Development and Evaluation of an Active Instructional Framework for Undergraduate Biology Education

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AUTHORIZATION TO SUBMIT DISSERTATION

This dissertation of Steven John Lysne, submitted for the degree of Doctor of Philosophy with a major in Education and titled "DEVELOPMENT AND EVALUATION OF AN ACTIVE INSTRUCTIONAL FRAMEWORK FOR UNDERGRADUATE BIOLOGY EDUCATION," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

The practice of science education in American colleges and universities is changing and the role of faculty is changing as well. There is momentum in higher education to transform our instruction and do a better job at supporting more students' success in science and engineering programs. New teaching approaches are transforming undergraduate science instruction and new research demonstrates that these new approaches are more engaging for students, result in greater achievement, and create more positive attitudes toward science careers. Additionally, teaching scholars have described a paradigm shift toward placing the burden of content coverage on students which allows more time for in-class activities such as discussion and problem solving. Teaching faculty have been asked to redesign their courses and rebrand themselves as facilitators of student learning, rather than purveyors of information, to improve student engagement, achievement, and attitudes. This dissertation is a critical evaluation of both the assumption that active learning improves student achievement and knowledge retention and my own assumptions regarding science education research and my students' resiliency. This dissertation is a collection of research articles, published or in preparation, presenting the chronological development (Chapters 2 and 3) and evaluation (Chapters 4 and 5) of an active instructional model for undergraduate biology instruction. Chapters 1 and 6.provide a broad introduction and summary, respectively. Chapter 2 is an exploration of student engagement through interviews with a variety of students. From these interviews I identified several themes that students felt were important, and science instructors need to address, including the place where learning happens and strategies for better engaging students. Chapter 3 presents a review of the science education literature broadly and more focused review on the how students learn and how faculty teach. Consistent with what my student interviews suggested, I found that engaging students by way of innovative instructional approaches is a major theme in science education. I conclude by arguing for the development of collaborative learning communities and the use of cognitive apprenticeships in science classrooms. In Chapter 4 I presented the development and initial evaluation of an instructional framework for undergraduate biology classrooms. I found that student satisfaction as measured by end-of-course evaluations increased compared to my previous instructional model. I concluded that the instructional framework was efficacious and proceeded to evaluate the model in the context of knowledge acquisition and retention. Chapter 5 is the culmination of the work I conducted for the research presented in Chapters 2 through 4. In Chapter 5 I formally test the hypotheses that my instructional framework presented in Chapter 4 results in no greater knowledge acquisition or retention compared to a more traditional lecture model of instruction. I failed to reject these hypotheses which runs contrary to much published literature; the implications of my findings are discussed.

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Dedication

For my Dad: you are responsible for everything I’ve become and I’m so very grateful.

Thank you Pops.

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Chapter 1 SCIENCE EDUCATION IN THE 21ST CENTURY: CHANGING PRACTICE AND CHANGING ROLES FOR UNDERGRADUATE TEACHING FACULTY

The practice of science education in American colleges and universities is changing and the role of faculty is changing as well. A decade ago Robert DeHaan was working at Emory University and wrote that a revolution was taking place in American science education (DeHaan, 2005). He described efforts in colleges and universities to adopt new teaching approaches such as a shift away from "traditional" lectures and toward more interactive learning environments. DeHaan advocated for change but did so without disparaging "lecture" faculty or even the value of lectures as a form of information transmission (DeHaan, 2005). Similarly, government organizations such as the National Research Council and the National Science Foundation published reports on developments in science education research and best practices (NRC, 2011) and biology education specifically (AAAS, 2011). These reports were the result of a series of conferences and workshops on science education curriculum and instruction convened over a decade beginning in the 1990s. They presented reviews of evidence-based instructional practices and even provided examples for individuals and institutions to use as they strove to meet the challenges of science literacy for non-majors and retention in STEM fields (NRC, 2011). But perhaps more importantly, DeHaan presented an emotional argument in favor of the new approaches that focused less on definitions and facts and more on concepts and scientific thinking. This may have been a more powerful argument than data but where are we ten years on?

New teaching approaches *are* transforming undergraduate science instruction and many college and university faculty are adopting evidenced-based practices and moving away from a more traditional approach to laboratory and lecture. For example Ma and Nickerson (2006) reviewed laboratory instruction and discussed the continuum of theory of practice occurring today including simulated and remote laboratory exercises; very different from the verification labs commonly used in instruction. Similarly, DiBartolomeis (2011) developed a 12-week activity to introduce students to basic molecular biology techniques within of an inquiry-based instructional approach. D'Costa and Schlueter (2013) used an active instructional approach called *scaffolding* to teach introductory biology students basic science-process skills. Remsberg, Harris, and Batzli (2015) developed a novel approach for teaching biology students applied statistics and Lysne and Miller (2014) introduced a novel approach for biology instruction generally. And the changes are not exclusively in general education transfer education. In vocational education similar changes have taken place over the past decade (Silverberg et al., 2004; Wolf, 2011) as new methods of instruction increase student achievement. These examples are a small sample of the research regarding transformed activities and models for science instruction. So was DeHaan's prediction (2005) prescient? The answer to this question depends, partly, on whether we are discussing the results of scholarly work or observations on praxis. For example, Andrews and Lemons (2015) report that the widespread adoption of interactive learning environments in higher education hasn't happened yet.

It is clear that interactive learning environments represent an improvement when compared to traditional instruction. For example research has demonstrated that interactive teaching approaches are more engaging for students. Hulleman and Harackiewicz (2009) demonstrated that journaling on relevant topics increased students' interest in science courses, particularly with students that entered the course with relatively low expectations for themselves. Lysne and Miller (2015), using data from anonymous end-of-course student evaluations, showed that an interactive learning environment resulted in consistently higher levels of student satisfaction when compared to traditional learning environments. Importantly, interactive learning environments improve more than simply student engagement, or interest, in our courses. Several authors have demonstrated that a transformed instructional approach can result in greater achievement (Deslauriers et al, 2011; Goldstein & Flynn, 2011; Freeman et al., 2014). Perhaps even more importantly, active learning environments create in students a positive self-attitude (Blaylock & Hollandsworth, 2008) and more positive attitudes toward science careers (Hulleman & Harackiewicz, 2009). Positive attitudes toward science careers are of great importance because all the achievement in the world will not advance science in America if our students do not consider scientific career paths as an achievable goal. A brief word regarding semantics is necessary before continuing further. Throughout this dissertation I use a variety of labels to refer to what I operationalize as "active and student-centered instruction." I use a variety of labels because this is what the authors of articles use when describing their own work. However I see these different descriptors such as interactive learning environments, collaborative learning communities, inquiry-based instruction, and others to be contained within the reform-oriented and broadly defined instructional paradigm of "active and student-centered instruction."

Clearly the argument for transforming one's instruction, by large or small degrees, is evident. So why have active learning environments not been adopted more broadly? It's a lot of work to develop new lesson plans (perhaps for the first time), new in-class or laboratory activities, and new modes of formative and summative assessments. The obstacles to reforming our instructional practices have been discussed in the literature previously (Hickcox, 2002; Smith et al., 2005; Allen & Tanner, 2009) and include fear of change, insufficient time to reconstruct lesson plans, a general disinterest in teaching undergraduate coursework, a lack of incentive to improve instruction or student outcomes, or an academic disagreement over pedagogical methods. Andrews and Lemons (2015) interviewed science faculty and reported that the primary inhibitors of change were that faculty felt they lacked the skillset to develop and implement an interactive lecture, the fact that many colleagues of their colleagues were unsupportive of changes to instruction, and faculty favored their own personal experience over the results of science education research. Further, Nobel Laureate Carl Wieman (2009) suggests that without supportive colleagues, indeed without the support of the entire academic department, instructional reform will not be achieved.

There is momentum in higher education to transform instruction and do a better job at supporting students' success in STEM programs. For example, *Vision and Change in Undergraduate Biology Education: A Call to Action* (AAAS, 2011) is a report that contains recommendations for transforming undergraduate science instruction including curriculum for introductory biology courses, instructional mechanisms for use in the classroom, and institutional motivations for change. The framework advanced by AAAS (2011) is being enthusiastically adopted by many individual faculty and academic departments (Chevalier, Ashley, & Rushin, 2010; Raimondi, Marsh, & Arriola, 2014) and functionally forms the foundation of the new paradigm in biology instruction specifically. Importantly, as Wieman (2009) suggested, colleges and universities are beginning to recognize the scholarship of science education as a "relevant area of research for traditional biologists" (Rutledge, 2013, p. 58) and Vision and Change can be specifically found in advertised position descriptions. Over the past ten years there has been an increase in the number of faculty positions for "science faculty with education specializations" (Rutledge, 2013, p. 58). A quick search of the Chronicle of Higher Education's job site (www.chroniclevitae.com/job_search) using the search term "science education" revealed 39 faculty positions for researchers or teaching scholars posted in the past 30 days (*retrieved* 6 June, 2015). When I began looking for employment opportunities in August 2014, there were by my estimation less than ten faculty positions being posted each month. Though anecdotal, I predict that a thorough trend analysis of faculty openings on Vitae and others (e.g. www.higheredjobs.com) would support my hypothesis. Despite increased opportunities, many of these faculty positions go unfilled due to a lack of qualified faculty that are both disciplinary scholars and trained in curriculum and instruction.

In addition to the national framework previously discussed for undergraduate biology instruction, a more prescriptive approach has recently been updated for the nation's high school science students. The Next Generation Science Standards (NGSS) was developed by a consortium of academics, administrators, and consultants from around the country with the aim of improving secondary science instruction and readiness for college (www.nextgenscience.org). This improved curricular framework, if adopted in Idaho, should significantly improve the readiness of prep-school students for college and also students' probability of completing a degree plan in a science discipline. The NGSS curriculum framework is consistent with Vision and Change and the NGSS emphasis on inquiry-based instruction should help prepare students for the transition to college where active classrooms are being explored and adopted and where much more responsibility for learning is placed on the students themselves.

Concomitant with these significant initiatives in secondary and higher education, federal government agencies such the National Institutes of Health and the National Science Foundation are supporting research in STEM learning and learning environments at a level unseen previously. A recent query of the NSF web site (www.nsf.gov/funding) resulted in 71 funding opportunities for STEM research and initiatives and the NSF's 2015 budget request includes $118 million specifically for improving undergraduate STEM education (www.nsf.gov/pubs/2014). The NIH's budget for 2015 is an astounding $31 billion (www.hhs.gov/about/budget) of which, $767 million is allocated for student and postdoctoral training via 52 grants or programs (www.grants.nih.gov/grants/guide/index.html). In addition to federal government support, private industry is also participating, often in cooperation with the federal government. For example, the Howard Hughes Medical Institute (HHMI) has realized the importance of supporting the next generation of American scientists and has developed an outstanding program supporting science education, supported research on STEM learning and learning environments, and hired faculty specifically to conducted STEM education research through participating colleges and universities. HHMI supports outstanding students and teacher-scholars to advance undergraduate research opportunities, competency-based curricula, and K-12 science teacher preparation (http://www.hhmi.org/programs/science-education-research-training). The United States federal government and medical institutes like HHMI are big players; the interest in and support for STEM learning and learning environments has never been greater.

As a consequence of this increased interest and support, researchers are conducting investigations and delivering findings that result in the establishment of best practices in science education (Freeman et al., 2014). For example, in the past decade we've seen the release of a national framework for undergraduate biology instruction (AAAS, 2011), important monographs on best practices (Allen & Turner, 2009; NRC, 2011), and contributions by teaching scholars that have implemented, tested, or reviewed a variety of proposed practices (Moust, Van Berkel, & Schmidt, 2005; Wilke & Straits, 2005; Handelsman, Miller, & Pfund, 2007; Goldstein & Flynn, 2011; D'Costa & Schlueter, 2013; Jin & Bierma, 2013; Nogaj, 2013; Simonson & Shadle, 2013). So, ten years on it appears that faculty at American colleges and universities are on track, keeping with DeHaan's (2005) prediction and revolutionizing science instruction. However DeHaan also called for researchers to consider the long-term retention of information and that, as far as we can ascertain, has not happened.

I set out to build upon the good work that has preceded us and to develop and evaluate an alternative approach for teaching undergraduate biology students. I begin in Chapter 2 by asking the students themselves what they wanted in terms of an instructional environment. Students explained that their science coursework at the College of Western Idaho was not very engaging. For example, students described our curriculum as irrelevant, our instruction as unhelpful, and our learning environment as a "plain white box." My students told me that Power Point lectures and sterile classrooms put them to sleep! I defined engagement as the time, energy, and resources that my students put into activities designed to enhance learning; activities like reading the text and showing up to class. However this model was not persuading my students to devote their time and energy to learning biology. And so I immediately made changes to my instructional practice by incorporating active-learning exercises, interesting photo-montages, and even using continuous audio streams designed to engage more of my students' senses; like they had suggested to me. Some of these early efforts worked and others didn't but the lesson I learned is that I can make changes to my instructional delivery and my learning environment, without changing content, and I can increase my student's engagement in the process. The critical assumption is that increased engagement will translate into increased retention and success.

Following my discussion with students, I reviewed the relatively large literature on best practices for teaching and learning from a variety of scholarly disciplines including biology, education, and psychology. I found, for example, that younger adults (e.g. 18 - 25) and older adults (e.g. 23+) have different goals for education and are also at very different levels of cognitive maturity. Younger adults are more likely to view the professor's teachings as fact whereas older adults are more likely to view her teachings with skepticism. Whereas the "traditional" college student may be graduated before they mature to adulthood cognitively, community college students span this continuum creating instructional challenges for faculty. Fortunately for both groups of students, active and student-centered classrooms create collaborative learning communities that appear to result in increased engagement and success. From this review, and my previous work on student engagement, I proposed a framework for teaching undergraduate science coursework (Chapter 3) which includes a collaborative learning community in lecture and a cognitive apprenticeship model in laboratory. Meanwhile I continued refining my instruction to include components of what I had learned from my students and my review of the literature and this early model remains, though improved, in my classroom today.

My first attempt to quantify this new model for teaching undergraduate biology looked back to my original question in Chapter 2 which was “are my students engaged with this course?” I had been using my new pedagogical approach for several semesters and needed to evaluate my students’ response to it. In Chapter 4 I describe the specific instructional approach I used, based on my previous work and in the context of the larger national discussion on undergraduate science education, and present results from my students’ end-of-course evaluations regarding the new model. I found that student satisfaction with my class increased by 10% - 20% after adopting the new teaching model and that satisfaction scores were similarly high in two very different courses; a fact I attributed to the reliability of this model to improve student satisfaction. I concluded that the new approach was beneficial in terms of both student engagement and a positive learning environment and called on researchers to similarly investigate achievement within the framework we developed.

Whereas Chapters 2, 3, and 4 represent separate projects related to, and supporting, my principle research interest, Chapter 5 represents the crux of my dissertation and my most significant contribution to the field of science education. In Chapter 5 I built upon the work presented in previous chapters to address a significant gap in the science education research literature; a comparison of two instructional models in the context of the long-term retention of knowledge gained in an undergraduate biology course. The research presented here builds upon my earlier work regarding instructional design to engage students and asks a very important question of student achievement: is the long-term retention of information a function of the instructional model a student experiences? The science education literature is replete with evidence-based findings regarding the improved success of students in active, collaborative learning communities (Ernst & Colthorpe, 2007; Hulleman & Harackiewicz, 2009; Deslauriers et al., 2011; Jenson, Kummer, & Banjoko, 2013). However, there were no studies specifically comparing retention as a function of instruction and this is the gap I filled with Chapter 5. What I found, surprisingly, is that there isn’t a difference in information retention. Further my data did not support the idea that an active, collaborative learning community results in greater student learning gains. Considering our experimental design and the validity of our results, our findings represent a dissenting voice amid the majority opinion regarding science instruction. I anticipate that others will critically evaluate the findings we present in Chapters 4 & 5 and I hope that this will lead to an improved understanding regarding the impact of new instructional approaches on a variety of institutionally-specific student learning outcomes.

Finally in Chapter 6 I provide a reflective summary of the progress I have achieved and future directions regarding my research agenda. I discuss implications for instructional practice and express my uncertainty with regard to the rapidly solidifying assumptions of best practice in American science education.

