with questions that did not influence responses.

Parent/Caregiver Questionnaire (05.2018)

1. Have any of your children had a sore throat?
   Pe sa maua se tasi o ou alo i le fa'aī tigā?
   ____Yes **____ Ioe**
   ____No **____ Leai**
   What would you do for your child? ***O le a lau mea e fai mo lou alo?*____**
   ____

2. Is a sore throat too common to be considered a serious condition?
   Pe o le ta'atele o le fa'aī tigā ua lē avea ai ma se tulaga anagatā?
   ____Yes **____ Ioe**
   ____No **____ Leai**

3. Do you trust doctors and/or nurses?
   E te fa'atuatuaina foma'i/poo tamaitai tausima'i
   ____Yes **____ Ioe**
   ____No **____ Leai**

4. Would you prefer the village healer?
   Pe sili atu ia te oe le taulasea?
   ____Yes **____ Ioe**
   ____No **____ Leai**
5. Mode of transport to nearest medical clinic or hospital?
   Su'ega Amata: Auala o femalagaa'iga i le ofisa poo le falema'i latalata ane
   ____Walk **____ Savali**
   ____Drive **____ Ave le ta'avale**
   ____Bus **____ Alu i le pasi**

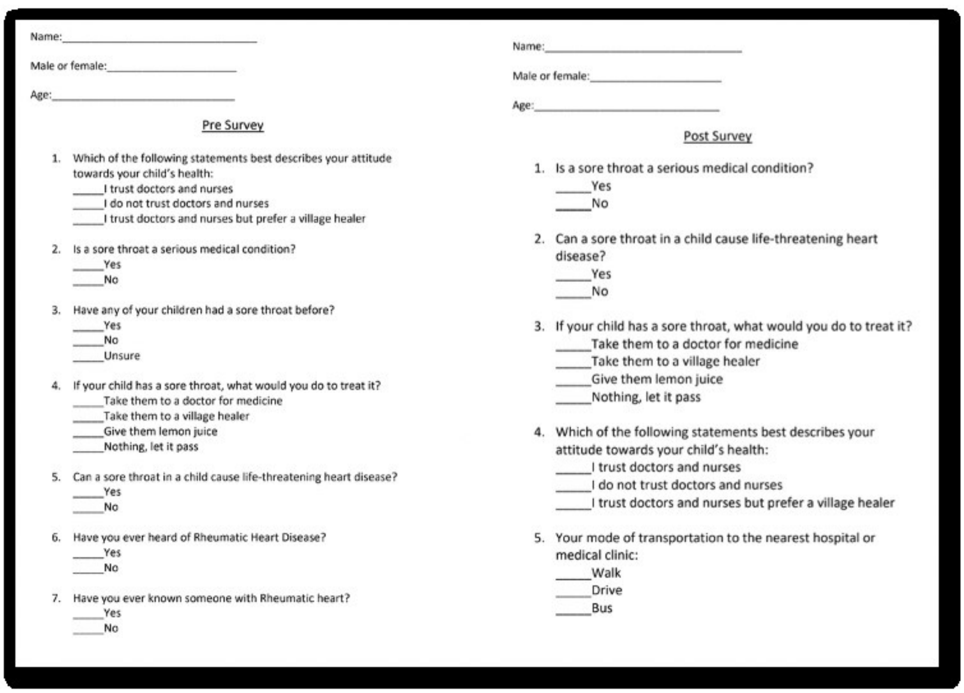
6. Have you ever heard of rheumatic fever or rheumatic heart disease?
   Su'ega Amata: Pe ua e fa'alogo ea i le fiva o le rumatika poo le gasegase
   o le fatu o le rumatika
   ____Yes **____ Ioe**
   ____No **____ Leai**
   Did you know someone with the disease? ***E fa'apefea? Sa e iloa se tasi ua maua ai i le gasegase?*** **____ Ioe ____ Leai**

Figure 12. 2018 caregiver survey

After the surveys were collected, the principal began the presentation by showing the decision tree to the caregivers and instructing them on the importance of taking a child symptomatic with a sore throat to the nearest medical facility to receive critical attention. Caregivers listened to the presentation and then were allowed to ask questions to the principal or make clarifying comments. A translator from the Rheumatic Relief team was available to assist the principal and ensure the correct information was given. Caregivers were also reminded of where their nearest hospital or clinic was located. The results of this phase of the study were used to develop the third phase indicated in Research Aim 3. Overall frequencies of answers were collected and used as a baseline to design the third step of the overall project.

Research Aim 3) Immediate efficacy of the RHD material within 30 minutes of the principal-caregiver presentation among participating caregivers

The third phase of this study was conducted in May 2019 and was designed to determine whether or not caregiver perception may have changed and pertinent RHD knowledge was gained by evaluating the immediate efficacy of a principal-run meeting, and associated materials, within 30 minutes of the presentation. This phase of the program was designed similar to the second phase, but survey questions were modified (Figure 13). A seven-item pre survey asked for the name, which we changed into an identification number for privacy purposes, to match and analyze pre- and post-responses. The pre-survey was administered while principals were prepped to give the presentation with the decision tree poster. Surveys also collected the age, gender, and island of each participant. Data was analyzed using a paired samples t-test.



Name:___________________________

Male or female:____________________

Age:___________________________

Pre Survey

1. Which of the following statements best describes your attitude towards your child's health:
   _____I trust doctors and nurses
   _____I do not trust doctors and nurses
   _____I trust doctors and nurses but prefer a village healer
2. Is a sore throat a serious medical condition?
   _____Yes
   _____No
3. Have any of your children had a sore throat before?
   _____Yes
   _____No
   _____Unsure
4. If your child has a sore throat, what would you do to treat it?
   _____Take them to a doctor for medicine
   _____Take them to a village healer
   _____Give them lemon juice
   _____Nothing, let it pass
5. Can a sore throat in a child cause life-threatening heart disease?
   _____Yes
   _____No
6. Have you ever heard of Rheumatic Heart Disease?
   _____Yes
   _____No
7. Have you ever known someone with Rheumatic heart?
   _____Yes
   _____No

Name:___________________________

Male or female:____________________

Age:___________________________

Post Survey

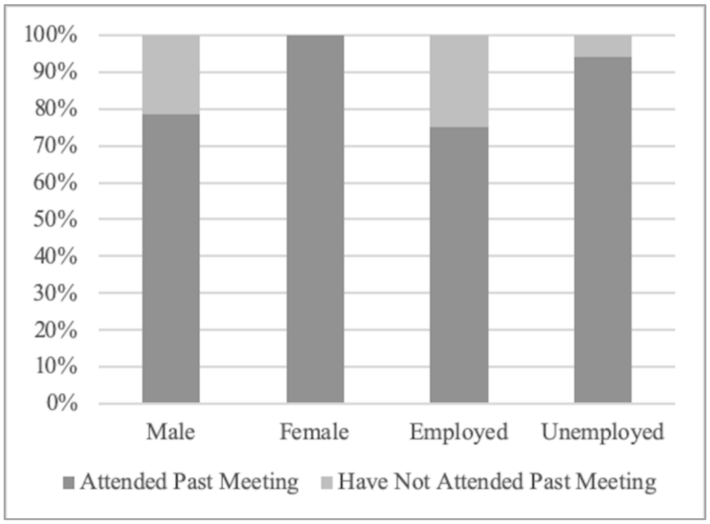
1. Is a sore throat a serious medical condition?
   _____Yes
   _____No
2. Can a sore throat in a child cause life-threatening heart disease?
   _____Yes
   _____No
3. If your child has a sore throat, what would you do to treat it?
   _____Take them to a doctor for medicine
   _____Take them to a village healer
   _____Give them lemon juice
   _____Nothing, let it pass
4. Which of the following statements best describes your attitude towards your child's health:
   _____I trust doctors and nurses
   _____I do not trust doctors and nurses
   _____I trust doctors and nurses but prefer a village healer
5. Your mode of transportation to the nearest hospital or medical clinic:
   _____Walk
   _____Drive
   _____Bus

Figure 13. 2019 pre and post surveys, English translation

Results:

Research Aim 1

Responses were collected in February 2018 from 20 MOH workers, 4 principals, and 25 caregivers. Of our sample of caregivers, 44% were male, 56% were female, 32% were employed outside of the home and 68% were not (50% of males were employed and 9% of females.) Results for whether or not gender or employment status has kept or would keep caregivers from attending a meeting with their dependent's principal is summarized in Figure 14. When asked whether or not they had attended a meeting organized by their child's principal in the past, 80% responded that they had with women more likely to have attended than the men ($P<0.05$) and those employed less likely to have attended than those unemployed ($P=0.01$). All of the women we sampled had attended a meeting in the past at their dependent's school with 91% responding they would be willing to attend future meetings. Of the men we sampled, 79% reported they have attended a meeting in the past with 93% responding they would be willing to attend future meetings. There was no significant difference between the men and women when asked if they would attend a meeting in the future ($P=0.117$). There was a significant difference in responses for whether or not they would attend a meeting in the future between those who work and those who do not work with those who work less likely to attend meetings in the future ($P=0.032$). All of the caregivers who do not work said they would attend future meetings, even if they had not attended one in the past. See Figure14.