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Chapter 2 EXPLORING STUDENT ENGAGEMENT IN AN INTRODUCTORY BIOLOGY COURSE[1]

Abstract

Successfully engaging students with our community college's introductory biology curriculum is a challenging endeavor. Students have numerous distractions competing with faculty for their attention. Traditional presentation of information may leave students longing for something more engaging to do, and the place where most college-level instruction happens lacks relevance to either the course content or the students lived experiences. The result is that we are failing in front of our students. This is not because we have failed to recognize the importance of engaging students. Rather it is because we have never asked our students what they want in terms of an instructional experience or we're reluctant to leave our comfort-zone and make large-scale changes to our pedagogies. For this paper, we explored the ideas of engagement and *place* at a mid-sized community college. We found that students have thoughtful opinions about each and are frustrated with some aspects of our current instruction. Our paper provides a brief review of research on engagement and place, reflections on student interviews, and recommendations for improving our instruction.

Key Words: Biology, Community College, Engagement, Experience, Instruction, Place

Introduction

Engaging students in introductory biology courses can be challenging for university faculty (Poli, 2013). With the exception of the occasional hyper-motivated student, it often feels as if our students are more interested in their mobile devices than they are in our carefully planned lessons. In fairness, a majority of our students likely have the best intentions but reserve their enthusiasm for upper division coursework in biochemistry, conservation biology, genetics, or whatever their eventual field will be. Concomitantly,

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university faculty can be reluctant to alter their classroom pedagogy for a variety of reasons (Crawford, 2007), but not because we fail to recognize student engagement as an important component of learning (Auman, 2011). Our challenge in introductory biology courses is to diversify our lessons and capture the interest of students, maintaining engagement until learning happens so that students are prepared for upper division coursework. For this article, we investigated what students perceived as an engaging course and the role of *place* in their learning experience. We have also reflected on student interviews and made recommendations for improving our instruction.

Engagement

Undergraduate student engagement has been investigated in a variety of contexts and at a variety of scales. Relatively small-scale research includes focused studies in the context of distance learning (Havice, Foxx, Davis, & Havice, 2011), future time perception (Horstmanshof & Zimitat, 2007), civic engagement (Musante, 2012), research-based instruction (Deslauriers, Schelew, & Wieman, 2011), and inquiry-oriented activities (Hu, Kuh, & Li, 2008) to name just a few. Relatively large-scale research includes efforts like the *National Survey of Student Engagement* (NSSE) which is in the context of "benchmarks" of good educational practice (Kuh, 2001, 2003) and the *College Student Experience Questionnaire* (Koljatic & Kuh, 2001). Other research has demonstrated, perhaps unsurprisingly, that the *concept* of engagement itself differs across educational institutions and scholarly disciplines (Brint, Cantwell, & Hanneman, 2008).

For the purpose of this manuscript, we use a functional definition of student engagement proposed by Exeter et al. (2010, p. 762): "engagement refers to the time, energy, and resources [students] spent on activities designed to enhance learning." Thus a goal was to understand what we could do to get students to invest the time, energy, and resources necessary to succeed in our courses. In order to better understand how to achieve this goal, we describe next the role that place plays in the learning environment.

Place

Similarly, place has been investigated much recently in the context of various disciplines (Gruenewald, 2005). Regarding the concept of place in the learning experience, we considered David Orr's (2004) *Earth in Mind*. He argues that to prepare today's students for the challenges of the 21st Century,

> "the way in which learning occurs is as important as the content of particular courses. Process is important for learning. Courses taught in lecture halls tend to induce passivity. Indoor classes may create the illusion that learning only occurs inside four walls, isolated from what students call, without apparent irony, the 'real world'" (p. 14).

All concepts of place share the key characteristic of attempting to understand the nature of our relationship with the world. Gruenewald describes five dimensions of place and how these are relevant to 21st Century pedagogical practice (Gruenewald, 2005). He argues that places *are* pedagogical and that educational institutions need to pay greater attention to the role of place in learning. We believe Gruenewald correctly states that "places teach us about how the world works and how our lives fit into the spaces we occupy" (p. 621).

Regarding science instruction more specifically, our goal is to develop a connection to local and regional concerns, practices, and/or research (Semken & Freeman, 2008) in an attempt to foster a sense of place that supports engagement. These concepts – engagement and place – are linked inexorably to learning, retention, and student success. Despite all that has been written regarding student engagement (Musante, 2012; Kazempour, Amirshokoohi, & Harwood, 2012), only a fraction of which we have discussed, very little research has been conducted with community college students and none to our knowledge has investigated how place engages the senses and enhances the experience of learning biology. Also lacking is the perspective of the students themselves, not just their responses to end-of-course or Likert-scale surveys, regarding what they want in terms of instruction.

Theoretical Framework

Eylon and Linn (1988) reviewed the literature to summarize research approaches to learning in science education. They found that four approaches were primarily used to research learning in the sciences. These approaches included 1) concept learning, 2) developmental learning, 3) differential learning, and 4) problem solving. Redish, Saul, and Steinberg (2009) suggest that if students experience a sequence of science courses at colleges and universities that challenge them to develop a deeper understanding and to grow in intellectual sophistication (*e.g*. by blending concept learning with problem solving), then those students will be more willing to invest the effort necessary for success in later coursework. We interpret this as: student engagement with the foundational *content* may actually be increased when we focus our curriculum on conceptual ideas and contemporary problems in science rather than on the memorization of the content itself. However, student engagement and learning are not new questions and the appropriate curricular models still need to be fully vetted (Zhang & Watkins 2009), at least insofar as undergraduate science courses are concerned. Absent from this discussion, however, and from traditional research approaches is the concept of place.

We believe that place and experiential learning (EL) are key constructs for curriculum models and, subsequently, student engagement. EL posits that learning happens best when learners are involved intellectually, emotionally, socially, and/or physically (Kolb, 1984; Luckman, 1996). The key characteristics of EL are described by Crosby (1981) as follows (*emphasis* added):

> "… learning will happen more effectively if the learner is as *involved as possible,* using as *many of his faculties* as possible, in the learning; and this involvement is maximized if the student has something that *matters to him* at stake" (p. 10).

She is suggesting that learning will happen when students are involved in what is presented and when they are given a reason to be interested. Thus, student engagement has something to do with interaction, place, our senses, and incentives for success. More recently, Hickcox (2002) reviewed the conceptual base for EL and writes that EL programs develop the individual's commitment to life-long learning. They are active, student-centered, and driven by experiences of shared inquiry (Hickcox, 2002). Considered together, our theoretical framework is: conceptual instruction is preferable to content instruction and EL, with a component of place, is the mechanism to achieve engagement and learning.

Course Description

The second semester of the year-long sequence in biology for many beginning biology majors is generally organismal biology; the biology of organisms such as bacteria, protists, plants, animals, and fungi. We teach this course during a sixteen week semester that meets twice a week for 75 minutes; it includes a three hour lab that meets once a week. Organismal biology is a very difficult class to teach due to the very broad nature of the content, the level of content detail expected, the tremendous topical differences between units of curriculum, and the context in which instruction is delivered (*i.e.* the traditional academic classroom and laboratory). Thus, the challenge for us is to meet the high expectations of students for such a potentially exciting course without boring them through the content objectives.

Research Design

Our research is an exploratory case study using a qualitative methodology. Case study research is an intensive examination of a particular group, event, or program (Lichtman, 2011). It deals with a phenomenon, for example, like how individuals experience a college course and they are commonly used in educational research. Key elements of a case study include focus on a particular individual or group, a case bounded by space or time, and the type of case; for example, exploratory, typical, or unique (Lichtman, 2011).

Conventional wisdom regarding case study research is that they are appropriate for exploratory studies, they cannot be generalized to larger populations, and their construct validity is weak (Flyvbjerg, 2006). While our work is exploratory, and we will not attempt to extrapolate our findings, Flyvbjerg argues that this view of case study research is grossly oversimplified and one can design unbiased, large-scale research projects and make valid generalizations of the results (Flyvbjerg, 2006).

Participants

The “field site” was a mid-sized community college in the Western United States with a general education student population of approximately 9,000 students. The sampling frame was those students enrolled in the Biology – Natural Resource program at the college. The students we interviewed had previously completed organismal biology in a traditional academic setting (*e.g.* the lecture hall and laboratory). We solicited students by asking colleagues to read a short description of the proposed research and then directed interested students to contact the first author. Of the seven students that initially expressed an interest in participating, four agreed to be interviewed and three eventually participated. The students participating in this study all received lecture-based instruction without an active-learning, experiential, or place-based component.

Methodology

Semi-structured Interview

We used semi-structured interviews to address our primary research questions. Our interview protocol consisted of five questions with as many follow-up questions as needed to understand the meaning of each student’s response. The questions we used were: Q_1: What do you think makes a class engaging?, Q_2: What activities in lab did you find interesting?, Q_3: Were you ever challenged to think about real-life problems?, Q_4: What aspects regarding working in groups did you like or dislike?, and Q_5: What does “place” have to do with the learning environment? The interview questions are designed to inform our two principle research questions; Q_1 through Q_4 dealing with the concept of engagement and Q_5 with the concept of place. We acknowledge a strong selection bias from our sampling frame and no attempt was made to interview a "representative" sample of the student population. Each interview lasted about one hour and was recorded using *Audacity*, a free, open-source recording and editing software program (©2012, available at: http://audacity.sourceforge.net/) and then transcribed.

Transcript Data Coding

Our analysis resembles a hierarchy whereby the raw data (*i.e*. student's statements) were coded on the basis of similarity into categories which, subsequently, were further grouped into themes. The exploratory first-cycle coding method (Saldana, 2009) was used in our initial data analysis. Saldana defines first-cycle coding as "techniques for enhancing the organization and texture of qualitative data… that permit open-ended investigations" (pp. 51-52). For example, in exploratory first-cycle coding we searched for words or phrases that captured the essence of the students' experiences and we then assigned preliminary codes to those data before refining it further (Saldana, 2009). A code could be as simple as a single word or as complex as an entire page of text. Since qualitative inquiry is an emergent process, our open-ended technique was holistic; we did not start with initial categories or hypotheses *a priori*. Rather, we allowed categories to emerge from the data and then later refined our analysis. Our second-cycle coding investigated our first-cycle codes further. We used the constant comparative method (Glaser & Strauss, 1967; Merriam, 2009) where we iteratively analyzed codes, categories, and themes until we felt comfortable that our description appropriately represented the students' experiences. Finally, these broad concepts, or themes, were related back to our original research questions in an attempt to understand student engagement with the curriculum and role of place in learning.

Results and Discussion

Transcribed interviews produced 52 pages of text. From the transcribed data, 73 words or phrases were identified as important during first-cycle coding. Our second-cycle coding process resulted in seven emergent categories that pertained to our research questions and included: 1) engagement, 2) place, 3) learning, 4) experience, 5) delivery, 6) content, and 7) application.

In the context our first research question, a student expressed excitement with the curriculum when she said: “We see these things [body organs] and can explain to someone else who doesn’t have a clue about biology, about how the kidney works and it’s, it’s really neat to see people get really excited about that” (Student A). Another student stated: “when the lecture and the lab come together real well, when they mesh together, me as well as other students find it a lot more interesting” and “when we looked at real things, it was more interesting” (Student B). Student C commented on classroom practice when he suggested that “one of the things I liked was the hands-on activities. That actually really helped me. It was like more of a hands-on visual thing. To be honest the basic thing, where you go and sit in lecture, that really didn’t help me.” The same student found the application of a “Jigsaw” method in another course to be valuable. He said:

> “my teacher did this one thing where we actually, we were in small groups and such, we did research and presented the material ourselves. That type of stuff actually makes it stick better than somebody just sitting up there and saying ‘this is how it works.’”

From these responses, and others, we understand that authentic experiences which are felt by the student are perceived as being of greater value and, thus, create an incentive for the student to become engaged (Hickcox, 2002; Auman, 2011; Poli, 2013).

In the context of our second research question, students commented on where learning happens and how it makes a difference to them:

> Student A: “everyone likes that room (a smaller room on campus).”
>
> Student B: “I mean, I don’t know, it almost puts you to sleep to walk into a sterile room and listen to someone give you a PowerPoint”
>
> Student C: “if the class was outside of the classroom every now and then [it would be more interesting],” and “I mean you’ve got smells you’ve got so many different senses are playing into your learning and I feel like the more senses you’ve got engaged in what you’re trying to learn then there’s more ways to try to remember it.”

Several student comments pertained to both research questions. For example, students stated: “when you’re going where there’s birds and doing it um, everybody really got into it!” and “listening to them [faculty] talk about real life things [was engaging]” (Student A); “when we actually got to the animals we were working with the animals and dissections and, I mean, taking them apart, and I just learned so much more” (Student C); “It [the lab manual] looks just like the book and that’s kind boring” and “I mean you’re just in a white box [classroom] and you’re trying to digest all of this information” (Student B). To us this clearly suggests that our traditional instructional styles and spaces do not inspire student engagement. Similar to previous findings (Kuh, 2003; Semken and Freeman, 2008), our students felt that the places were disconnected from their lived experience and that the presentations were disengaging. One student described our typical college classroom as “a white box” and this has the exact opposite effect from what we are trying to achieve! All students expressed their dissatisfaction with the familiar lecture format and Student A suggested that her dissatisfaction actually motivated her to find more interesting material online. Another student said: “if you went out to the field even half time and were like this is what this is instead of just the book and the lectures it would be awesome!” (Student C).

However, students in our study recognized that this is not always possible and Student B suggested that we bring the outside in, making the classroom feel more like an experience to be remembered. He stated this well when he said: “I mean, if you can’t get away from the classroom having classrooms that feel like you're in a biology class I think would matter quite a bit."

Conclusions and Implications

The National Research Council suggests that colleges and universities should provide opportunities for students to experience scientific investigations in a field environment (NRC, 1996). Others have argued that faculty should model scientific behaviors in class (Donovan, Bransford, & Pellegrino, 2005) or use an active learning instructional model (Wilke, 2003). We do this in some cases already but we can certainly do better. For example, scheduling core biology coursework at field science camps or offering short, single or multi-day outings (Rone, 2008) to complement traditional classroom instruction are examples of such opportunities. Conversely, if we cannot get outside we might bring the outside in. Playing background audio files of nature sounds, running looped slideshows with high-definition images, passing around demonstration materials in class, and tailoring discussions to local/regional issues – our students' lived experience – are very simple examples of how we can engage more of our students' senses and foster a sense of place.

Our research has presented the unique case of three community college students and their perspectives on classroom engagement and the role of place in learning. We found that the students in our study do not find our instruction engaging and that, from their perspective, the traditional classroom setting does not facilitate learning. While acknowledging the difficulties of implementing change, students in our study all expressed their hope that will we change. Our research was necessarily limited in scope but a large-scale, and more representative, case study would be of value for understanding student engagement and sense of place and would possess the added benefit of generalizability.

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Chapter 3 A Review of Research on Student Learning with Implications for Teaching College Science in Idaho[2]

Abstract

The purpose of this manuscript is to review research from the fields of biology, education, psychology, and others regarding how students learn and then use this information to propose a new curricular paradigm for teaching college science in Idaho. Scholars have devoted considerable time to ideas such as how students learn, how faculty teach, and what constitutes best practices in education. However while no clear consensus exists regarding a specific model for teaching generally, or for teaching college science specifically, there are several emerging themes that should be considered best practices and incorporated into undergraduate science instruction. We reviewed the primary literature regarding student learning, faculty teaching, and emerging themes in education and offer a framework for curriculum design and classroom instruction.

Keywords: learning, active, inquiry, research, college, teaching, science

Introduction

The purpose of this manuscript is to review research from the fields of biology, education, psychology, and others regarding how students learn and then to use this research to propose an approach to teaching science in Idaho's colleges and universities. Research in learning has an important role (NSTA, 2010) and a long history beginning in the early 20th Century (Sawyer, 2006). It began as a response to *instructionism*, an educational paradigm designed to prepare young people for entry into the workforce of the late 1800s and early 1900s. As the needs of society changed, however, from students prepared for an industrial workforce to those prepared for an innovation workforce,

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educational practice changed too (Sawyer, 2006). Today science educators and researchers are again advocating for change based on a growing understanding of how students learn (Donovan et al., 1999; DeHaan, 2005; Bransford *et al*., 2006; AAAS, 2011). Indeed, the research literature from the fields of biology, chemistry, education, neuroscience, physics, psychology, and sociology has grown so vast that a comprehensive treatment of the subject is untenable for the practicing educator. New developments on how students learn, educational psychology, and educator practice are transforming our profession both in the lecture hall and in the lab (Collins, 2006; Sawyer, 2006; NRC, 2011). Professional scientific societies such as the American Association for the Advancement of Science (AAAS) have joined forces with educators, researchers, administrators, and states to review research literature, debate best practices, and propose a contemporary framework for science education in American public schools at all levels (*i.e.* K – 16). This review will attempt to distill the current understanding of what good educational practice looks like based on the relatively new field of the learning sciences (Sawyer, 2006). The works considered and suggestions offered are targeted to faculty teaching undergraduate biology coursework in Idaho however the implications of research reviewed transcend disciplines and institutions.

A Brief History of Educational Thought

As societal goals, values, and needs for an educated populace changed, research in education flourished and gave rise to multiple competing philosophical positions regarding what education should look like (Paul, 2005). Philosophers lead the transformation in education. Individuals including Karl Popper, John Dewey, and Jean Piaget promoted divergent views such as post-positivism, pragmatism, and constructionism, respectively (Paul, 2005; Kafai, 2006, Gutek, 2011). Research followed these *avant-garde* philosophers and today there are numerous journals addressing issues of educational practice, reform, and research. Science education research, and the practice of science education, has lagged behind other academic disciplines for a variety of reasons (DeHaan, 2005; Wieman, 2009), particularly at the college level. Therefore, as considerable work has been conducted with primary and secondary school-aged children, findings and suggestions from these studies, where applicable, will be included.

Research on Student Learning

People learn in both formal and informal settings (Bransford *et al*., 2006). Formal settings include the familiar classrooms and laboratories that we, in academia, have all experienced. Informal settings, however, also produce significant learning gains. These may include social settings like the workplace, job site, playground, chat room, community center or social club (Bransford *et al*., 2006). In many situations, informal settings may be preferable to formal settings for learning. For example, in conjunction with reflecting on learning activities, students might use an online discussion board to interact with peers, make tentative conjectures, test ideas, and refine their understanding of a concept or topic. This type of learning is both informal and social and it takes place in a low-risk environment that may be more attractive to today's students no matter how "relaxed" we try to make our formal learning environments.

Bransford *et al*. (2006) reviewed developments in how students learn from cognitive science and state that there are two pathways to become experts at something; by routine or by adaption. Routine expertise is achieved, essentially, through repetition even if this expertise is in the realm of higher cognitive function; a task that an adult might perform, for example. Similarly, children learn by imitation (Bransford *et al*., 2006) so it may be that a range of learners will discover the process of science by imitating us as we model the process in our classrooms and laboratories as Sawyer (2006) has suggested. More useful is adaptive expertise. This form of expertise is accomplished by integrating various types of learning activities into the curriculum. For example, learning activities should be diverse and responsive to students' needs with a focus on conceptual understanding, discovering new knowledge, collaboration, appropriate scaffolding, and deep reflection (Sawyer, 2006). This is consistent with Kolb's (1984) learning styles of experience and conceptualization. Students can learn how to efficiently solve problems (*i.e*. experience) but by utilizing an adaptive expertise approach, students will also learn how to adapt to novel situations (*i.e*. conceptualize); adopting new tools to help them solve new problems.

Adults learn differently than children (Fiser, 2008) and while many of the basic methodological principles may be transferable, just how adults learn differently should be considered explicitly by faculty in higher education. Merriam reviewed Malcolm Knowles concept of andragogy; the art and science of helping adults learn (Merriam, 2001). She discussed five characteristics of adult learners that differentiated adults from young adults or children. Adult learners 1) have an independent self-concept and can direct this to their own learning, 2) have a rich reservoir of life experiences to situate learning within, 3) have different social forces influencing their learning, 4) are interested in applying new knowledge immediately, and 5) are motivated by internal factors (like an independent self-concept) as opposed to external factors (like parents!). Merriam (2001) points out, however, that many adults desire or need strong guidance (*i.e*. not #1 above) while some children do possess an independent self-concept. The distinctions between children and adults, in learning, are not as clean as the practicing educator might wish. As andragogy as a conceptual framework evolved, Knowles moved from a position of contrasting andragogy to pedagogy to a position acknowledging a continuum of learning from teacher-directed to student-directed, respectively (Merriam, 2001). Regardless of interpretation, androgogy as a conceptual framework for education is not widely discussed in North America or the U.K. Instead, a synonymous term, adult education, is used where andragogy is but one model of how educating adults should proceed (Merriam, 2001). And Knowles model, Merriam (2001) suggests, is still valid and to consider adult education without considering Knowles ideas is inconceivable. Knowles suggested three principles for educating adults that includes 1) an emphasis on learning techniques, 2) an emphasis on practical application, and 3) learning to learn from experience (Knowles, 1972). As we will discuss below, these ideas will not disappear over the next 40 years of educational research.

Not only do adults have different learning characteristics (Merriam, 2001), their cognitive ability is different from that of adolescents (Fiser, 2008). Complicating this fact of neurobiology is the concomitant fact that our classrooms may be filled with students at very different levels of brain development. Adolescents aged 13 to 19 have a less developed ability to reason conceptually (Fiser, 2008) than do older individuals. It isn't until age 23 to 25 that most adults acquire the cognitive ability to combine multiple abstractions and synthesize them into a larger conceptual understanding (Fiser, 2008). Our challenge, of course, is that changing demographics in higher education results in a diversity of students in our classrooms with a wide range of cognitive maturity. For example in 2013, 45% of degree-seeking students at the College of Western Idaho were older than 25 years of age (CWI, 2013). Therefore, faculty are teaching to students with varying levels of cognitive maturity making classroom instruction more difficult.

Kolb & Kolb (2009) discuss learning in education in the context of their spiral learning cycle of experiential learning. This concept posits that learners prefer different styles (experience, reflection, conceptualization, or actualization) and modes (concrete experience, reflective observation, abstract conceptualization, and active experimentation) and that the interplay between these styles and modes can be conceptualized as a cyclical, or spiral, process.

Bransford *et al*. (2006) would likely consider experiential learning both an informal and social learning setting. We believe what matters; however, in this context is the place in which the learning happens. For example, many students enter biological fields following a passion for the outdoors. When one is passionate about something, that *thing* becomes very important; that is, the student has something at stake. In this context, bringing the learning experience outdoors, in whole or in part, involves all the student's faculties (sight, sound, smell, touch, cognition, and even taste!) and may better facilitate learning. Similarly, Kuh (1995) wrote that, "Out-of-class experiences presented students with personal and social challenges, encouraged them to develop more complicated views on personal, academic, and other matters, and provided opportunities for synthesizing and integrating material presented in the formal academic program" (p. 146).
Kuh (1995) found that the informal social setting of experiential learning provided students the opportunity to concretize abstractions or concepts from the formal learning environment.

Hickcox (2002) suggests that no single hypothesis of education is appropriate for every student in all situations and a combination of practices is probably the best design for instruction. She cites the work of David Kolb (1984) and his highly regarded learning style inventory as a model for curriculum design. Kolb proposed that people approach learning from different perspectives; experiencing, reflecting, or conceptualizing, for example (Kolb, 1984). Therefore a successful learning program would incorporate multiple learning styles (Hickcox, 2002) and these should be cyclical or repetitive (Kolb & Kolb, 2009) in order to reach as many students as possible during the period of learning.

Research on Teaching

In addition to the physiological development of our students, the educational practices of our faculty influence learning (Sawyer, 2006; Deslauriers, Schelew, & Wieman, 2011). Just what practices, however, are “best” remains a topic of considerable discussion and much research continues in an attempt to develop a comprehensive model for teaching in higher education. For the greater part of the 20th Century, American education was influenced by the post-positivist philosophy of science and, subsequently, education (Paul, 2005). Instruction was expositional, consisting primarily of lecture with little or no engagement of students (Allen & Tanner, 2009). This may be because scientists (and, thus, college professors) were trained by scientists and not educational researchers (Slater, Slater, & Bailey, 2010). It is generally not the case that these scientist/educators do not care about their teaching; rather, they are either ignorant or skeptical of educational research and findings (Slater *et al*., 2010). This paradigm has shifted, however, and over the past few decades there has been a revolution slowly brewing in science education (DeHaan, 2005).

Emerging Themes from Educational Research

Fortunately for the college professor there have been several excellent reports and texts in the past ten years on best practices in science education as reviewed by educational researchers (Handelsman, Miller, & Pfund, 2007; AAAS, 2011; Allen & Turner, 2009; NRC, 2011). What follows is a brief discussion of what has been reviewed and synthesized from the diverse field of the learning sciences.

Research in the learning sciences, generally with K-12 students, has converged on several themes for improving educational practice in the technologically-driven 21st Century. These include: 1) the importance of a deeper conceptual understanding, 2) a focus on learning as well as teaching, 3) creating learning environments, 4) the importance of the learner's prior knowledge, and 5) the importance of active reflection (Sawyer, 2006). The AAAS (2011) has recommended the following core competencies for undergraduate biology instruction: 1) the ability to apply the process of science, 2) the ability to use quantitative reasoning, 3) the ability to use modelling and simulation, 4) the ability to recognize and develop an interdisciplinary ethos, 5) the ability to communicate and collaborate with others, and 6) the recognition of the connection between science and society. All of the teaching practices below (active-learning, cognitive apprenticeships, and scaffolding) support these six competencies.

Active-Learning

Active-learning is promoted by advocates as a way to improve student learning by engaging students directly in the learning process (Wilke, 2003; Freeman et al., 2014). For example, Freeman et al. (2014) conducted a meta-analysis of 225 studies and found that students enrolled in an active, student-centered course had a failure rate 12% lower than students enrolled in an exposition-styled course. Wilke (2003) describes active-learning as "students doing things and thinking about the things they are doing" (p. 207). Things that students might do include refining their science process skills. This means working through the scientific process in a structured, scaffolded environment. It might include the student developing multiple hypotheses that could be tested, designing experiments, collecting and analyzing data, and presenting that data graphically, in writing, or by way of presentations. These are the skills used by scientists that students need time to explore in a safe and controlled environment. Active-learning may also coach students in the use of higher order thinking skills. In Blooms Taxonomy, the cognitive levels of synthesis and evaluation are higher order thinking skills and can be supported by faculty. For example, faculty might present challenging questions to students and then model the appropriate behavior for working through those problems

(Collins, 2006). After modelling an effective approach to addressing a complex problem, we might present students with a similar problem and coach them through the process of solving the problem. The instructional approach of modelling, coaching, and scaffolding (see below) are hypothesized to be of value in student learning (Collins, 2006). Indeed in one of the best recent examples of such research utilizing an evidentiary standard, Deslauriers *et al*. (2011) used their entire class time to engage students in thinking scientifically; making scientific arguments, testing predictions, and solving problems. As students engaged in thinking scientifically, they were actively coached and scaffolded by their peers and professors. Perhaps more simplistically, faculty can engage students in learning by the use of simple activities. For example in our introductory biology courses we've asked students to draw illustrations of complex biological molecules, work in groups to solve problems, or evaluate simple cases that can be completed in 20 minutes or less. All of these are examples of "doing things" and incorporating self-reflection, journaling for example, brings in the important piece that Wilke (2003, p. 207) described as "thinking about the things they are doing."

Cognitive Apprenticeships

A particularly attractive alternative to traditional laboratory instruction is the cognitive apprenticeship model (Collins, 2006) whereby students engage in the scientific process from beginning to end (Switzer & Shriner, 2000; Hofstein, 2004; Collins, 2006). Guided, inquiry-based laboratory work has been demonstrated to be more effective than traditional verification labs (Blanchard *et al*., 2010). Apprenticeships give students opportunities to engage with and model expert behaviors as they work alongside experts and a community of peers to solve authentic problems (Collins, 2006). Utilizing the apprenticeship model may be a powerful tool as we realign the focus of laboratory work from verification labs to those that emphasize science process skills (Eylon & Linn, 1988; Switzer & Shriner, 2000). Modeling behaviors that we want students to perform and then coaching them through similar tasks allows students to acquire a complex set of skills in a guided yet exploratory situation. To implement a cognitive apprenticeship, instructors would *model* the process of science by elaborating on a project they've completed (from start to finish, both descriptive and experimental), *coach* students with regard to their own projects, *scaffold* their learning as they are coaching them, and provide a *community of learning* in the context of lab groups that are working on novel problems they've come up with themselves (Collins, 2006).

Scaffolding

The examples of active-learning teaching practices above that engage students and explore issues are consistent with the patterns, principles, processes, and themes described by researchers (Knowles, 1972; Kolb, 1984; Sawyer, 2006; AAAS, 2011; Freeman et al., 2014). However, as with any instructional model, *scaffolding* of student learning should be employed. Learning scientists refer to scaffolding as "the help given to a learner that is tailored to that learner's needs in achieving his or her goals of the moment" (Sawyer, 2006; p. 11). It is not help in terms of giving the learner the steps necessary to solve a problem, rather it is help provided to the student so she can derive the necessary steps herself. It involves prompts and questioning to move the learner in the right direction so he can discover for himself the correct answer or process. Successful science instruction will scaffold learners' active knowledge development.

A Framework for Science Education

Curriculum Design

Curriculum should be designed following the backward design approach of Wiggins & McTighe (1998). Backward design forces faculty to consider the desired outcomes of instruction and then work backwards to develop assessment strategies and classroom practice. Curriculum should incorporate activities and techniques to reach the multiple learning styles of students (Kolb, 1984, Hickcox, 2002). For example to reach adult students, activities and content should emphasize technique, application, and how to positively incorporate previous life experiences (Knowles, 1972). Our courses should be designed to create a rich environment for students including social interactions, physical experiences, and new situations (Bransford *et al*., 2006) that are relevant to students' lives or potential careers. We should be adaptive in nature, incorporating various types of instructional activities because of the differences between younger adults and older adults (Fiser, 2008) and different learners (Kolb & Kolb, 2009). And we should focus on conceptual understanding and science-process skills as broad curriculum objectives.

Instructional Practice

Combining the general themes and specific examples we've reviewed into a framework for science education, we can envisage a model of instruction that encourages the development of a collaborative learning community in lecture and a cognitive apprenticeship in the laboratory (Figure 3.1). The lecture would engage students and explore issues with an active, student-centered, and inquiry-based instructional approach (Wilke, 2003; Kafai, 2006; Kirschner et al., 2006; Hmelo-Silver et al., 2007; Yager, 2009, AAAS, 2011; Deslauriers et al., 2011. Freeman et al., 2014). Opportunities for reflection and self-directed learning would reinforce the issues, provide students the flexibility to manage their own learning, and create formative assessment measures. Multiple, low-stakes quizzes and exams, with a focus on conceptual understanding, can be used as summative assessments and one part of an evaluation of student achievement. In lab we would develop a cognitive apprenticeship to model and get students thinking about the process of science like scientists (Wilke & Straits, 2005). In science, as in other fields, research suggests that students learn more and better when they are actively engaged in scenarios that model professional practice (Sawyer, 2006). All of instruction should support collaboration and community building via in-class, out-of-class, online, informal, and/or social activities and experiences.

Summary Remarks

While the AAAS (2011) recommends a focus on conceptual understanding and student-centered learning environments, a reformed pedagogy does not preclude the value of recitation and foundational information such as facts and processes. Rather, it improves on this knowledge by providing the learner with the ability to utilize this information in novel situations. For example, some researchers have advocated for active-learning strategies and learner construction of knowledge as opposed to the learner as the recipient of an instructor's knowledge (Switzer & Shriner, 2000; Deslauriers, Schelew, & Wieman, 2011). Again, this theme does not remove the importance of the teacher; rather, it changes her role to one of a facilitator of learning as opposed to a transmitter of knowledge. The creation of learning environments deals with making schools places of exploration, places where students can use baseline knowledge to address "real world" problems and processes (we use quotations around this phrase because what authors, and educators, mean by this phrase is actually *contrived scenarios that mimic problems routinely encountered by practitioners in a particular field*). For the teacher, this concept provides the justification for taking chances. The acquisition of new knowledge is not a linear path, it is more often characterized by trial and error, asking the wrong questions, dead ends, and restarts. This *is* the process of science and as science educators we should incorporate this uncertainty into instruction. In engaging classrooms, the learner is given the opportunity to apply knowledge, ask questions, practice processes, and be wrong in the safety of the learning environment where error is not a failure but a "real world" outcome and a teachable moment. Some might describe this model as *inquiry-based instruction* but it much more than simple inquiry. For example, the importance of building on the learner's preexisting knowledge is an important and challenging concept emerging from the learning sciences (DeHaan, 2005; Sawyer, 2006) but is not generally associated with IBI (NSTA, 2004). It's important because if the learner's prior knowledge is not acknowledged, then any new information that is inconsistent with their prior knowledge may be seen with skepticism or contempt. It's challenging because sometimes the learner's preexisting knowledge is incorrect and the job of the teacher is to transform the misconception into a conceptualization that is consistent with the current knowledge base. For example, most learners will have a hypothesis regarding why trees lose their leaves in the fall and this may be partially correct or it may be wholly inaccurate. The truth is a complex relationship between air temperature, photoperiod, and plant hormones and the teacher's job is to get the student to this new understanding without disrespecting her prior knowledge in the process. The importance of reflecting on an experience is because it is during this process of thinking deeply about an event that the learner really has an opportunity to analyze his state of knowledge (Linn, 2006; Sawyer, 2006). In our experience, when we are compelled to talk or write about our knowledge on a particular subject, the process of thinking deeply about my words enhances our ability to situate a developing understanding into a larger context. Research in the learning sciences has demonstrated that these themes, at least within the context of the studies reviewed, maximize learning (Collins, 2006; Kafai, 2006; Sawyer, 2006). What follows necessarily is the need for rigorous, externally valid research to test the hypothesis proposed here and we look forward to Idaho scientist's and scholar's approach to this call.