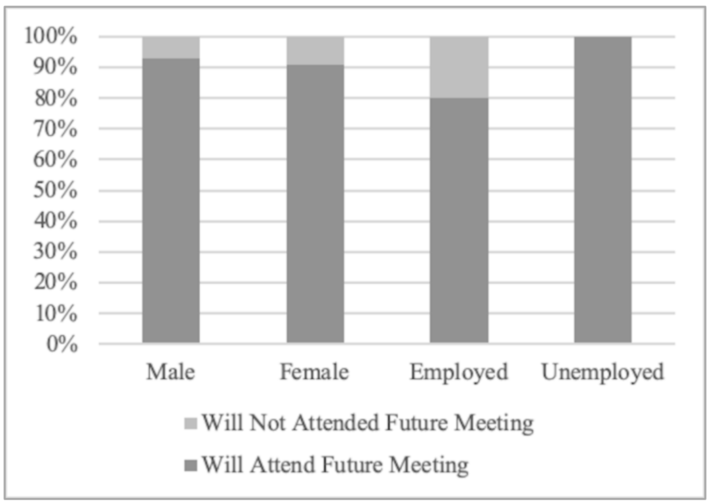


Figure 14. Comparison of gender and employment status to determine differences between past and potential meeting attendance

Caregivers and principals were both asked to respond on how frequently principal-caregiver meetings are held (Figure 15). We had 84% of caregivers report that they hear from their child's principal frequently. Six of these caregivers responded to an additional open-ended question, which prompted them to write down how often they hear from their dependent's principal: 33% responded "daily", 33% "at least once a week", 17% responded "at least once a month," and 17% responded "at least four times a year". Out of our sample of principals, 100% reported that they have held group caregiver meetings in the past. In a follow up question, 25%

reported holding meetings with their students' caregivers biannually, 50% reported they hold meetings at the start of every term, and 25% reported an equivocal answer such as "always" (Figure 15).

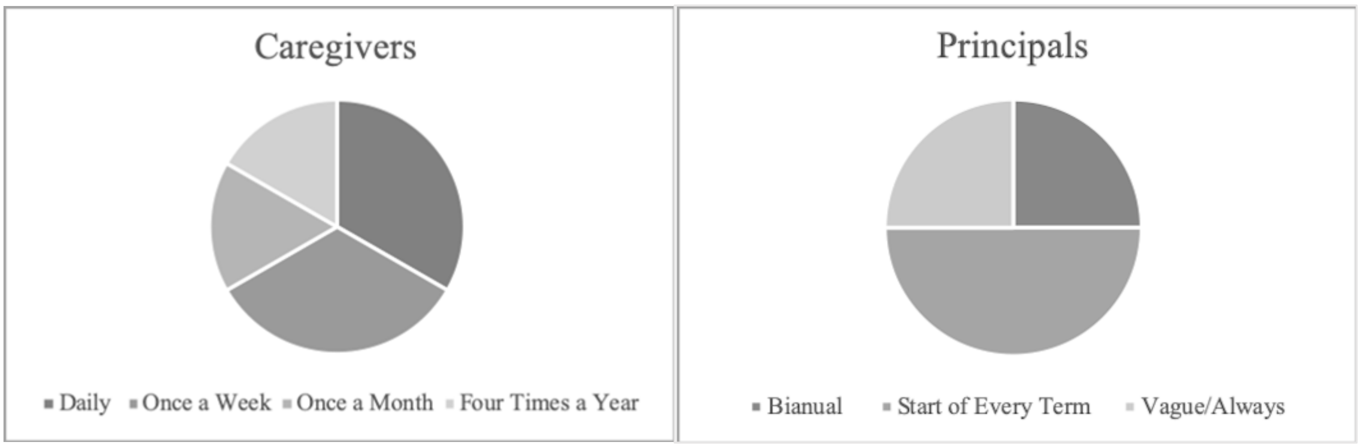


Figure 15. How often principal-caregiver meetings are held from the caregivers' and principals' perspectives

We also see in our sample of principals that 100% know where to go for medical assistance in their area, and 50% currently utilize medical information on students' behalf. This indicates their ability to help relate this information correctly to their students and their caregivers.

The principals and MOH workers were also asked how influential primary school principals are in relation to their impact within their respective villages (Figure 16). For the principals, 75% responded "very influential" and 25% responded "no influence." For the 19 MOH workers 53% responded "very influential," 16% responded "some influence" and 32% responded "no influence." There was no difference in responses between the two types of positions an employee could have in the government, clinical or administrative (P=0.772), or gender, male or female (P=0.085).

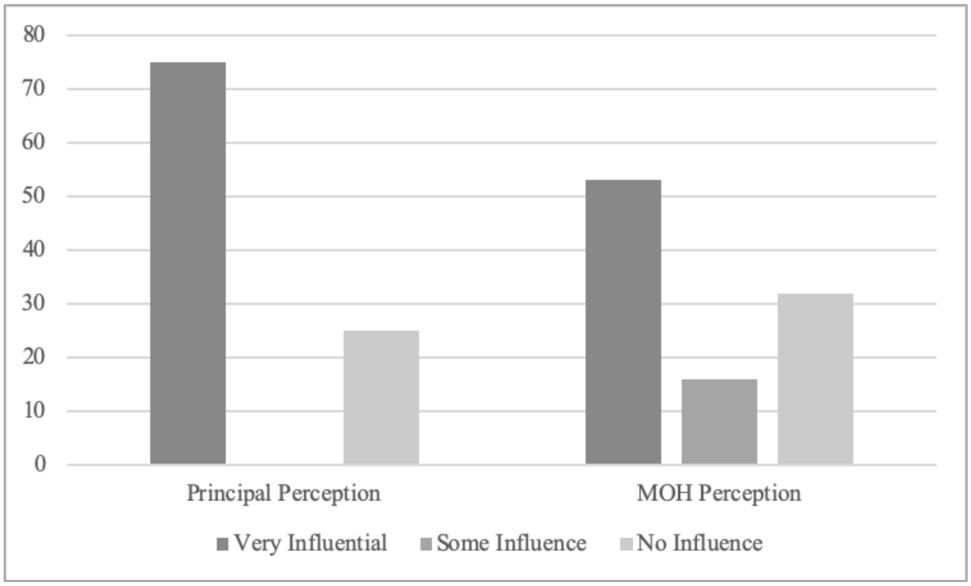


Figure 16. Perception of influence of principal among students and caregivers from the principals' and caregivers' perspectives.

An independent samples t-test was used to compare MOH workers and principals in terms of principal status. Results showed no significant difference between the two groups (P=.435). The majority of both groups reported principals to be influential in their respective positions.

Every MOH worker surveyed reported that the status of a principal (importance within their respective villages/communities) was at least "somewhat important" We found 5% of our sample responded, "somewhat important" while 95% responded "very important." No one reported that principal status was "not at all" important. Out of our sample, 95% responded that the MOH has utilized principals in the past. Participants who responded "no" indicated that they had not personally contacted principals themselves, have never been involved in a project that contacted principals, or were not certain. When prompted in what ways the MOH has utilized principals in the past, responses included: to help organize MOH visits, communicate health issues to student's, organize health programs within schools, check on students with known health issues, collect information on students they cannot contact in other ways, and even organize parent's meetings or send out information to parents and caregivers to disseminate health information.