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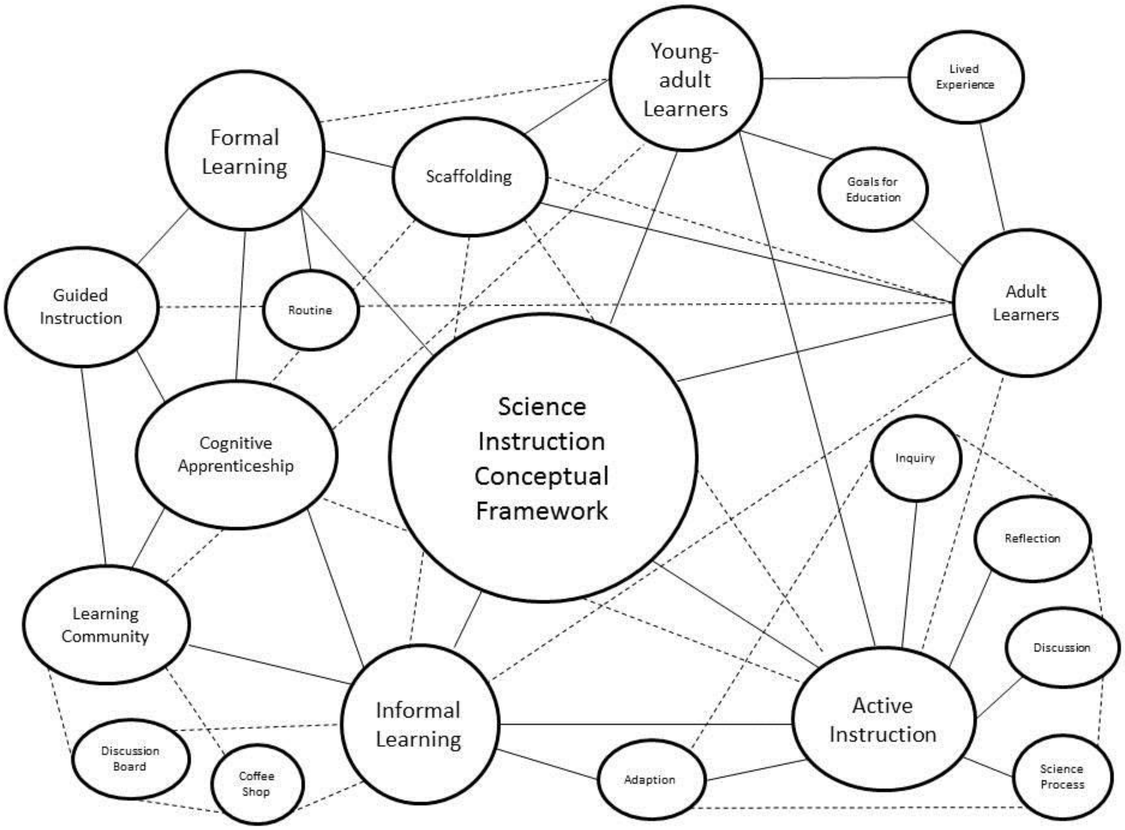

Figure 3.1 Graphic organizer representing a conceptual framework for instructional practice in higher education. Solid lines represent primary connections, broken lines are secondary connections. Additional connections exist but have been omitted for clarity.

Chapter 4 IMPLEMENTING VISION AND CHANGE IN A COMMUNITY COLLEGE CLASSROOM[3]

Abstract

The purpose of this paper is to describe a model for teaching introductory biology coursework within the Vision and Change framework. The intent of the new model is to transform instruction by adopting an active, student-centered, and inquiry-based pedagogy consistent with Vision and Change recommendations. We begin with a review of the Vision and Change framework and continue by describing a novel model for teaching introductory biology coursework based on Vision and Change. We outline steps contained in the model, the goals of instruction, and pedagogies we used to transform our instruction in the classroom. Next we provide an analysis of student satisfaction with our model based on end-of-course evaluations from the preceding three semesters. Results demonstrate that students are more satisfied with our active model compared to the traditional model of instruction. We conclude by suggesting recommendations for future research and by discussing the broad applicability of the Vision and Change framework to STEM disciplines other than biology.

Keywords: Vision and Change, biology, active learning, engagement, student-centered, instruction

Introduction

Engaging students in undergraduate courses can be challenging for college and university faculty (Exeter et al., 2010; Poli, 2011; Lysne, Miller, & Bradley-Eitel, 2013). Proponents of science education reform have challenged faculty to develop instructional models that are engaging by integrating the elements of active and inquiry-based instruction and shifting away from didactic instruction toward more student-centered pedagogies. (AAAS, 2011; Lysne & Miller, 2014; NRC, 2011; NSTA, 2008). There is

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considerable evidence that active teaching models outperform exposition-style models (Freeman *et al*., 2014) and the *Vision and Change* framework for science education encourages college and university faculty to adopt active teaching in their classrooms (AAAS, 2011). Indeed, scholars are beginning to ask if we are doing our students harm by the continued use of a primarily exposition-style lecture (Freeman *et al*., 2014).

Vision and Change

Vision and Change in Undergraduate Biology Education A Call to Action (AAAS, 2011) is a report that contains recommendations ranging from curriculum for introductory biology courses to institutional motivations for change. In terms of what students should know and be able to do, the report outlined several core concepts and competencies that should be included in any introductory undergraduate biology course. The report recommended that students know and understand evolution, structure and function, information flow, exchange, and storage, pathways and transformations of energy and matter, and systems as representing the interconnectedness of life at different levels of biological organization (AAAS, 2011). The report also recommended that students be able to apply the process of science, use quantitative reasoning, use models and/or simulations, engage with other disciplines to address complex questions, communicate and collaborate, and understand the dynamic relationship between biology and society openly while managing a growing body of knowledge (AAAS, 2011). We think that the vision implied in the report is a student-centered model of instruction that is more engaging for students and faculty and the change pertains to how we teach it. The report describes, and references, a variety of tools for transforming lecture into an active, student-centered learning environment. A student-centered environment is one that is interactive, inquiry-driven, collaborative, and relevant (AAAS, 2011). The tools include models describing the development of curriculum, examples of instructional methods, and assessment instruments for a variety of course objectives. Faculty are encouraged to draw on a variety of instructional strategies that have been demonstrated to be engaging and simultaneously increase student success (AAAS, 2011). In the model that we developed and describe below, we've incorporated as many of the core concepts and competencies from the report as we could fit into the instructional template we are provided. Our model specifically concerns the classroom, or lecture, component of instruction. The laboratory component of instruction, insofar *Vision and Change* report, in not considered here but requires attention from researchers.

Cartwheel Model

The cartwheel model uses six learning modules (Figure 4.1) each consisting of two or three chapters of content. We colloquially refer to it as the "cartwheel" due to the cyclical, or repetitive, pedagogical design but the name is irrelevant; it is an active and student-centered design consistent with the objectives of *Vision and Change*. Each module uses five, 75 minute class periods and takes 2 ½ weeks to complete for a total of 30 class meetings in a 16 week semester. To engage students, we used two instructional practices that repeat in each of the six learning modules. The definition of engage is to "get and maintain someone's attention" (http://www.merriam-webster.com/dictionary/engage). Exeter et al. (2010) suggest that engagement is providing students with opportunities during lecture [*sic*] to explore content more deeply. For this manuscript we define engagement as activities and opportunities during class that get and maintain students' attention. The two instructional practices we use to engage students are guided question-and-answer sessions and group activities (Table 4.1). These are considered instructional best practices (AAAS, 2011) and are vital to transforming instruction from exposition to a student-centered and active learning environment.
The guided question-and-answer session is where instruction has been transformed from information transmission to information acquisition. Students are provided a set of questions to answer before coming to class and then during class students are called on, at random, to share their responses to questions. The questions explore what students know about a topic and then transition to new information from their assigned readings via "key guiding questions and opportunities for discussion" (AAAS, 2011 p. 26). Student participation is incentivized by providing everyone with points for participation at the beginning of the term and then taking points away when students do not attend class or fail to participate fully.

The guided questions are answered by the students, making them the center of learning, and are a starting point for discussing content by way of analogies and examples. Importantly, students are acquiring information on their own or in groups and not simply receiving information from the instructor. Activities are designed to support the content covered in the assigned readings and guided discussions. Activities are small and large group projects and provide opportunities for peer-to-peer learning. Scaffolding is provided during the discussion and activities to support students as they struggle with concepts and content. Scaffolding provides the help students need in the moment to get past a particular challenge. It does not prematurely give students the answer but, rather, allows an appropriate and desirable degree of difficulty and support so that students can reach the answer as autonomously as possible (Sawyer, 2006). Examples of activities we have used with the cartwheel model are presented in Table 4.2.

These activities are not prescriptive and should be tailored to suit individual faculty. That is, in our experience we've observed that students enjoy discussing and learning about projects that their professors have been involved with and tailoring a case-study, for example, to our own research, we believe, has intangible benefits. Subsequent to discussion and activity days, students reflect on their learning experiences via journal entries. Students reflect on the content covered in the learning module, their prior understanding of content, how their understanding has changed, and how the content is connected to their life or career path. Self-reflection reinforces content and issues and creates an opportunity for formative assessments (Sawyer, 2006). On the final day of a module before the assessment, the instructor provides a summary lecture, or recap, of major concepts, themes, and expectations for the assessment. It also provides a final in-class opportunity for the students to ask questions and for the instructor to clarify information.

Preliminary Analyses

We used end-of-course evaluations from two courses over three semesters to determine student satisfaction with the teaching model. The courses were *Biology 1* (the first term of a two-term sequence for biology majors; topics include biochemistry, cytology, and genetics) and *Biology 2* (the second term of a two-term sequence for biology majors; topics include early-life studies, evolution of plants and animals including humans and an introduction to ecology). We chose two questions from the college's universal 15 question evaluation distributed to all students that we felt best represented student satisfaction with the teaching model. Many of the questions in this student-self-reported evaluation pertained to course logistics (e.g. "did you receive a syllabus?") or facilities (e.g. "was the technology in the room useful?") and were not useful for our analysis. We make two important assumptions: 1) if satisfaction scores are consistent across the two questions and across semesters, this demonstrates the reliability of the questions and 2) if students are satisfied with the course, then they are satisfied with the cartwheel model. The questions from the end-of-course evaluation that we used for analysis were 1) "Rate your overall satisfaction with the course" and 2) "I would recommend this instructor to others." Satisfaction scores for each question were normalized as a percentage. For example, while faculty may not easily contextualize what a "3 out of 4" score signifies at our institution, all instructors understand what 75% means. We analyzed satisfaction scores with simple descriptive statistics in Excel.

We found that students in *Biology 1* reported increased satisfaction with the cartwheel model compared to the lecture model (Figure 4.2). The single semester utilizing the cartwheel (N = 15) had the highest scores for both course satisfaction (M = 0.84, SD = 0.18) and instructor recommendation (M = 0.76, SD = 0.19). The average course satisfaction and instructor recommendation scores for the preceding two semesters (N = 51) were similar (M = 0.63, SD = 0.23; M = 0.63, SD = 0.28) and were 21 and 13 percentage points, respectively, lower than the semester where we employed the cartwheel model. In *Biology 2* over three semesters (N = 63, Figure 4.3), average course satisfaction and instructor recommendation scores were similar to active classroom scores in *Biology 1* (M = 0.86, SD = 0.17 and M = 0.77, SD = 0.26 respectively).

Discussion

Student-centered instruction is that which provides the students with opportunities to engage with and share information from a diversity of perspectives; not solely the instructors (Exeter et al., 2010). It is collaborative and flexible and the instructor's role is that of a facilitator, mentor, and subject expert rather than only a purveyor of knowledge. It is clear that student satisfaction is greater in sections utilizing the active and student-centered cartwheel model compared to sections where a traditional lecture model was employed. Though *Biology 1* and *Biology 2* are very different courses, and our analysis of *Biology 2* had no lecture sections for comparison, the result demonstrates that the cartwheel can facilitate consistently high student satisfaction scores.

Surprisingly, course satisfaction scores are higher despite, or perhaps because of, the additional responsibilities placed on the students. The model we are proposing explicitly states the expectations for work and participation and it holds students accountable in the event they fail to meet expectations. We interpret the success of our model as a positive response to our challenge on the part of students. They not only met our challenge but told us, via end-of-course evaluations, that they enjoyed the learning experience. Similarly, we were surprised with our own satisfaction regarding the implementation of the proposed model. Rather than an uncomfortable departure from lecturing, the cartwheel is exciting to teach, the interactions with students are genuine and stimulating, and this has resulted in a more positive learning environment.

Though examples in this manuscript are concerned with undergraduate biology instruction, the model developed is appropriate for any STEM discipline and the guided questions, activities, and signature assignments are easily modified for discipline-specific needs. Indeed, the authors of *Vision and Change* (AAAS, 2011) devote only a small portion of the report to biology specifically. While entirely appropriate to modify the structure or sequence used to fit the individual faculty member's resources and needs, what should be preserved is the cartwheel's emphasis on the *Vision and Change* framework (i.e. active, inquiry-based, and student-centered instruction) and how these factors constitute an improved approach to undergraduate science instruction. The cartwheel model is easily scalable to large-enrollment classes but as Freeman *et al*. (2014) demonstrated, greater student achievement can be expected with smaller class sizes. Much work remains to be completed to fully understand the instructional paradigm shift described here. While our initial findings indicate that students are responding positively to the change, we have not addressed the critical issue of student achievement.

There is a need for long-term and generalizable studies that can demonstrate how active, inquiry-based, and student-centered instructional approaches add value to our students' experiences as well as achievements.

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Table 4.1 The *cartwheel* instructional model that is student-centered and based on the *Vision and Change* framework. Module components marked with as asterisk (*) are completed by students out of class. For specific examples of activities, see Table 4.2.

Module Component	*Lesson Description*	*Goal of Lesson*	*Role of the student/instructor*	*Assessment*[4]
Guided Discussion	Instructor-generated questions are provided to students to complete before coming to class. Guided questions are the starting point for exploring module content. Students are called on to share their responses to questions while others join in to add details, correct misconceptions, or provide examples	Introduce information and discuss as a community of learners	Student – center of discussion, apprentice, colleague, presenter of information Instructor – facilitator, mentor, colleague, subject expert	Formative – immediate or timely feedback from the instructor and peers regarding the validity of student responses
Journaling*	Students actively maintain an online journal to reflect on the learning module. They are directed to journal on what they knew coming in to class, how their understanding has or has not changed, and how the content of discussion relates to their life or careers. Provides an opportunity for students to summarize information and concretize understanding	Concretize understanding via active reflection	Student – analyst, apprentice, presenter of information Instructor – mentor, online instructor, listener	Formative - immediate or timely feedback from the instructor; in our class this is not a discussion board but it could be used that way
Activity	Activities designed to relate the learning module to applied or contrived scenarios, preferably with a local or regional connection.	Explore problems and topics in detail in a social, small group/large group format	Student – center of learning, apprentice, colleague, problem solver Instructor – facilitator, colleague, subject expert	Formative – immediate or timely feedback from the instructor and peers while conducting small/large group work
Summary Lecture	Short presentations generally not to exceed 30 slides that cover the most important concepts in the learning modules. Time at the end of this class period is used to address student questions.	Summarize information and expectations for examination; address questions	Student – colleague, peer Instructor – colleague, mentor, subject expert	

[4] This article's thesis is not assessment. Individual faculty and their departments should consider what types of assessments best meet their student learning outcomes.

Quiz*	An online assessment follows lecture; ca. 20 questions, unlimited attempts, formatted to contain higher-order questions (*e.g*. application and synthesis).	Provide feedback on student readiness for examination; promote time-on-task, repetition	Student – apprentice, learner Instructor – proctor, online instructor	Formative – immediate feedback via quiz question analysis and quiz review Summative – criterion-referenced questions provide a valid and reliable indicator of content knowledge
Examination	Assessments cover content in the assigned readings, guided discussions, and activity. The cartwheel is a framework where activities are nested within concepts contained in the guided questions which are nested within relevant sections of the assigned readings. In this way, students approach learning form several different aspects before they are assessed on it.	Assess student knowledge and understanding	Student – apprentice, learner Instructor – proctor, mentor, subject expert	Summative – criterion-referenced questions provide a valid and reliable indicator of content knowledge; application questions assess the student's ability to use content knowledge in an applied/contrived scenario; short-answer questions assess the student's ability to synthesize concepts and applications into a comprehensive understanding

Table 4.2 Examples of active learning exercises used within learning modules. The primary literature contains many detailed descriptions of valuable activities.