Research Aim 2

Overall descriptive frequencies were analyzed to determine baseline data among caregivers (Table 4). In addition, participants were asked an open-ended question to determine what they have done or would do if their child had a sore throat. Follow up answers were coded under four possible answers: 1. Take them to doctor/hospital; 2. Take them to village healer; 3. Give them lemon juice or massage; 4. I do not know. Only 46% of the caregivers surveyed responded to the open-ended question. Of those who did, 61% responded "take them to doctor/hospital," 20% responded "take them to village healer," 16% responded "give them lemon juice or massage," and 3% responded "I don't know." Caregivers were also asked their mode of transportation to the nearest hospital or medical clinic. Of the 376 responses, 45% responded "drive," 34% responded "bus" and 21% responded "walk."

Table 4. Caregiver survey responses

	Yes	NO
Has your child ever had a sore throat?	45%	55%
Is a sore throat a serious health condition?	58%	42%
Do you trust doctors and nurses?	90%	10%
Do you prefer a traditional village healer?	16%	84%
Have you heard of RHD	62%	38%
Have you known someone with RHD	35%	65%

Research Aim 3

We compared and analyzed the differences between pre-survey and post-survey responses among participating caregivers. On the pre-survey, 84% of caregivers responded that they trusted doctors, 95% responded that a sore throat is a serious medical condition and 88% would take their child to see if a doctor if they presented with a sore throat. Those that did not answer correctly were matched with their post survey answer to determine whether or not their answered changed following the principal-run meeting (Table 5). No changes were made from a correct answer to a wrong answer between pre- and post-surveys.

Table 5. Pre- and post- survey comparisons

	Yes	No	p-value	*n*
Do you trust doctors?	66%	34%	($p < 0.00001$)	44
Is a sore throat a serious medical condition?	79%	21%	($p = 0.000011$)	14
Would you take a child with a sore throat to the doctor?	85%	15%	($p < 0.00001$)	33

Table 5 Description: *Post-survey responses of those that answered incorrectly on pre-survey were analyzed using a paired-samples t-test to determine if a change was made after the principal-run caregiver meeting.*

Caregivers were asked whether or not their child has ever presented with a sore throat, if they had heard of RHD, and if they had known anyone with RHD. Results from a descriptive frequency analysis are summarized in Table 6. Caregivers were also asked their mode of transportation to the nearest hospital or medical clinic. Of the 285 responses, 12% responded "drive," 74% responded "bus" and 14% responded "walk."

Table 6. Percentages of Caregivers who have RHD awareness

	Yes	No	Unsure
Has your child had a sore throat?	58%	35%	7%
Have you heard of RHD?	71%	29%	N/A
Do you know someone with RHD?	30%	70%	N/A

Discussion

The results of this study were completed in a methodical way, over time, to demonstrate the potential of primary school principals in Samoa to disseminate valuable RHD prevention and/or treatment information at the interpersonal level of influence. Representation from the two main islands was equally distributed. The first phase, directed at Research Aim 1, was framed as a pilot study. The randomly selected participants were independently unified in their perception of the influential role principals play in village life, specifically with issues concerning children. There is limited research on caregiver inclusion, but a review article by Ainscough and Sandhill, which included developing counties, argues that school administrators should be selected and trained to link with parents, offering an efficient and more personal way to disseminate potential life-saving information.

We were encouraged by the percentage of caregivers who had attended a school meeting organized by the school principal. The benefit of such meetings uses local people and context in the implementation of valuable programs. (Sharma, et al, 2015). The difference between those who work and those who do not work suggests the improved outreach by offering evening meetings. Communication is key, so advertising any meeting would require a deliberate effort with clearly stated objectives, including the fact that the subject matter is children and their heart health.

Since the problem with RHD in Samoa is a health concern on the national level, the opinion of MOH staff was essential relative to initiating and sustaining a principal-run education program. According to MOH staff responses, the objectives for the RHD prevention program developed by Rheumatic Relief are in-line with past collaborations between the MOH and school principals. An example was a prevention program for helminth in the Western Pacific Region.

(Nakagawa, J, et al, 2015) Evaluation of this program concluded that the multi-sectoral approach not only impacts the specific health issue, but also contributes to program sustainability, education attainment, improved productivity, and reduced health inequities.

The second phase, for Research Aim 2, demonstrated trust of medical professionals in Samoa. Although majority responses were favorable toward RHD understanding and prevention, opposing responses from those in this sample group who preferred village healers and who did not consider a sore throat serious were high enough to warrant concern among Samoan health sector leadership. Over half of respondents (55%) did not recall their child having a sore throat. Although possible, the probability is questionable. According to a recent study on the global burden of RHD, Samoa was identified as an endemic country due to the high estimated childhood mortality rate from RHD. (Watkins, et al, 2017) The seemingly common, benign, and uneventful nature of a sore throat, with no visible signs for concern, offers a rational argument.

The final phase, for Research Aim 3, advanced phase 2 by enhancing the analyses through matching before and after responses to determine the effectiveness of the educational presentation. In a developing country as Samoa, the number of respondents (n=275), is a solid archetypal sample size. The changes from pre- to post-survey responses in trust of local doctors and the potential seriousness of a sore throat should not be underestimated, and show that among these participants, the intended message was conveyed. In addition to establishing high trust, the significant change among those who preferred a village healer for treating a sore throat to a doctor not only demonstrates the message was understood, but also bodes well for the children of these caregivers.

Another finding from this study demonstrated that a prospective benefit of programs such as this among the Samoan people would be more effectual if availability and/or transportation modes were considered. Over half of the respondents were dependent on public transportation, which in Samoa costs money and is an inefficient use of time due to bus schedules. More respondents indicated walking as their mode of transportation than those who had access to a car. Future programs should consider accessibility by utilizing existing, more readily available resources and facilities.

The second and third phases of this study were limited to those caregivers who either chose, or were available, to attend the principal-run meeting. The pilot study was disrupted by a natural disaster which limited the number of principals, caregivers, and MOH members we were able to survey.

Conclusion

The educational presentation prepared by Rheumatic Relief, and presented by primary-school principals in Samoa, demonstrated effective communication of critical aspects relative to RHD among this sample of caregivers in Samoa. The potential seriousness of a sore throat and associated trust of local doctors, improved. Accessibility to care is an issue that needs to be addressed.

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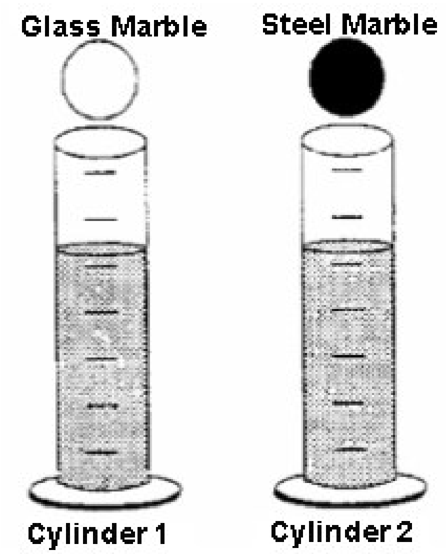
APPENDIX A

Classroom Test of Scientific Reasoning

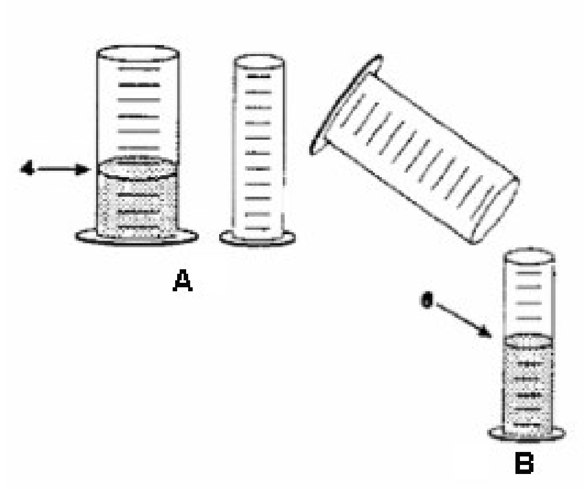
Revised Edition: August 2000 by Anton E. Lawson, Arizona State University. Based on Lawson, A. E. 1978. Development and validation of the classroom test of formal reasoning. *Journal of Research in Science Teaching*, 15(1): 11-24.

1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct*?
   a. The pancake-shaped piece weighs more than the ball
   b. The two pieces still weigh the same
   c. The ball weighs more than the pancake-shaped piece
2. This is because (referring to the question directly above)
   a. The flattened piece covers a larger area.
   b. The ball pushes down more on one spot.
   c. When something is flattened it loses weight.
   d. Clay has not been added or taken away.
   e. When something is flattened it gains weight.
3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape. Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one. When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*
   a. To the same level as it did in Cylinder 1.
   b. To a higher level than it did in Cylinder 1.
   c. To a lower level than it did in Cylinder 1.



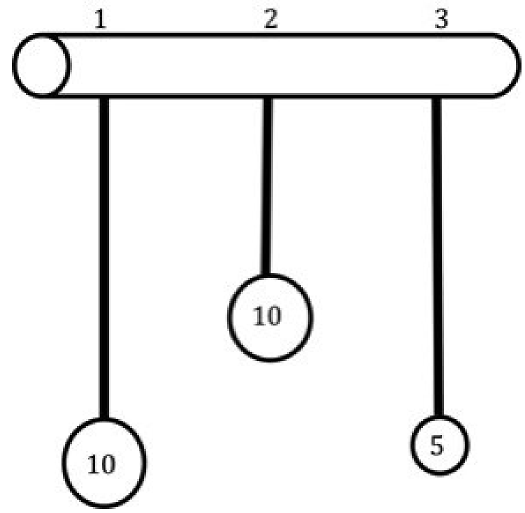
4. This is because (referring to the question directly above)
   a. The steel marble will sink faster.
   b. The marbles are made of different materials.
   c. The steel marble is heavier than the glass marble.
   d. The glass marble creates less pressure.
   e. The marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B). Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder*?



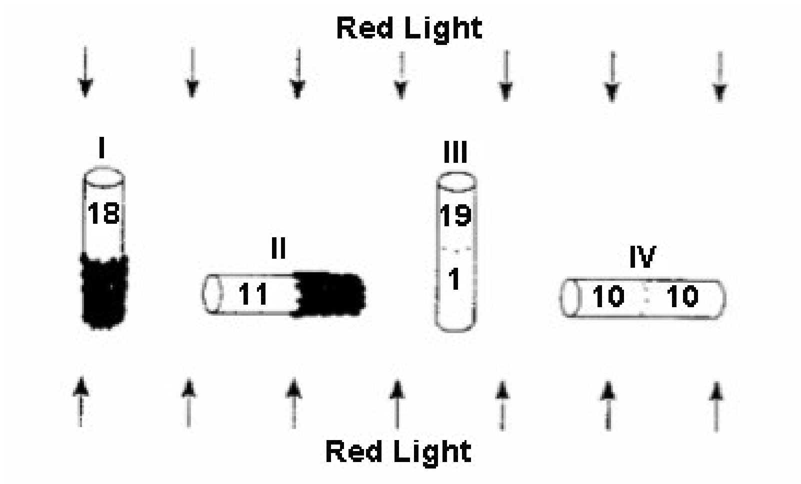
   a. To about 8
   b. To about 9
   c. To about 10
   d. To about 12
   e. None of these answers is correct
6. This is because (referring to the question directly above)
   a. The answer cannot be determined with the information given.
   b. It went up 2 more before, so it will go up 2 more again.
   c. It goes up 3 in the narrow for every 2 in the wide.
   d. The second cylinder is narrower.
   e. One must actually pour the water and observe to find out.
7. Water is now poured into the narrow cylinder (described in the question above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder*?
   a. To about 7 1/2
   b. To about 9
   c. To about 8
   d. To about 7 1/3
   e. None of these answers is correct
8. This is because (referring to the question directly above)
   a. The ratios must stay the same.
   b. One must actually pour the water and observe to find out.
   c. The answer cannot be determined with the information given.
   d. It was 2 less before so it will be 2 less again.
   e. You subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10-unit weight is attached to the end of Strings 1 and 2. A 5-unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed. Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out*?



    a. Only one string
    b. All three strings
    c. 2 and 3
    d. 1 and 3
    e. 1 and 2
10. This is because (referring to the question directly above)
    a. You must use the longest strings.
    b. You must compare strings with both light and heavy weights.
    c. Only the lengths differ.
    d. To make all possible comparisons.
    e. The weights differ.

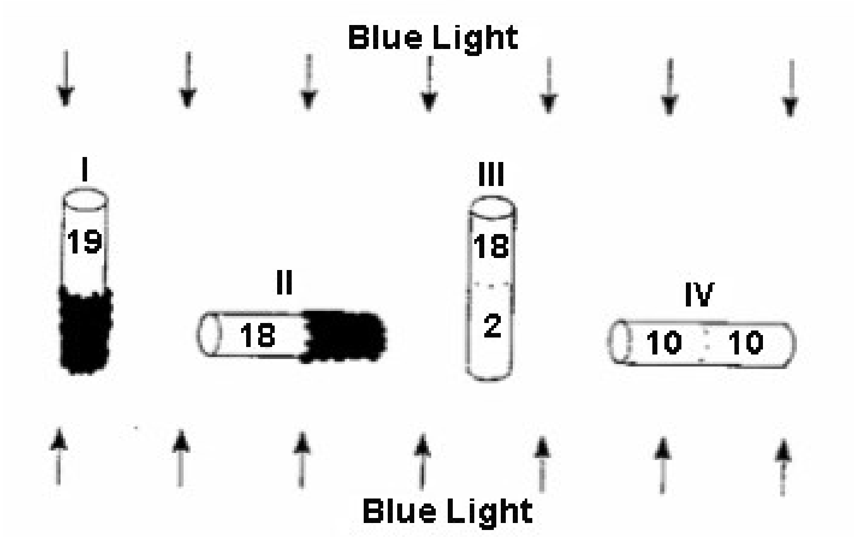
11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing. *This experiment shows that flies respond to* (response means move to or away from)



   a. Red light but not gravity
   b. Gravity but not red light
   c. Both red light and gravity
   d. Neither red light nor gravity

12. This is because (referring to the question directly above)
   a. Most flies are in the upper end of Tube III but spread about evenly in Tube II.
   b. Most flies did not go to the bottom of Tubes I and III.
   c. The flies need light to see and must fly against gravity.
   d. The majority of flies are in the upper ends and in the lighted ends of the tubes.
   e. Some flies are in both ends of each tube.

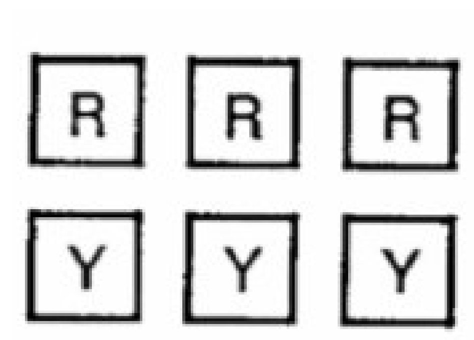
13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing. *These data show that these flies respond to* (respond means move to or away from)



a. Blue light but not gravity
b. Gravity but not blue light
c. Both blue light and gravity
d. Neither blue light nor gravity

14. This is because (referring to the question directly above)
a. Some flies are in both ends of each tube.
b. The flies need light to see and must fly against gravity.
c. The flies are spread about evenly in Tube IV and in the upper end of Tube III.
d. Most flies are in the lighted end of Tube II but do not go down in Tubes I and III.
e. Most flies are in the upper end of Tube I and the lighted end of Tube II.

15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red*?