Activity	*Description of activity*
Art/Drawing	Students construct models of protein structure and the interactions maintaining protein shape. Scaffolding by the instructor can give students just enough information to complete the activity.
Case-study	Students read supplemental material preferably regarding a local or regional issue of interest to your students. Then via guided questions, students discuss related concepts from the learning module. Many fine examples are available from the National Center for Case Study Teaching in Science (http://sciencecases.lib.buffalo.edu/cs/) or you can create your own.
Online Exercises	Numerous online tools exist to engage students in learning. One that we use is designed by the Howard Hughes Medical Institute (www.hhmi.org/biointeractive) and has several exercises that support student learning.
Model Scientific Thinking	Modeling scientific thinking involves demonstrating to students how to problem solve. We develop questions toward the synthesis/evaluation side of Bloom's Taxonomy and model how to use known information in a novel scenario. Students are next given the opportunity to demonstrate scientific thinking and are scaffolded appropriately.

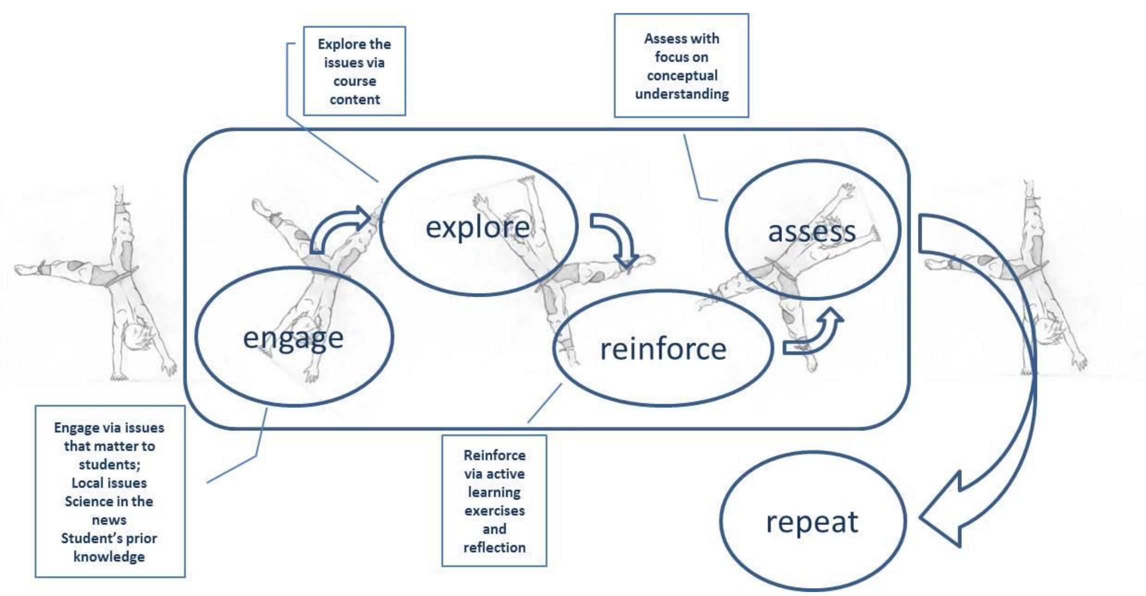

Figure 4.1 The cartwheel concept map adapted from AAAS (2011). Each learning module follows this general format via guided Q&A, activity, lecture, reflection, and assessment.

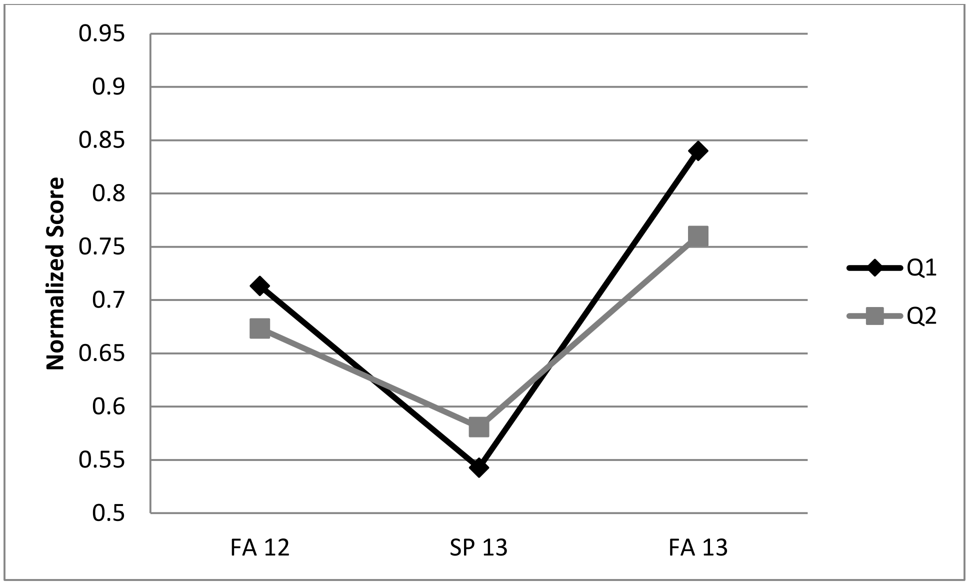

Figure 4.2 Normalized student satisfaction scores for three consecutive semesters of *Biology 1* (n = 66). Question 1 (Q1) is "Rate your overall satisfaction with the course" and Question 2 (Q2) is "I would recommend this instructor to others."

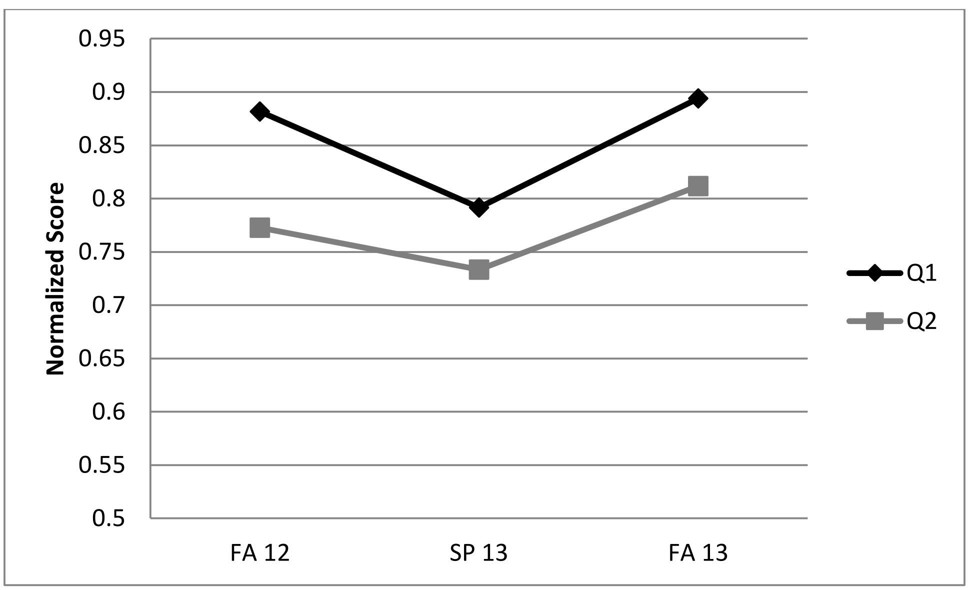

Figure 4.3 Normalized student satisfaction scores for three consecutive semesters of *Biology 2* (n = 63).

Chapter 5 A Comparison of Long-term Knowledge Retention Between two Teaching Approaches in an Undergraduate Biology Course

Abstract

The purpose of this research was to begin filling a major gap in our understanding of how reform-based instructional approaches meet faculty-developed student learning outcomes. Active teaching models have been demonstrated to result in greater student engagement and knowledge in many cases but little work has been conducted on the retention of knowledge gains by students from active classrooms. If colleges and universities are transitioning to an emphasis on active instructional approaches then we should better understand the influence of active approaches on long-term student knowledge retention. To address this gap, we conducted an experimental study of content knowledge retention by undergraduate biology students at a mid-sized community college. We used a modified Solomon four-group design with control (lecture) and treatment (active) groups and a pre/post/post assessment protocol. We found that knowledge retention after approximately 140 days did not differ across groups. However we also found that knowledge gains were different and so were other metrics such as student engagement, retention, final exam scores, and programmatic measures of student success. We conclude by discussing the implication of our findings to the broader science education reform movement and suggest future research to refine our incipient understanding.
Key Words: science education, active instruction, student-centered learning, gain score, community college

Introduction

In 1968 John Check lamented that little was known about long-term retention of academic content learned during the normal course of an educational program (Check, 1968). He reviewed the available literature from a variety of academic disciplines including biology and mathematics and found that reported levels of information retention were much higher than predicted and reported in the psychological literature (where most research on memory had been conducted). He asked himself why reported values of knowledge retention resulting from research in classrooms were so much different than values resulting from research in laboratories. He concluded that meaningful learning, as opposed to remembering random lists of numbers, objects, or words, was retained much more readily by students (Check, 1968). However I assume, because of the year of publication and lack of explanation, that Check's work was based entirely on instruction utilizing a lecture format. Active instructional approaches, by contrast, have been demonstrated to be more engaging for students (Handelsman, Miller, & Pfund, 2007; Lysne & Miller, 2015), result in greater achievement (Deslauriers et al, 2011; Goldstein & Flynn, 2011; Freeman et al., 2014) particularly with students from disadvantaged educational backgrounds (Haak, 2011), create positive self-attitudes (Blaylock & Hollandsworth, 2008), and create more positive attitudes toward science careers generally (Hulleman & Harackiewicz, 2009). However no comparison has been conducted, with meaningful learning or otherwise, to compare knowledge retention (K_r) in terms of student achievement between these two different styles of instruction. Further, student achievement can be measured at multiple scales (e.g. an exam, a final grade, a gain score, or knowledge retention) and in multiple contexts and no information exists regarding the relative contribution of each, in undergraduate biology instruction specifically, in terms of achievement or retention. Ricker and Cowan (2014) suggest that "the presence or absence of forgetting based on the passage of time is in some ways the most basic question that can be asked about working memory" (p. 417). Yet researchers have not yet asked this crucial question in the context of changing approaches to undergraduate science instruction.

Several investigators have approached the subject of long-term science content K_r but these studies were conducted outside the discipline of undergraduate biology instruction and did not address the context in which students learned the material. For example, EL-Bab et al. (2011) studied K_r in 2^{nd} – 5^{th} year medical students and demonstrated a significant decline in basic science content information with 5^{th} year students retaining 62% of 2^{nd} year medical students' knowledge on a standardized examination. However the question addressed in this study was K_r and not how alternative instructional approaches influence K_r. Similarly Custers & ten Cate (2011) investigated basic science

K_r in medical students and practicing physicians. They found a consistent decline in K_r with 5th and 6th year medical students demonstrating the greatest retention values (i.e. K_r = 40%). Goldszmidt et al. (2012) found that K_r increased when causal explanations were provided to elaborate on basic medical science concepts. And Price, Lumpkin, Seemann, & Calhoun Bell (2012) found that peer assisted study strategies increased K_r with undergraduate psychology students. Other researchers found that K_r was improved when instruction was enhanced by technology. Yildirim, Ozden, & Aksu (2001) demonstrated that K_r increased with secondary biology students when they experience instruction in a multimedia learning environment compared to a traditional learning environment. Similarly, Yang et al. (2014) demonstrated improvements in K_r with medical students when instruction was supplemented with a multimedia, web-based learning platform. While research regarding K_r with high school students, undergraduate psychology students, and professional graduate students is valuable, there is still a relative paucity of studies suitable of forming a comprehensive understanding of long-term K_r. Thus the question remains "Do different methods of instruction result in different levels of K_r?"

To address this information gap, we conducted an experimental study (Trochim & Donnelly, 2008) of content knowledge retention (K_r) by undergraduate biology students at a mid-sized community college in Idaho, USA. Slater, Slater, and Bailey (2010) describe several psychometrics (i.e. mathematical models used in measuring knowledge) available to researchers and from these we chose to calculate gain scores (G) and knowledge retention scores (K_r). Gain scores are easily calculated in pre/post-test research designs simply by subtracting the pre-test dependent variable (e.g. the proportion of correct responses) from the post-test dependent variable (Slater, Slater, & Bailey, 2010). Using the same set of questions leads to valid inferences and is a reliable measure of content knowledge (Trochim & Donnelly, 2008). Our research question for the present study is: "Do students enrolled in an active, inquiry-based, and student-centered biology course retain knowledge as well as students in a lecture-based and instructor-centered biology course?" We specifically tested two null hypotheses: H_{01}) there is no difference in biology content gain scores (G) between undergraduate students enrolled in either active (hereafter referred to as the treatment) or lecture (hereafter referred to as the control) teaching environments (groups); H_{02}) there is no difference in biology content knowledge retention (K_r) between undergraduate students enrolled in either treatment or control groups. Our predictions included 1) there will be a difference in *G* between treatment and control groups, 2) the treatment group will demonstrate the greater value for *G*, 3) there will be a difference in K_r between treatment and control groups, and 4) the treatment group would demonstrate the greater value for K_r.

Methods

Study Area & Sampling Frame

The proposed research was conducted at the College of Western Idaho (CWI), a comprehensive community college in south-western Idaho, USA. The 27 academic programs at CWI have a combined enrollment of approximately 10,000 freshman and sophomore, credit-seeking students (CWI, 2014). Forty-five percent of CWI students in 2013 were older than 25 years of age. Fifty-eight percent of students are white, 21% are Hispanic, 4% are Asian, and 10% were not reported. The remaining seven percent reported ethnicity as Black or African American (3%), Multi-Racial (2%), American Indian (1%), or Hawaiian/Pacific Islander (1%). The biology program at CWI has approximately 1400 students and is the largest declared major at the two-year college. However half of the approximately 400 students that enroll each term in the undergraduate biology course we've elected to utilize in our study choose an online delivery option leaving just four sections of face-to-face instruction for experimental use. Our sampling frame therefore includes undergraduate biology majors enrolled in face-to-face sections of the first term of a year-long general biology sequence. The research conducted has been approved by the Institutional Review Boards at the College of Western Idaho and the University of Idaho (Appendix A) and all student participants provided consent for their responses to be used. A more detailed discussion of experimental methods including information about course curriculum and delivery can be viewed in Appendix C.

Experimental Design

We used a modified Solomon four-group design (Wilke, 2003) to assess *G* and $\acute{K}_r$ between two different instructional approaches; control and treatment. Lysne and Miller (2015) provide a detailed description of an active instructional approach and we used that approach in the present study. In the Solomon design, four groups of participants are used (Figure 5.1). In the control group, which is primarily lecture, no active instructional interventions were used and half of the enrolled students were randomly chosen to complete the pre-test during the first week of instruction. The remaining half of students received a placebo pre-test. In the treatment group, students receive the active instructional interventions and half were randomly selected to complete the pre-test as in the control group. To ensure that the results will be transferable, we randomly assigned 1) course sections to either the control instructional approach or the treatment instructional approach and 2) students receiving the pre-test. All other aspects of the course (e.g. number of mid-term exams, quizzes, signature assignments, etc.) were conducted similarly; only the variable of instructional model differed between control and treatment sections. A total of four face-to-face sections were used.

Pre/Post-tests

Pre/post-tests were composed of the same 18 questions that captured the major concepts from each of the five units (i.e. combined set of chapters) that constitute the curriculum of the introductory biology course. The questions were routed to, and considered by, the biology faculty at CWI for their usefulness at addressing major curricular concepts. The tests were administered during the first and last weeks of the fall term to assess *G* and again at the end of the subsequent spring term, a retention interval (RI) of approximately 140 days, to assess K_r. Selection mortality was minimized by administering the second post-test during the second term of the year-long biology sequence. Students often take both courses sequentially however we expected, *a priori*, an approximately 50% re-test rate because this is the customary matriculation rate from the first course in the sequence to the second. All testing instruments (i.e. pre, 1st post, 2nd post) can be examined in Appendix D.

To test for instrument validity, we conducted correlation analysis between two variables; the first post-test score and final course grades (expressed as a percent) using the Pearson correlation coefficient (r). If final course grades, which are based on multiple pieces of evidence, are positively correlated with the dependent variable scores then our testing instrument has validity. Cronk (2012) defines a positive correlation as weak ($r < 0.03$), moderate ($0.03 < r < 0.07$), or strong ($r > 0.07$).

Defining the Dependent Variables

Custers (2010) describes three types of studies that are commonly used to study knowledge retention but he emphasizes that there is no definition, agreed upon by the scholarly community, for knowledge retention. We define *G* in terms of positive gain scores or the difference, per student, of the first and second post-tests. K_r will be defined as the percentage of correct responses to the instrument during the 1st post-test (P_1) divided by the percentage of correct responses during the 2nd post-test (P_2) at the end of the 140 day RI. K_r will be calculated for each student and averaged across all students within treatment or control groups for population-level estimates of $\acute{K}_r$ using the following equation:

$$\acute{K}_r = \sum^{i-n} \frac{\left[K_r = \frac{P_1\,(\%)}{P_2\,(\%)} \right]}{n}$$

Where: $\acute{K}_r$ = Population knowledge retention; K_r = Individual knowledge retention for students $i - n$; P_1 = first post-test score as a percentage of correct responses; P_2 = second post-test score as a percentage of correct responses; n = total number of students.

Control and Treatment Groups

In the control group, information was transmitted to students via lecture. Time in class was used by the instructor to carefully and thoroughly explain the content and concepts via anecdotes, examples, and information taken from the assigned readings. We recognize that using singular categories of instruction masks the complex dimensions of how many faculty practice the craft of teaching (Hora & Ferrare, 2014). However for the purpose of this study, the control was principally a didactic transmission of information. The control group experienced similar quizzes, examinations, and assignments as the treatment group and differed only in the context of how information is presented to, or acquired by, students (Table 5.1, Appendix C).

The treatment model was an active, inquiry-based, and student-centered model of instruction (Lysne & Miller, 2015) that may be described broadly as a collaborative learning community. The principle differences between the control and treatment models of instruction were how information was introduced to students and how time was spent in the classroom. In the treatment, students acquired information on their own and were held accountable for doing so. In class, time was used to discuss content and concepts, explore examples, and engage in activities to deepen student understandings of the material being discussed.

Analysis

The independent variable in this study is the instructional model (i.e. control vs. treatment). The dependent variables are G and K_r. Individual knowledge retention scores were pooled for population-level estimates ($\acute{K}_r$) by group (i.e. control vs. treatment). Student scores (i.e. the dependent variable) on the pre-test, first post-test, and second post-test are represented as the number of correct responses. All data collected was entered into Microsoft's Excel and IBM's SPSS (SPSS Statistics v22), double-backed-up, and analyzed using descriptive (e.g. M, sd, %, etc.) and inferential statistics (e.g. t-test, ANOVA, correlation). Cohen's *d* is reported for all significant t-tests to estimate effect size and can be interpreted to describe the percent of variance that can be explained by a given variable. Cohen's *d* is expressed as numeric values between 0 and 1 and the value of *d* is zero when there is no difference between population means (Privitera, 2012). Effect size conventions can be used generally by researchers to identify small, medium, and large effects (Privitera, 2012). Those values of *d* below 0.2 are considered small, those between 0.2 and 0.8 are considered medium, and those values greater than 0.8 are considered large effect sizes. Results from these analyses are presented in tabular format (arranged in Microsoft Excel) and are displayed visually using Excel and SPSS graphing applications.

Results

A total of 158 students were enrolled in the four sections of introductory biology. 140 student participants consented to have their information used as a part of this study. Seventy-six students completed the instrument pre-test and 64 students took the placebo pre-test. Twenty-one students (15%) declined to participate in either the first or second post-test. Two students' scores were omitted from analysis for administrative reasons. Twenty-four students (17%) withdrew from the course before attempting the first post-test; 13 and 11 in the control and treatment, respectively. In the control group, 45 students completed the first post-test and 16 the second post-test; 65% and 23%, respectively, of the original control group participants. In the treatment group, 50 students completed the first post-test and 15 the second; 70% and 21%, respectively, of the original treatment group participants. Across groups, 22% of students that completed the pre-test nine months earlier completed the second post-test; half of our predicted re-test rate. Table 5.2 provides a summary of the data presented here.

A Pearson correlation coefficient was calculated for the relationship between participants' first post-test score and final grade. A moderate positive correlation was found (r (77) = 0.629, $p < 0.01$), indicating a significant linear relationship between the two variables (Figure 5.2). This demonstrates that students scoring higher on the first post-test tend to earn higher final scores and that our instrument is a valid indicator of student achievement.

Combining all students across both treatment and control teaching approaches, pre-test scores (M = 5.47, sd = 2.58) to post-test scores (M = 10.38, sd = 3.2) demonstrate a 28% increase in content knowledge during the academic term (Figure 5.3). The average *G* per student (M_G) from the pre-test to the first post-test was 4.71 (sd = 3.3). This was followed by a 3% loss of content knowledge over the 140 d RI between the first post-test (M = 10.38, sd = 3.2) and the second (M = 9.87, sd = 3.08) demonstrating that content knowledge was retained by students but diminished, independent of teaching approach, over the duration of the RI used in this study.

Results differed, however, between experimental groups. Pre-test scores in the control group (M = 4.55, sd = 1.84) were significantly less (t(43) = 2.22, p =0.03, *d* = 0.66) than the treatment group (M = 6.2, sd = 2.87). However, post-test scores were not significantly different (t(89) = 0.46, p = 0.64) between the control (M = 10.21, sd = 2.81) and treatment (M = 10.53, sd = 3.51) groups (Figure 5.4) and this is reflected in a very small estimation for Cohen's *d* (0.1). This demonstrates that *G* was greater in the control group though gains were non-significant by a narrow margin (t(43) = 1.95, p = 0.058).

Importantly, post-test scores did not differ (t(89) = 1.01, p = 0.32) between those students that completed the instrument pre-test (M = 10.04, sd = 3.3) and those that completed the placebo pre-test (M = 10.72, sd = 3.05). This demonstrates that post-test scores are independent of having completed the pre-test; that is, no testing threat exists in the present study.

Rates of knowledge retention ($Ḱ_r$) did not differ significantly (t(29) = 0.18, p = 0.86). The average estimated $Ḱ_r$ for the control group (88.8%) was slightly higher than $Ḱ_r$ for the treatment group (87.5%; Figure 5.5).

Finally, we performed a 2x2 mixed factorial ANOVA comparing $Ḱ_r$ scores for two instructional approaches (control and treatment) with the version of pre-test completed (instrument and placebo). We found no significant main effect for instructional approach (F(1) = 0.071 , *p* = 0.792) or pre-test version (F(1) = 0.112, *p* = 0.74). Similarly, there was no interaction between instructional approach and pre-test version (F(1) = 1.22, *p* = 0.28). This demonstrates, similar to results already reported, that in our study neither the teaching approach, pre-test version, nor the interaction between teaching approach and the version of the pre-test students completed had any effect on $Ḱ_r$.

Discussion

We designed and implemented a robust experimental study and have started to fill an important gap in the literature pertaining to the retention of basic biology information when using alternative or "reformed" instructional approaches. Our finding of no difference in $\acute{K}_r$ between an active instructional model and lecture was unexpected and complicates the assumed superiority of collaborative learning communities in the context of knowledge gains and knowledge retention. We anticipate with interest the discussion that will follow. For example in Freeman et al.'s (2014) meta-analysis of 225 studies using active instructional approaches, they found that using an active approach resulted in 6% better student achievement. However what defined achievement varied and the degree of active instruction similarly varied greatly. In the context of Freeman's analysis, our work would have been far to one side of the active instructional spectrum. For example in Freeman et al. (2014), active courses included a continuum of what we consider a minimal amount of active instruction such as simple clicker-type lecture response systems to much more active peer instruction or workshop approaches. The treatment group in our study employed multiple active strategies () and the control may have been considered active! While we found no difference in $\acute{K}_r$, our experimental design should be replicated by other researchers and the results compared to our own. In addition, future work should unpack the variability inherent in active instructional approaches to discern the relative contribution of each to student achievement. One research approach might be to estimate the relative use of active instructional tools via faculty interviews and then correlate this to levels of student achievement. In addition what needs to happen is we need to ask the question: "Why did we see greater values of *G* in the control group and no difference between groups for $\acute{K}_r$?" This is an intriguing question and should be considered further because it contradicts current assumptions and the results of many published

Memory retention is a challenging topic because few educational studies are conducted with appropriate controls and treatment groups, randomization procedures, and the necessary assessments including a pre-test, post-test, and retention test (Custers, 2010). Further, many studies lack specificity with regard to procedures, curriculum, or testing instruments (Custers, 2010) making comparisons difficult and replication impossible. Of our original predictions 1) there will be a difference in *G* between treatment and control groups, 2) the treatment group would demonstrate the greater value for *G*, 3) there will be a difference in $\acute{K}_r$ between treatment and control groups, and 4) the treatment group would demonstrate the greater value for $\acute{K}_r$, all were disproved. Of our original hypotheses H_{01}) there is no difference in biology *G* scores between undergraduate students enrolled in either treatment or control groups; H_{02}) there is no difference in biology $\acute{K}_r$ scores between undergraduate students enrolled in either treatment or control groups, only H_{01} was supported but the difference between groups was not significant and it was the control group demonstrating the higher value for *G*.

Various hypotheses have been forwarded to account for the retention of memories including an individual's age (Kausler, 1994), their brain biochemistry (Sandstrom & Williams, 2001), or even their sleep status (Scullin & McDaniel, 2010). Additionally, some research has been conducted on memory, or knowledge retention, and forgetting with medical students (Custers & ten Cate, 2011; Goldszmidtz et al., 2013; Yang et al., 2014). For example, EL-Bab et al. (2011) studied knowledge retention in 2^{nd} – 5^{th} year medical students and demonstrated a significant decline in basic science content information. Interestingly, EL-Bab et al. (2011) also showed that content knowledge retention improved with repeated exposure to relevant information. They asked two sets of questions to participating medical students; one set of questions addressed basic science content and one set addressed clinical content. Over time, medical students lost basic science content knowledge but improved in the context of clinical content knowledge due to repeated exposure; a presumably favorable outcome and one used to argue for changes that reduce or eliminate basic science content from medical school curricula (EL-Bab et al., 2011). Though content is different in the two-course introductory biology sequence, the second course does build on the first thereby providing with "repeated exposure to relevant information."

However Ricker and Cowan (2014) studied memory retention in the context of how information is presented; similar to the thesis of this article but different in terms of content, the presentation of information, and duration of the study or, as used here, retention interval. They reviewed the literature on forgetting and found that there was generally a difference in retention when objects or images were presented briefly – an image of a non-verbal item, for example – compared to a "longer sequential item presentation method" (p. 418) – for example a list of words, letters, or digits. Though the RIs used in reviewed investigations were short (i.e. seconds) and the content was meaningless (i.e. random lists of letters, digits, or non-verbal images), the research demonstrates that how information is presented matters in memory retention.

Check (1968) designed a study very similar to our own though the content was different and he did not compare alternative instructional models. In the fall of 1964 he gave students in an introductory psychology class a multiple-choice assessment about five weeks into a standard academic term. Then in the spring of 1965 he gave the same group of students, who had matriculated into "the sequential social foundations course" (Check, 1968, p. 160), the exact same test. It is not exactly clear when during the spring term that his students completed the re-test. Further, Check (1968) did not administer a pre-test, only a "post-test" given about five weeks into the fall term but he did estimate a value for K_r at 78%; similar to our average estimated value of 88%. Similarly high values of K_r were observed by Tyler (74%; 1933) in zoology and by Gagné and Paget (60%, 1980) in psychology. Custer (2010) similarly reviewed the literature on long-term retention and reported that values for K_r between 66% and 75% can be expected after one year which fits with our data and the results of others previously discussed (El-Bab et al., 2011; Custers & ten Cate, 2011).

Bernot and Metzler (2014) compared achievement and student engagement in a large enrollment biology course between two delivery models: instructor-led and student-led. They found no difference in achievement as measured by homework, exam scores, and final grades but, in contrast to our study, they found that students in treatment instructional model (i.e. student-led) demonstrated higher *G* scores than students in the control (i.e. instructor-led) classroom. This means that, like in our study, students entered the course at different levels of readiness but ended with similar levels of achievement. This, we believe, is what is responsible for the difference in *G* that we found between the control and treatment groups. Approximately half of College of Western Idaho students are non-traditional; returning to college years after their secondary education was completed. These students may be less well prepared for the course and therefore may have earned lower scores on the pre-test. However these same non-traditional students, in our experience, generally perform better though we can only speculate why. If true that non-traditional students are less prepared but demonstrate higher achievement, and that the control section used in our study and offered on a Saturday had a higher proportion of non-traditional students, then it may explain why observed values for *G* were higher in control sections in this study. Future studies need to control for incoming students level of preparation and investigate *G* further. In addition, investigators should consider age (i.e. status as a “traditional” or “non-traditional” student) as independent variable when calculating *G* and $\acute{K}_r$. Incidentally, Bernot and Metzler (2014) also found that student engagement, as measured by end-of-course evaluations, was significantly less favorable in their active classroom and this is in contrast to what Lysne, Miller, and Bradley-Eitel (2013) found in a similar study.

Interestingly, Lewandowsky, Oberauer, and Brown (2008) found that the number of distractors during a learning period increased the cognitive load of the learning process but did little to affect memory. Perhaps this mechanism is operating in our study; we found no difference in long-term $\acute{K}_r$ but had a very long RI with many, and difficult, distractors during the learning period. It is plausible that our active instructional model could be considered to have more distractors, thus creating a higher cognitive load for students and lower achievement. Alternatively, some sort of “memory-refreshing” mechanism (Anderson, Bjork, & Bjork, 2000; Lewandowsky, Oberauer, & Brown 2008) could be operating but we did not examine or quantify this.

Specifically in biology instruction, O’Day (2007) studied memory retention in undergraduate students but used a shorter RI (21 days) and compared retention for information presented via static images or video animations. This study investigated specific, complex concepts such as protein synthesis and folding and asked if image presentation influenced K_r. Similar to the findings of Ricker and Cowan (2014), O’Day (2007) found that the method of presenting information, video animations in this case, significantly impacted retention of that information. Also within the context of information presentation, Yildirim, Ozden, & Aksu (2001) compared two instructional approaches with a design similar to our own in the present study. They used a control/treatment, pre/post-test design with a long RI (ca. 30 days) to compare traditional instruction (i.e. primarily lecture) to instruction supported by a "hypermedia" learning environment (i.e. a computer-mediated, web-based environment). They found no difference in post-test scores for some metrics (e.g. *G* as used in this study) but a significant difference between the groups for $\acute{K}_r$ (Yildirim, Ozden, & Aksu, 2001); we found no difference for either metric (Figures 5.4 & 5.5).

While these recent studies address knowledge acquisition, retention, and/or compare methods of presenting information, none are like our study in complexity, content, or duration and, thus, we have begun to fill an important information gap in the literature regarding knowledge retention in science instruction. For example, what if there was a difference between *G* and $\acute{K}_r$ such that one group had a slightly higher gain score but a much lower score for information retention? If, to continue this example, retention was significantly different between groups studied, and retention was a prioritized student learning outcome, then we might alter our instruction and forego the short-term gain in content knowledge in favor of the improved long-term retention. This is not what we found but was a necessary question to address and should be repeated by others to support or refute our findings.

The question addressed in this chapter is knowledge retention. However this is not the only outcome of interest to college and university faculty and administrators. For example, both student engagement and retention (i.e. persistence) are important metrics that should be considered in a comprehensive evaluation of alternative instructional approaches. Motivating students to persist in science coursework and programs is a major goal of STEM initiatives nationally (AAAS, 2011) and increasing student engagement (i.e. interest and participation) supports retention (Schmidt et al., 2009). Similarly, additional metrics of achievement such as 1) fail rates, 2) withdrawal rates, and/or 3) percentages of students meeting programmatic learning outcomes (e.g. "C or better") should be considered. While not specifically addressed in the present study, we considered these outcomes along with our principle question of knowledge retention.