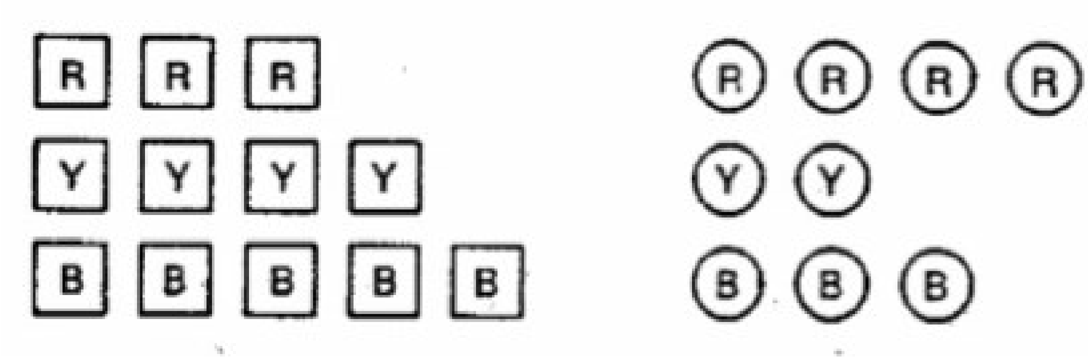


a. 1 chance out of 6
b. 1 chance out of 3
c. 1 chance out of 2
d. 1 chance out of 1
e. cannot be determined

16. This is because (referring to the question directly above)
a. 3 out of 6 pieces are red.
b. There is no way to tell which piece will be picked.
c. Only 1 piece of the 6 in the bag is picked.

d. All 6 pieces are identical in size and shape.
e. Only 1 red piece can be picked out of the 3 red pieces.

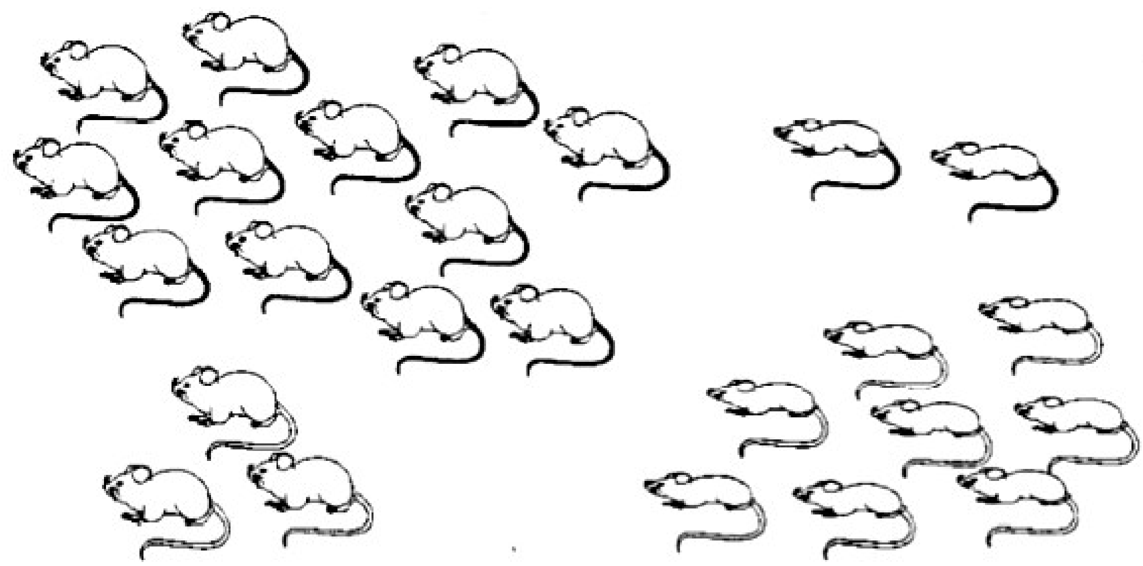
17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece. *What are the chances that the piece is a red round or blue round piece*?



a. Cannot be determined
b. 1 chance out of 3
c. 1 chance out of 21
d. 15 chances out of 21
e. 1 chance out of 2

18. This is because (referring to the question directly above)
a. 1 of the 2 shapes is round.
b. 15 of the 21 pieces are red or blue.
c. There is no way to tell which piece will be picked.
d. Only 1 of the 21 pieces is picked out of the bag.
e. 1 of every 3 pieces is a red or blue round piece.

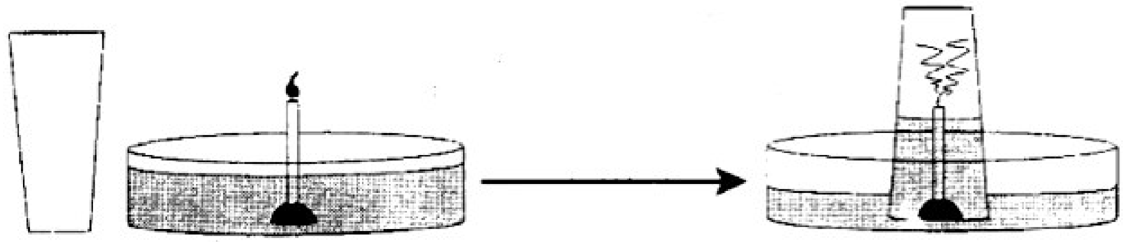
Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So, he captured all of the mice in one part of his field and observed them. Below are the mice that he captured. *Do you think there is a link between the size of the mice and the color of their tails*?



f. Appears to be a link
g. Appears not to be a link
h. Cannot make a reasonable guess

19. This is because (referring to the question directly above)
    a. There are some of each kind of mouse.
    b. There may be a genetic link between mouse size and tail color.
    c. There were not enough mice captured.
    d. Most of the fat mice have black tails while most of the thin mice have white tails.
    e. As the mice grew fatter, their tails became darker.

20. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown at the right). This observation raises an interesting question: Why does the water rush up into the glass?



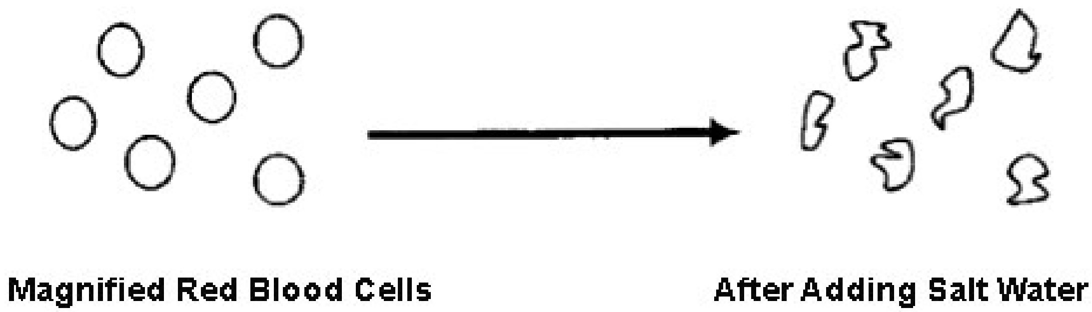
Here is a possible explanation. The flame converts oxygen into carbon dioxide. Because oxygen does not dissolve rapidly into water, but carbon dioxide does, the newly formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass. Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). *Using some or all of the materials, how could you test this possible explanation*?

a. Saturate the water with carbon dioxide and redo the experiment noting the amount of water rise.
b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.
c. Conduct a controlled experiment varying only the number of candles to see if that makes a difference.
d. Suction is responsible for the water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.
e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.

21. What result of your test (mentioned above) would show that your explanation is probably wrong?

a. The water rises the same as it did before.
b. The water rises less than it did before.
c. The balloon expands out.
d. The balloon is sucked in.

22. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller. This observation raises an interesting question: Why do the red blood cells appear smaller?



Here are two possible explanations: I. Salt ions (Na^+ and Cl^-) push on the cell membranes and make the cells appear smaller. II. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.
To test these explanations, the student used some saltwater, a very accurate weighting device, and some water-filled plastic bags, and assumed the plastic behaves just like red-blood-cell membranes. The experiment involved carefully weighting a water-filled bag, placing it in a salt solution for ten minutes and then reweighting the bag. *What result for the experiment would best show that explanation I is probably wrong*?

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

23. *What result of the experiment would best show that explanations II is probably wrong*?

a. The bag loses weight
b. The bag weighs the same
c. The bag appears smaller

APPENDIX B

BIOLOGY CONCEPT INVENTORY

Question: 1]

Many types of house plants droop when they have not been watered and quickly "straighten up" after watering. The reason that they change shape after watering is because ...

- ☐ Water reacts with, and stiffens, their cell walls.
- ☐ Water is used to generate energy that moves the plant.
- ☐ Water changes the concentration of salts within the plant.
- ☐ Water enters and expands their cells.

Question: 2
In which way are plants and animals **different** in how they obtain energy?

- ☐ Animals use ATP; plants do not.
- ☐ Plants capture energy from sunlight; animals capture chemical energy.
- ☐ Plants store energy in sugar molecules; animals do not.
- ☐ Animals can synthesize sugars from simpler molecules; plants cannot.

Question: 3
In which way are plants and animals **different** in how they use energy?

- ☐ Plants use energy to build molecules; animals cannot.
- ☐ Animals use energy to break down molecules; plants cannot.
- ☐ Animals use energy to move; plants cannot.
- ☐ Plants use energy directly, animals must transform it.

Question: 4
How can a catastrophic global event influence evolutionary change?

- ☐ Undesirable versions of the gene are removed.
- ☐ New genes are generated.
- ☐ Only some species may survive the event.
- ☐ There are short term effects that disappear over time.

Question: 5
There exists a population in which there are three distinct versions of the gene A (a1, a2, and a3). Originally, each version was present in equal numbers of individuals. Which version of the gene an individual carries has no measurable effect on its reproductive success. As you follow the population over a number of generations, you find that the frequency of a1 and a3 drop to 0%. What is the most likely explanation?

- [ ] There was an increased rate of mutation in organisms that carry either a1 or a3.
- [ ] Mutations have occurred that changed a1 and a3 into a2.
- [ ] Individuals carrying a1 or a3 were removed by natural selection.
- [ ] Random variations led to a failure to produce individuals carrying a1 or a3.

Question: 6
Natural selection produces evolutionary change by ...

- [ ] changing the frequency of various versions of genes.
- [ ] reducing the number of new mutations.
- [ ] producing genes needed for new environments.
- [ ] reducing the effects of detrimental versions of genes.

Question: 7
If two parents display distinct forms of a trait and all their offspring (of which there are hundreds) display the same new form of the trait, you would be justified in concluding that ...

- [ ] both parents were heterozygous for the gene that controls the trait.
- [ ] both parents were homozygous for the gene that controls the trait.
- [ ] one parent was heterozygous, the other was homozygous for the gene that controls the trait.
- [ ] a recombination event has occurred in one or both parents.

Question: 8
You are doing experiments to test whether a specific type of acupuncture works. This type of acupuncture holds that specific needle insertion points influence specific parts of the body. As part of your experimental design, you randomize your treatments so that some people get acupuncture needles inserted into the "correct" sites and others into "incorrect" sites. What is the point of inserting needles into incorrect places?

- It serves as a negative control.
- It serves as a positive control.
- It controls for whether the person can feel the needle.
- It controls for whether needles are necessary.

Question: 9
As part of your experiments on the scientific validity of this particular type of acupuncture, it would be important to ...

- test only people who believe in acupuncture.
- test only people without opinions, pro or con, about acupuncture.
- have the study performed by researchers who believe in this form of acupuncture.
- determine whether placing needles in different places produces different results.

Question: 10
What makes DNA a good place to store information?

- The hydrogen bonds that hold it together are very stable and difficult to break.
- The bases always bind to their correct partner.
- The sequence of bases does not greatly influence the structure of the molecule.
- The overall shape of the molecule reflects the information stored in it.

Question: 11
What is it about nucleic acids that makes copying genetic information straightforward?

- Hydrogen bonds are easily broken.
- The binding of bases to one another is specific.
- The sequence of bases encodes information.
- The shape of the molecule is determined by the information it contains.

Question: 12
It is often the case that a structure (such as a functional eye) is lost during the course of evolution. This is because ...

- It is no longer actively used.
- Mutations accumulate that disrupt its function.
- It interferes with other traits and functions.
- The cost of maintaining it is not justified by the benefits it brings.

Question: 13
When we want to know whether a specific molecule will pass through a biological membrane, we need to consider ...

- The specific types of lipids present in the membrane.
- The degree to which the molecule is water soluble.
- Whether the molecule is actively repelled by the lipid layer.
- Whether the molecule is harmful to the cell.

Question: 14
How might a mutation be creative?

- It could not be; all naturally occurring mutations are destructive.
- If the mutation inactivated a gene that was harmful.
- If the mutation altered the gene product's activity.
- If the mutation had no effect on the activity of the gene product.

Question: 15
An allele exists that is harmful when either homozygous or heterozygous. Over the course of a few generations the frequency of this allele increases. Which is a possible explanation? The allele ...

- is located close to a favorable allele of another gene.
- has benefits that cannot be measured in terms of reproductive fitness.
- is resistant to change by mutation.
- encodes an essential protein.

Question: 16
In a diploid organism, what do we mean when we say that a trait is dominant?

- It is stronger than a recessive form of the trait.
- It is due to more, or a more active gene product than is the recessive trait.
- The trait associated with the allele is present whenever the allele is present.
- The allele associated with the trait inactivates the products of recessive alleles.

Question: 17
How does a molecule bind to its correct partner and avoid "incorrect" interactions?

- The two molecules send signals to each other.
- The molecules have sensors that check for incorrect bindings.
- Correct binding results in lower energy than incorrect binding.
- Correctly bound molecules fit perfectly, like puzzle pieces.

Question: 18
Once two molecules bind to one another, how could they come back apart again?

- A chemical reaction must change the structure of one of the molecules.
- Collisions with other molecules could knock them apart.
- The complex will need to be degraded.
- They would need to bind to yet another molecule.

Question: 19
Why is double-stranded DNA not a good catalyst?

- It is stable and does not bind to other molecules.
- It isn't very flexible and can't fold into different shapes.
- It easily binds to other molecules.
- It is located in the nucleus.

Question: 20
Lipids can form structures like micelles and bilayers because of ...

- their inability to bond with water molecules.
- their inability to interact with other molecules.
- their ability to bind specifically to other lipid molecules.
- the ability of parts of lipid molecules to interact strongly with water.

Question: 21
A mutation leads to a dominant trait; what can you conclude about the mutation's effect?

- It results in an overactive gene product.
- It results in a normal gene product that accumulates to higher levels than normal.
- It results in a gene product with a new function.
- It depends upon the nature of the gene product and the mutation.

Question: 22
How similar is your genetic information to that of your parents?

- For each gene, one of your alleles is from one parent and the other is from the other parent.
- You have a set of genes similar to those your parents inherited from their parents.
- You contain the same genetic information as each of your parents, just half as much.
- Depending on how much crossing over happens, you could have a lot of one parent's genetic information and little of the other parent's genetic information.

Question: 23
An individual, "A", displays two distinct traits. A single, but different gene controls each trait. You examine A's offspring, of which there are hundreds, and find that most display either the same two traits displayed by A, or neither trait. There are, however, rare offspring that display one or the other trait, but not both.

- The genes controlling the two traits are located on different chromosomes.
- The genes controlling the two traits are located close together on a single chromosome.
- The genes controlling the two traits are located at opposite ends of the same chromosome.

Question: 24
A mutation leads to a recessive trait; what can you conclude about the mutation's effect?

- It results in a non-functional gene product.
- It results in a normal gene product that accumulates to lower levels than normal.
- It results in a gene product with a new function.
- It depends upon the nature of the gene product and the mutation.

Question: 25
Imagine an ADP molecule inside a bacterial cell. Which best describes how it would manage to "find" an ATP synthase so that it could become an ATP molecule?