Evidence demonstrating that increased engagement is directly related to increased achievement is scarce (Blaylock & Hollandsworth, 2008) and the answer really depends, as discussed above, on what we mean by achievement. For example, Hu, Kuh, & Li (2008) found that engagement had a positive impact on some measures like intellectual development but a negative impact on others like personal development. By contrast Haak (2011) reported only positive results. He found that active and engaging instruction resulted in greater achievement by students in an introductory biology course and that students from disadvantaged educational backgrounds benefited more, on average, than other students; reinforcing the importance of active and engaging instruction (Haak, 2011). More philosophically, Brint, Cantwell, and Hanneman (2008) have discussed the disparity in the concept of engagement itself between students in liberal arts career paths and those in natural sciences career paths and they raise subsequent questions about the "normative conceptions of good educational practice" (Brint, Cantwell, & Hanneman, 2008, p. 398) considering these differences between students. Similarly, Horstmanshof & Zimitat (2007) have suggested that it isn't even the teaching approach, *per se*, that influences engagement. Rather it's the students' "orientation to the future" (Horstmanshof & Zimitat, 2007, p. 714); that is, their long-term vision of where they are going and what they need to achieve to get there.

In the present study, we found that fewer students dropped out from our treatment groups (14%) compared to our control groups (19%; Figure 5.6). In a meta-analysis with Dutch medical students, Schmidt et al. (2009) demonstrated similar results. They found that students in programs emphasizing active teaching approaches graduated more students (8%) earlier (ca. 5 mo.) than did programs emphasizing traditional teaching approaches (Schmidt et al., 2009). Keeping students in class seems to be important in the context of achievement and a five percent improvement in retention should be considered when evaluating new or reformed instructional approaches for implementation.

We also found that demonstrating improved achievement in active classrooms depends on the metric used to assess it. While we've shown that in our study K_r is no different between groups, if we consider achievement across multiple assessments and not just a common set of questions on pre and post-test instruments we see a slightly different result. In our study we found that, on average across all mid-term examinations, students performed approximately 2.5% better in active classrooms (Figure 5.7). Similarly, final exam scores were 2% greater in active classrooms compared to lecture classrooms (Figure 5.8).

Two additional metrics regarding student failure are important to consider in a comprehensive evaluation of instructional approaches. For example, if we consider the withdrawal rate of students in our study, we see a reduction in the number of students dropping out (5%) compared to the traditional lecture classroom. Also, when we deconstructed the failure rate of students (which were not different across control and treatment groups; 25%), we found that the rate of earned Fs (i.e. students that complete the final examination and, regrettably, fail) was 4% lower in active classrooms compared to lecture classrooms (Figure 5.9). These results suggest that in active classrooms in our study, fewer students are dropping out and of those that persist, fewer fail. Finally, in some academic departments a grade of "C or better" is required for the course to apply to degree requirements. If we consider this programmatic learning outcome for students that participated in our study, we find that students in active classrooms performed 4% better than students in lecture classrooms (Figure 5.10). The importance of the metric used to evaluate alternative instructional approaches should not be underestimated. Our study systematically evaluated just one important metric; knowledge retention. However, there are additional student learning outcomes of interest to faculty and administrators and considerable work remains to be completed before we fully understand the value of active and student-centered instructional approaches.

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Table 5.1 A comparison of teaching models in proposed study. For more specific information, please see Chapter 4 and Appendix C.

Activity/Assessment	Active Model	Lecture Model	Type of Activity/Assessment
Discussion	☑		Formative
Activity	☑		Formative
Lecture	☑	☑	(not graded)
Signature Assignment	☑	☑	Formative
Quiz (10)	☑	☑	Formative
Mid-term Exam (5)	☑	☑	Summative
Self-reflection	☑		Formative
Final Exam (1)	☑	☑	Summative

Table 5.2 Comparison of sample sizes for different aspects of our research. A total of 158 students enrolled in the four sections of Biology 1. Of these, 140 students initially consented to participate; three of those students declined participation prior to the second post-test.

	Control	Treatment
Sample Size	64	76
Instrument	34	40
Placebo	28	36
Declined Participation	6	15
Withdrew From Course	13	11
Completed Post-test	45	50
Completed Second Post-test	16	15

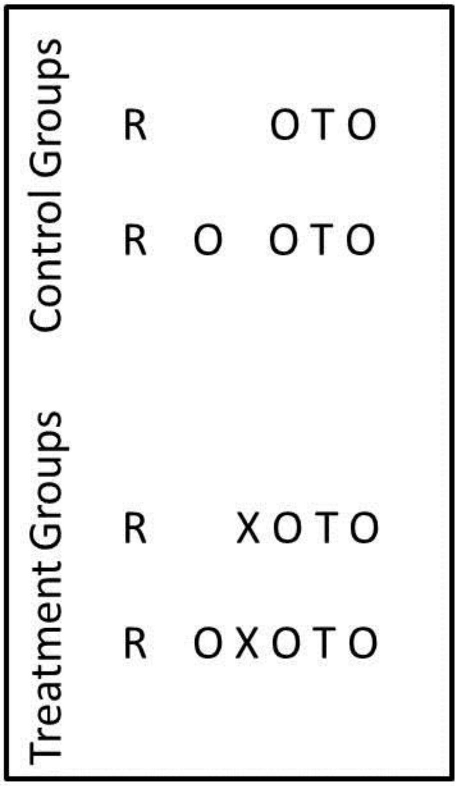

Figure 5.1 Schematic of the modified Solomon four-group design where: R = random designation, X = treatment (i.e. active instruction), O = presentation of the test instrument, and T = subsequent 140 day interval.

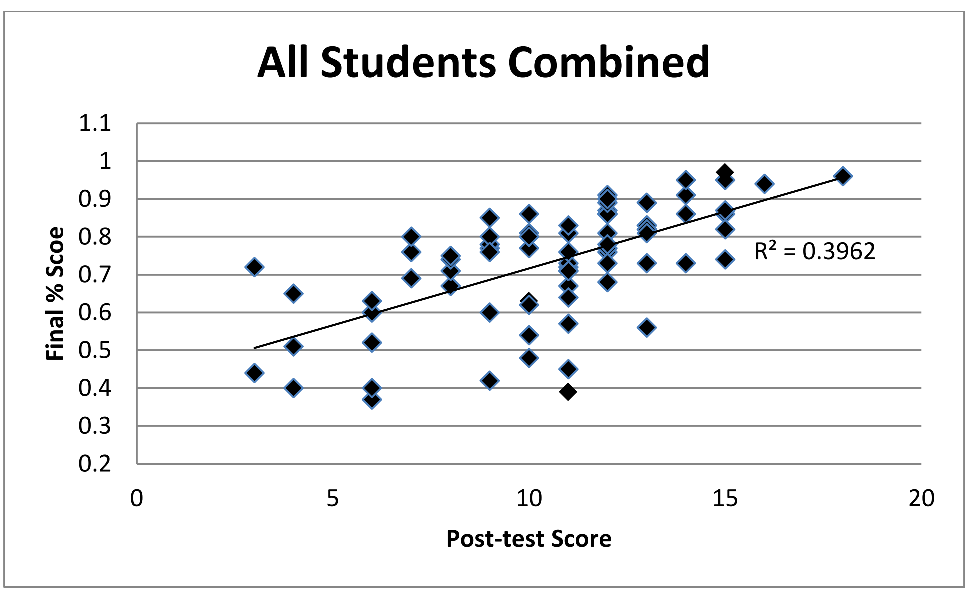

Figure 5.2 Scatter plot demonstrating significant positive correlation ($p < 0.01$) between student scores on our testing instrument and final course grades (n = 70) expressed as a percentage.

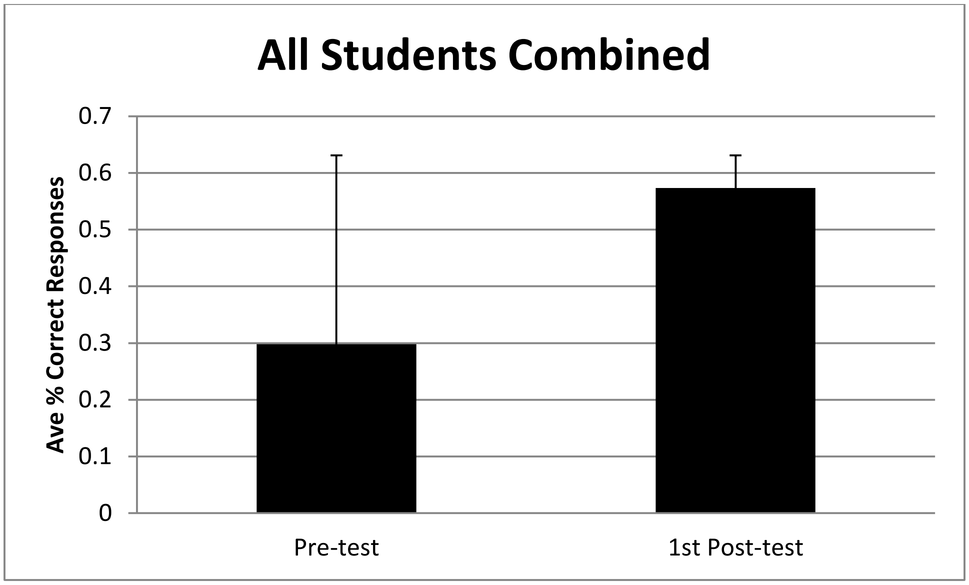

Figure 5.3 Average scores, expressed as a percentage, from pre-test and first post-test for all students across experimental groups (n = 95).

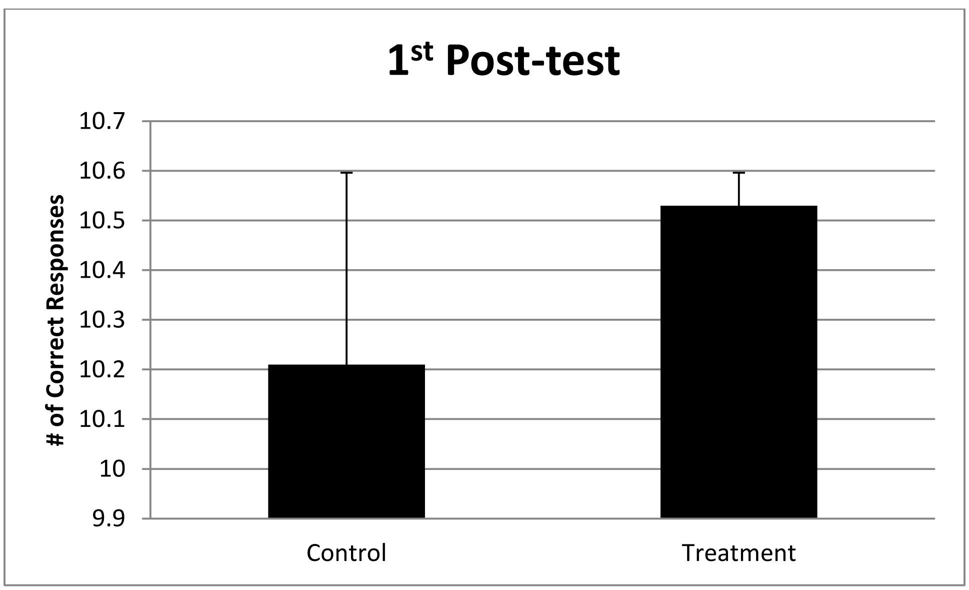

Figure 5.4 First post-test scores for students in the control (n = 45) and treatment (n = 50) groups.

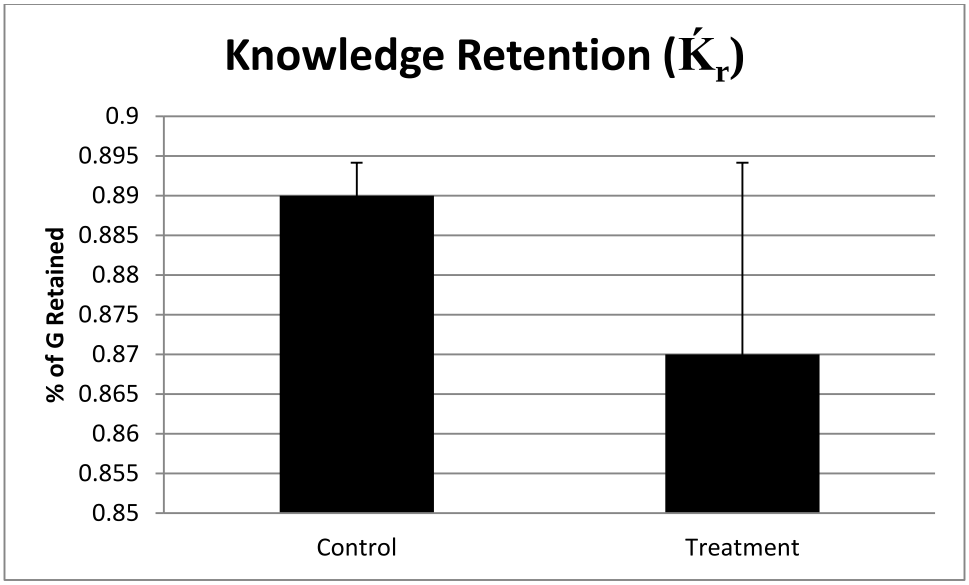

Figure 5.5 Estimates of population knowledge retention ($\acute{K}_r$) for students in the control (n = 16) and treatment (n = 15) groups.

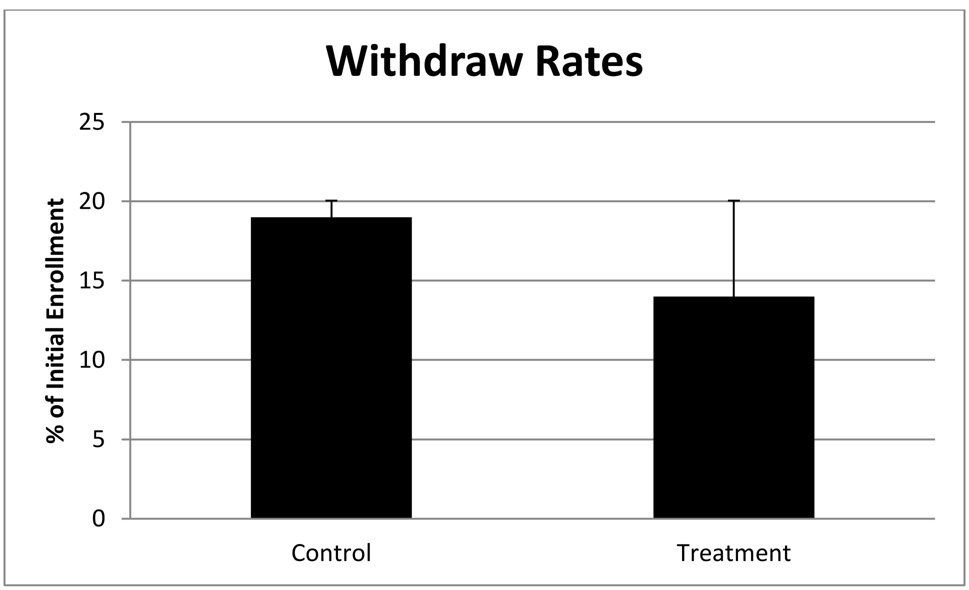

Figure 5.6 Percent of students that withdrew from the course before completion in the control (n = 13) and treatment (n = 11) groups.

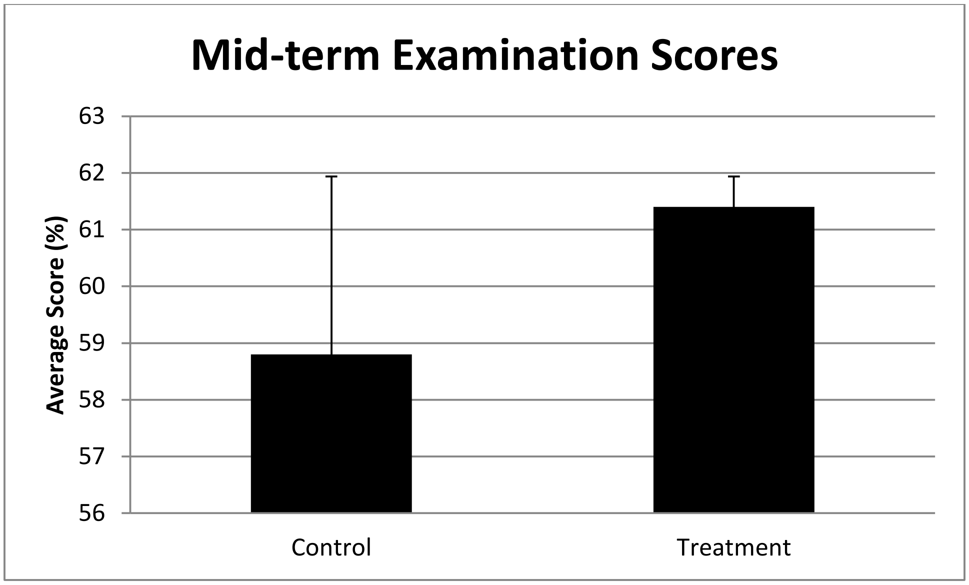

Figure 5.7 Average scores across three mid-term exams from students in the control (n = 151) and treatment (n = 177) groups. Mid-term exams were not standardized but covered the same content and were similarly formatted (e.g. criterion-referenced questions, short-answer, essay, etc.).