- It would follow the hydrogen ion flow.
- The ATP synthase would grab it.
- Its electronegativity would attract it to the ATP synthase.
- It would actively be pumped to the right area.
- Random movements would bring it to the ATP synthase.

Question: 26
You follow the frequency of a particular version of a gene in a population of **asexual** organisms. Over time, you find that this version of the gene disappears from the population. Its disappearance is presumably due to ...

- genetic drift.
- its effects on reproductive success.
- its mutation.
- the randomness of survival.

Question: 27
Consider a diploid organism that is homozygous for a particular gene. How might the deletion of this gene from one of the two chromosomes produce a phenotype?

- If the gene encodes a multifunctional protein.
- If one copy of the gene did not produce enough gene product.
- If the deleted allele were dominant.
- If the gene encoded a transcription factor.

Question: 28
Gene A and gene B are located on the same chromosome. Consider the following

cross: AB/ab X ab/ab. Under what conditions would you expect to find 25% of the individuals with an Ab genotype.

- It cannot happen because the A and B genes are linked.
- It will always occur, because of independent assortment.
- It will occur only when the genes are far away from one another.
- It will occur only when the genes are close enough for recombination to occur between them.

Question: 29
Sexual reproduction leads to genetic drift because ...

- there is randomness associated with finding a mate.
- not all alleles are passed from parent to offspring.
- it is associated with an increase in mutation rate.
- it produces new combinations of alleles.

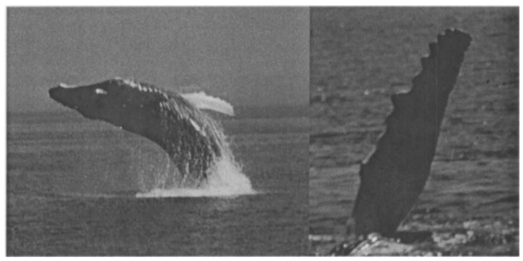
Question: 30
How is genetic drift like molecular diffusion?

- Both are the result of directed movements.
- Both involve passing through a barrier.
- Both involve random events without regard to ultimate outcome.
- They are not alike. Genetic drift is random; diffusion typically has a direction.

APPENDIX C

HD Quiz Bank

1. The humpback whale (Megaptera novaeangliae) is exceptional among the baleen whales in its ability to undertake acrobatic underwater maneuvers to catch prey. In order to execute these maneuvers, humpback whales utilize extremely mobile flippers. The humpback whale flipper is unique because of the presence of large bumps located on the leading edge, which gives the edge a scalloped appearance. Researchers hypothesize that the unique shape of the flipper improves stall angle, lift, and drag which are factors that would cause increased maneuverability (D. S. Miklosovic, et. al. 2004).



Which experimental design could we use to test the hypothesis of the researchers?

a. Create two models of humpback whale flippers: one without large bumps and one with. Test for differences in stall angle, lift, and drag on each model using a wind tunnel.
b. Find other whales with and without the same bumps on the leading edge of their flippers and observe whether they exhibit the same maneuverability.
c. Measure the stall angle, lift, and drag of a humpback whale's body to see how it affects the stall angle, lift, and drag of the flippers.
d. Attach covers to a humpback whale's flippers as to smooth out the flipper. Test to see of the whale maintains the same maneuverability.

2. Which result of your test (mentioned in the question above) would show that your hypothesis was wrong?

a. Whales with smooth flippers exhibited the same maneuverability.
b. Whales with smooth flippers exhibited less maneuverability.
c. There were no differences in stall angle, lift, and drag.
d. There were significant differences in stall angle, lift, and drag.

3. Unemployment rates for African Americans are double the rates for whites. Black men also have much higher crime conviction rates than white men – which is a disadvantage in the labor market. One hypothesis is that black men experience higher unemployment due to racial discrimination. Another hypothesis is that black men experience higher unemployment because they are more likely to be ex-offenders (having previously been convicted of a crime). As a sociologist you are interested to know if there is racial discrimination in hiring, or if the higher unemployment rates of black men are because more are ex-offenders. Using a matched pair study, two white men and two black men (one of each race

with no criminal record, and one of each race with a drug arrest on his record) with identical resumes/profiles applied for entry level jobs in a large metropolitan city. Employer preference was determined by the number of call-backs the job candidates received (white/no criminal record, white/ex-offender, black/no criminal record, black/ex-offender). Based on this study, answer the questions below:

If you hypothesize that higher black unemployment is due to racial discrimination, which of the following results would support this hypothesis?

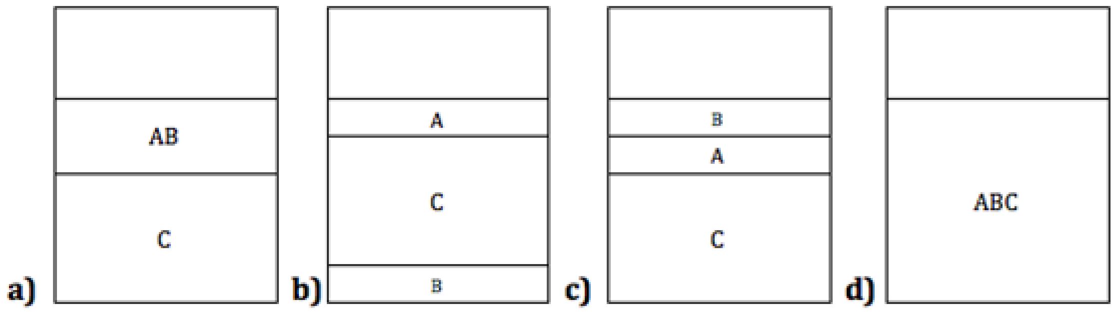
a. Black and white applicants with criminal records receive the same number of call-backs, and black and white applicants without criminal records receive the same number
b. Black applicants receive fewer call-backs than whites, but only if they have a criminal record
c. Black applicants receive fewer call-backs than whites, even if they do not have a criminal record
d. Applicants with a criminal record (both black and white) receive fewer call-backs than those without a criminal record

4. Results of the above study found that 34% of white males with no criminal record were called back, 17% of white ex-offenders were called back, 14% of black males with no criminal record were called back, and 5% of black ex-offenders were called back. Which of the following conclusions is supported by the evidence?

a. High black unemployment is due to both racial discrimination and discrimination against ex-offenders.
b. Black males experience racial discrimination, but there is no racial discrimination in terms of ex-offenders. Ex-offenders of both races are discriminated against equally.
c. The evidence indicates that discrimination against criminal offense is greater than racial discrimination
d. The evidence supports the hypothesis that high black unemployment is due to the higher conviction rates of black men, not racial discrimination

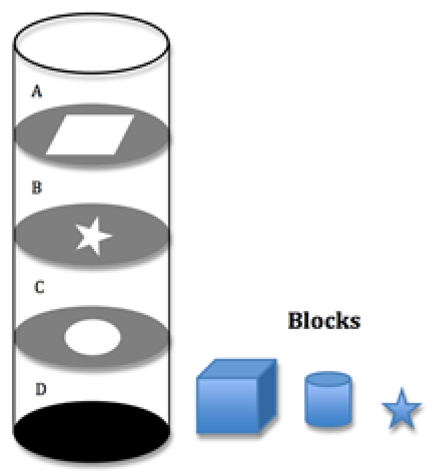
5. Burying beetles lay babies on dead animal carcasses. The mother beetle measures the size of the carcass only once—*before* laying her eggs. She lays the number of eggs based on the amount of food available on the carcass. If we switched out her carcass, *after* she laid the eggs, with a carcass smaller in size, what will happen?
a. This will result in no differences in offspring survival
b. None of her offspring will survive
c. Some of her babies will starve
d. She will lay additional eggs

6. Substance A and substance B mix, but both are repelled by substance C. If I have a beaker that already contains 50mL of substance A and 50mL of substance B, and I add 150mL of substance C, what will the beaker look like?



7. Given the following set of rules,
A is attracted to B, but only if A is bound to C
C prefers to bind to D over A, if D is present
B destroys molecule D
If we mix A, B, C, and D together in a beaker, what should I see?
a. CD A B
b. AB D
c. BAC
d. AC B D

8. I have a child's shape sorting toy. It is a tall cylinder with three levels. Each level has a hole in it with a given shape (as the picture to the right indicates). The three blocks are progressively smaller: Square then circle then star. (i.e., the circle block will fit through the square hole, but not through the star hole, and the star block will fit through all three holes). If I drop all three blocks into the sorter and shake it up, where will each block end up?

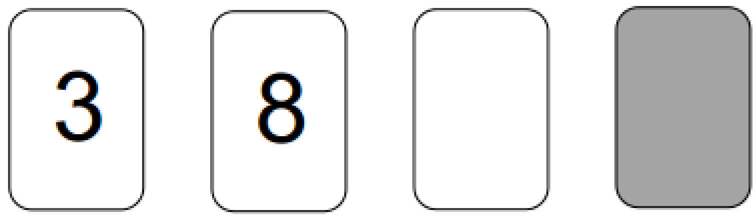


a. All three will be in space B
b. All three blocks will be in space D
c. The square will be in space B, and the circle and star will be in space D
d. The square will be in space B, the star will be in space C, and the circle will be in space D
e. The square and circle will be in space B, and the star will be in space D

9. Dr. Dane is surveying guppy populations in Costa Rica. He notices that guppies in streams *with* predators are smaller as adults than guppies in streams *without* predators. Dr. Dane believes predators have caused guppies to evolve to be smaller because predators prefer to eat the larger guppies. To test his idea, Dr. Dane places a predator in a large tank with 100 small and 100 large guppies. After 2 weeks, Dr. Dane counts the guppies that are left. Which result would best support his idea?
a. Mostly large guppies are left

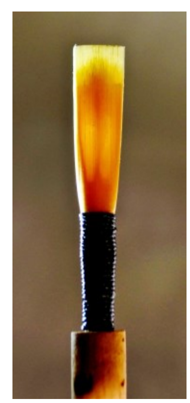
b. Mostly small guppies are left
c. There are an equal number of large and small guppies
d. None of these results would support his idea

10. You and your friends play a new card game. One side of each card shows an integer number while the other side is either white or gray. After playing for a while, one of your friends discovers that if a card shows an even number on one side, it will always be gray on the other side. Your friend lays out four cards in front of you as shown. If you want to test whether the rule your friend discovered is true or not, which cards should you turn over (choose as few cards as possible)?



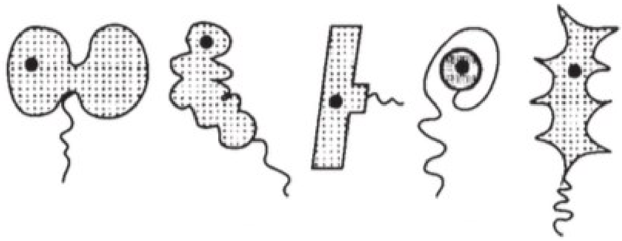
a. 3 only
b. 8 only
c. 3 and white
d. 3 and gray
e. 8 and white
f. 8 and gray
g. all four cards

11. The oboe is a double reed instrument. To make the reeds, oboists tie two pieces of can onto a piece of metal. Oboists then scrape on the reed with a knife until the reed vibrates enough to perform on. Josh the oboist has a reed that is too vibrant. To fix this, he shaves the reed thinner and cuts it shorter. The vibrations decrease. What can Josh conclude?

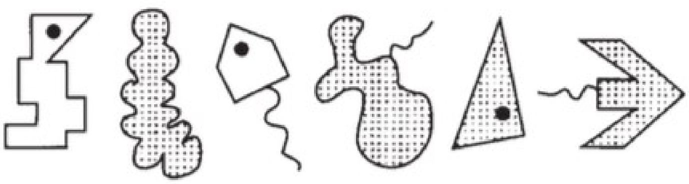


a. Shorter reeds vibrate less than longer reeds.
b. Thinner reeds vibrate less than thicker reeds.
c. Reed length influences vibrations but not reed thickness.
d. Reed thickness influences vibrations but not reed length.
e. None of these conclusions can be drawn.

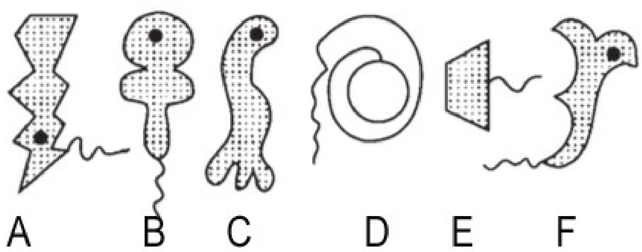
12. All of the following are Mellinarks:



None of these are Mellinarks:

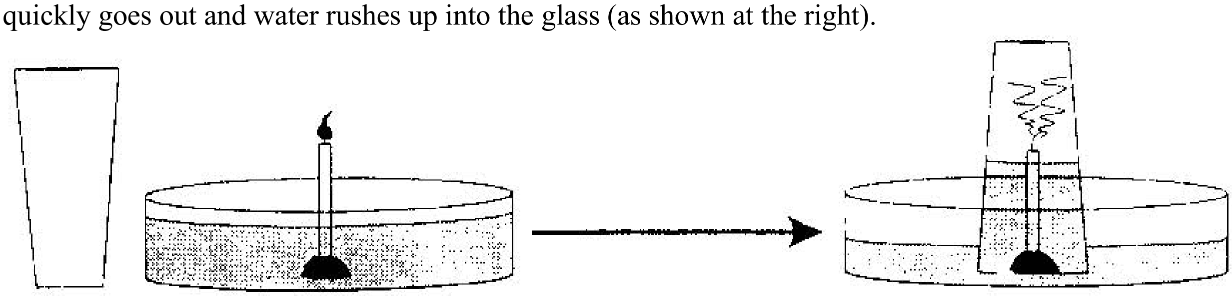


Which of these are Mellinarks (mark all that apply)?



(answer = A, B, F)

13. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown at the right).



This observation raises an interesting question: Why does the water rush up into the glass?

Here is a possible explanation. The flame converts oxygen into carbon dioxide. Because oxygen does not dissolve rapidly into water but carbon dioxide does, the newly formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass.

Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). Using some or all of the materials, how could you test this possible explanation?
a. Saturate the water with carbon dioxide and redo the experiment noting the amount of water rise.
b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.
c. Conduct a controlled experiment varying only the number of candles to see if that makes a difference.
d. Suction is responsible for the water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.
e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.

14. What result of your test (mentioned in #10 above) would show that your explanation is probably wrong?
a. The water rises the same as it did before.
b. The water rises less than it did before.
c. The balloon expands out.
d. The balloon is sucked in.

15. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller.

Magnified Red Blood Cells After Adding Salt Water

This observation raises an interesting question: Why do the red blood cells appear smaller?

Here are two possible explanations: I. Salt ions (Na+ and Cl-) push on the cell membranes and make the cells appear smaller. II. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.

To test these explanations, the student used some salt water, a very accurate weighing device, and some water-filled plastic bags, and assumed the plastic behaves just like red-blood-cell membranes. The experiment involved carefully weighing a water-filled bag, placing it in a salt solution for ten minutes and then reweighing the bag.

What result of the experiment would best show that explanation I is probably wrong?
a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

16. What result of the experiment would best show that explanation II is probably wrong?
a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

APPENDIX D

Class Concept Connections

1. Based on what you already know about natural selection, why might sexually reproducing species have an advantage over asexually reproducing species, when placed in a new environment?

2. Based on everything we've learned this semester; how would you define "living"?

3. How is the structure of a protein in complex 4 related to its functioning in the electron transport chain? How might a mutation affect its function?

4. Why is carbon an ideal atom for building all of the compounds of living organisms?

5. What do valence electrons have to do with energy and how do plants and animals utilize this principle in metabolizing food?

6. Does crossing over during meiosis affect Hardy-Weinberg equilibrium? If so, how? If not, why not?

7. What is the relationship between Meiosis and our phenotype?

8. What is the relationship between cellular respiration and translation?

9. Beyond our religious obligation, why is it important to preserve habitats and species?

10. How might natural selection create mutualistic relationships?