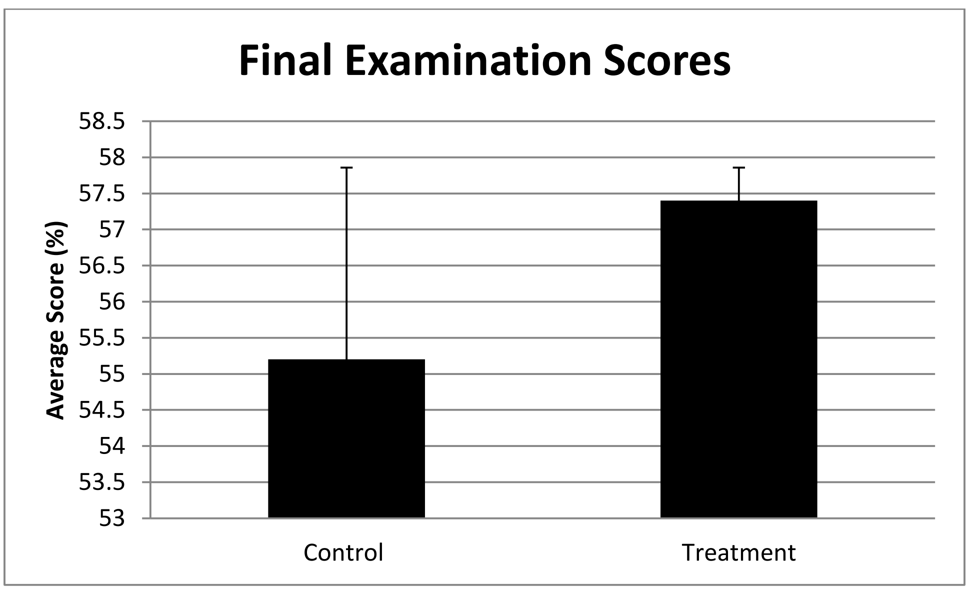

Figure 5.8 Average scores on the comprehensive final examination for students in the control (n = 45) and treatment (n = 50) groups.

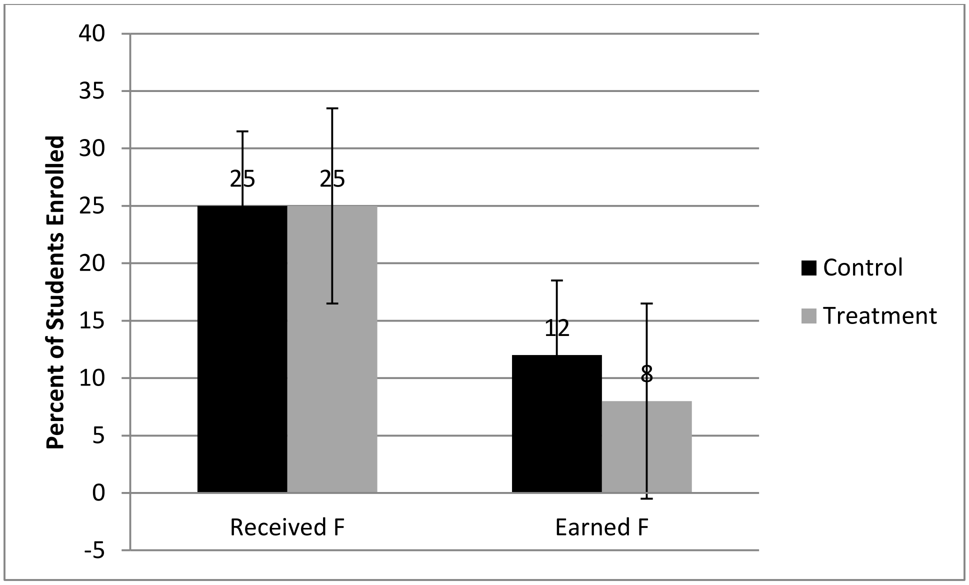

Figure 5.9 Comparison of students receiving a failing grade versus those earning a failing grade. Students that completed the course and final examination were 1.5 times less likely to fail if they were enrolled in the treatment group.

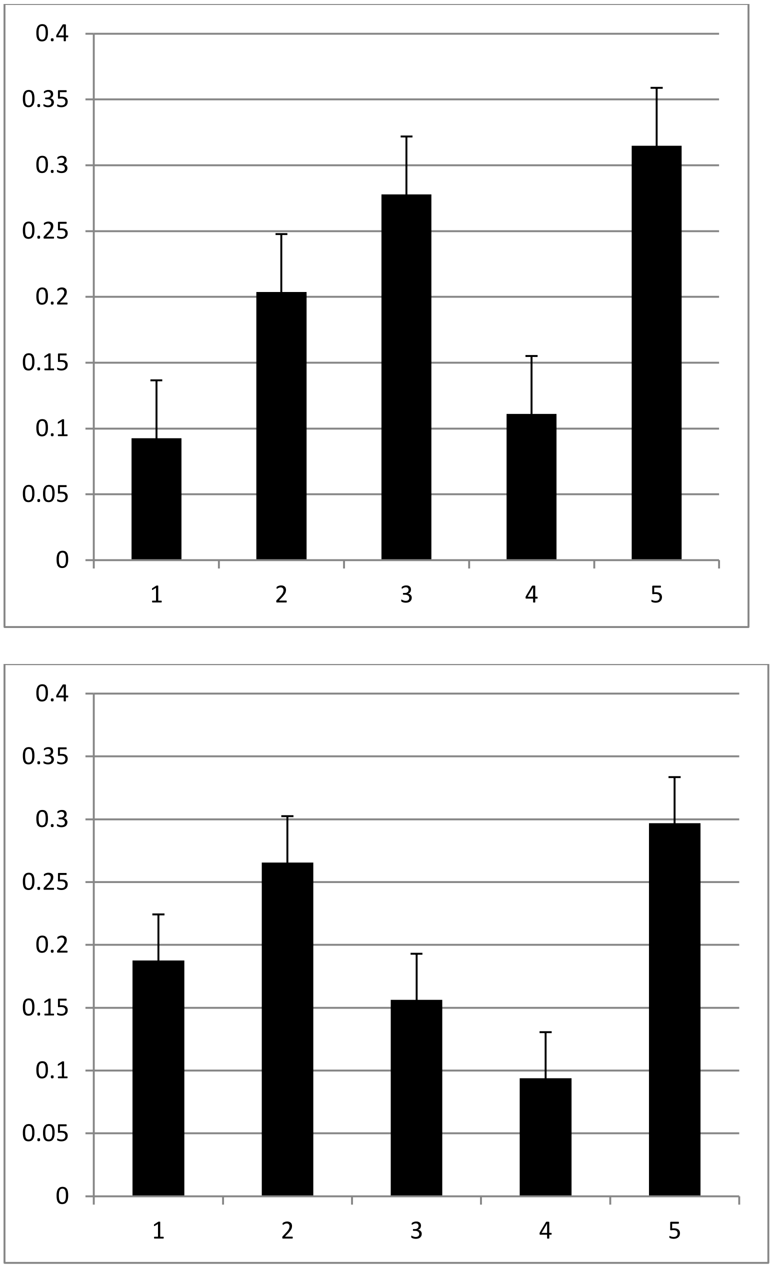

Figure 5.10 Final grade distribution (l to r = A – F) of students enrolled in the control (top) or treatment (bottom) groups during the present study. In the control, 57% of students met the hypothetical "C or better" standard for some institutions' programmatic degree requirements. In the treatment group, 61% of students met this standard.

Chapter 6 Reflections on a Dissertation and our Incipient Understanding of Knowledge Retention in Undergraduate Biology Students

Introduction

My intention when I began this project was to develop, implement, and evaluate alternative instructional approaches to replace traditional instruction via lecture in undergraduate biology classrooms. The purpose of this chapter is to reflect on the process I engaged in, discuss the progress we made with regard to filling an important information gap in the literature pertaining to science education, and consider the future of our research agenda in the context of the present study. Throughout Chapter 6 I use "I" and "we" very purposefully. There are actions that I, as the graduate student, took independently and I have identified those with the appropriate personal pronoun. However here, as in Chapters 2, 3, & 4, where I use the pronoun "we" I have done so for a reason; this research has been a closely collaborative experience between myself, my co-authors, and my committee.

Student Interviews

The first question that we were interested in was what our students thought about the way we were delivering instruction and what they would like to see in higher education. Students told us that they did not find the typical college classroom to be conducive to a positive learning environment (Lysne, Miller, & Bradley-Eitel, 2013). Windowless classrooms, endless Power Point presentations, and a perceived lack of applicability to students' life and careers were among the reasons for our students' discontent.

As a consequence of our conversations with students and the concomitant release of the final version of *Vision & Change* (AAAS, 2011), I reformed my instructional practice to become an active and student-centered learning environment. In addition to the new pedagogical approach, I attempted to alter the classroom itself to make it a more engaging environment in which to learn biology. For example I created slide shows with hundreds of high-definition images that would loop on the lecture hall's projection screen. Images of fossils, artists' renditions of early-life environments, representatives from major plant and animal phyla, and exceptional transitional species (depending on the lesson for the day) are just a few examples of the visual aids I used to enhance the learning environment. This was an attempt to "bring the outside in" (Lysne, Miller, & Bradley-Eitel, 2013, p. 17) as a student suggested; make the sterile white box that is typical of college and university lecture halls into something more engaging. In addition to visual aids, I experimented (with mixed success) with looping audio tracks of forest sounds, ocean waves, or thunderstorms to similarly enhance the classroom experience. It was a tremendous amount of work in addition to developing new lesson plans as well as "normal" preparation for classroom instruction! The logistical challenges of the transformation are exactly one of the barriers cited by researchers preventing broader adoption of active and student-centered classrooms (Hickcox, 2002; Smith et al., 2005; Allen & Tanner, 2009). Though not all of my interventions have persisted over the intervening semesters, it was important to experiment with alternative approaches and engage in what is termed scientific teaching (Handelsman, Miller, & Pfund, 2007); tweaking our instruction, evaluating the outcomes, and making modifications, the very process of science we engage in as professional biologists.

Literature Review

The next question that we addressed was: "What does the literature suggest we should be doing in undergraduate science classrooms?" Fortunately there is a relatively large body of information on science education in the form of original research. The recommendations are derived from both qualitative and quantitative perspectives, reviews of research, and commentaries on every conceivable aspect of science instruction. Importantly there were several very good recent texts and reports to guide our review (Handelsman, Miller, & Pfund, 2007; Allen & Turner, 2009; AAAS, 2011) that we supplemented with primary literature (Freeman et al., 2014) to derive a framework for undergraduate science instruction in Idaho (Lysne & Miller, 2014).

Our review followed two lines of inquiry including research on student learning and research on teaching. In the context of student learning we described a collaborative learning community during assembly (i.e. lecture) and a cognitive apprenticeship during the laboratory component of instruction. The assembly would be active, engaging, and student-centered and would follow the recommendations contained in *Vision & Change* (AAAS, 2011) for undergraduate biology instruction. Instructional interventions such as those described by Lysne and Miller (2015) are expected to create such learning communities. In lab, a cognitive apprenticeship engages students in process-of-science skill building activities (Wilke & Straits, 2005). Rather than formalized and academic laboratory activities (Kirschner & Meester, 1988), process-of-science labs engage in scenarios that model professional practice and this has been demonstrated to result in greater achievement of student learning outcomes (Hofstein, 2004; Sawyer, 2006). We concluded that all instruction should facilitate collaboration and community-building via in-class and out-of-class, informal and formal, individual and social activities and experiences.

B-testing the Model

Following our initial research, and what might be called an "information gathering phase," we developed a framework that attempted to incorporate as many insights and interventions as possible within curricular and logistical constraints and necessities. It should be discussed, however, that the development of the framework was more like an evolution of ideas and praxis rather than a big-bang, or one-time event, where the final framework emerged in an instant. For example, in Chapter 5 we describe an active instructional approach that applies fundamental tenets of the *Vision & Change* (AAAS, 2011) framework for undergraduate biology instruction and this is an entirely accurate characterization of our work. But the genesis of the approach was not the singular result of synthesizing the information in the AAAS report. Rather the approach was a response to our students' needs (Lysne, Miller, & Bradley-Eitel, 2013), our review of the literature (Lysne & Miller, 2014), and our classroom experiences as we implemented changes in curriculum, experimented with active instruction, and began to develop collaborative learning communities. Beta testing in software development is the second phase of product development where the targeted population of individuals is first allowed to experience the product (i.e. in our case, the instructional intervention). Chapter 5 describes such a phase allowing investigation of student learning outcomes and validation of the treatment group model for future use in addressing our primary research question.

Controlled Classroom Study

The final phase of our research, which was suggested by us in Chapter 4, was to implement the framework we had developed and evaluate it in the context of one or more student learning outcomes student learning outcomes. We identified two student learning outcomes as independent variables (G, $\acute{K}_r$) to compare across instruction approaches; a traditional, exposition-style lecture and an active, student-centered approach (Lysne & Miller, 2014). We developed a randomized and replicated experimental design to address our questions regarding G and $\acute{K}_r$ (see Chapter 5 for definitions). Because this was research on real students taking classes for credit we did not have random selection of individuals, only random assignment to group. However, our research design is experimental, rather than quasi-experimental, due to possessing one or more groups for comparison and our random assignment of sections to either the treatment or control groups (Privitera, 2012; Trochim & Donnelly, 2008).

Our design possessed internal and external validity. Internal validity is degree to which our inferences truthfully address the question asked and external validity is the degree to which our results can be applied to other similar situations (Trochim & Donnelly, 2008). Our research possesses internal validity because of the robustness of our design. We randomly assigned classroom sections to either the treatment or control group. We administered a placebo exam and instrument to students during the pre-testing period and found no differences in post-test scores as a function of having completed the instrument (Chapter 5) thus demonstrating that testing-threat did not influence our results. History, maturation, and mortality threats (Trochim & Donnelly, 2008) are all minimized by our use of students matriculating from Biology 1 to Biology 2. Because our sampling frame was students transitioning immediately from the first course in the sequence to the next, we minimize (but do not eliminate) threats posed by historical events outside of instruction, threats associated with the students themselves maturing and their worldview/thought processes maturing, or threats associated with students dropping-out or failing to take the next course. Our research also possesses external validity because of our experimental design. A situation similar to what we describe in Chapter 5 might be any population of freshman and sophomore students in American public colleges or universities studying introductory biology. Because we used a control and treatment groups for comparison and randomized assignment to either group, we build a case for our inferences being valid at other places and times; a very important statistical assumption and one that we strove *a priori* to achieve via experimental design. However, an important threat to external validity is mortality (i.e. the drop-out of students during the investigation) and while we may have minimized the mortality threat, drop-out was extensive; only 22% of students that completed the pre-test nine months earlier completed the second post-test. All of these threats exist and one cannot eliminate them in the human condition or from social science research. However, specifically because of our design we have diligently minimized these threats and increased the robustness of our inferences.

Going Forward

We set out to begin filling an important information gap in our understanding of alternative instructional approaches and their influence on long-term content knowledge retention. Ricker and Cowan (2014) suggested that memory retention over time is the fundamental question that researchers should be asking but in undergraduate science instruction generally, and biology instruction specifically, we have just begun to address this question. Our research provides a starting point for future work on the retention of basic science content by undergraduate students.

In addition to beginning to fill this information gap, we made real progress in reforming undergraduate biology instruction in Idaho. My own classroom practice has changed dramatically over the past four years and several colleagues have adopted the cartwheel model (Lysne & Miller, 2015), or components of it, for their classrooms. The cartwheel model engages students better and results in improved student learning outcomes for several important metrics (e.g. earned-fs, exam scores, “C or better” standard). Further, our work is being actively disseminated to our peers in Idaho via workshops, speaking invitations, professional symposia, and publications. Thus the impact of our research has been rapid and substantial and will hopefully be long-lived and transformational.

Additional research that might build on our own could be a comparison of instructional approaches including the cartwheel, case studies, POGIL, and others and compare them quantitatively via the metrics used in Chapter 5; *G* and $\acute{K}_r$. Each of these instructional models is considered an active approach and research has demonstrated that these approaches result in increased student achievement. However, research should compare these approaches against each other to determine which design, or combinations of designs, results in the greatest achievement.

Finally researchers should investigate, and I am personally interested in, alternative learning environments such as specifically-active classroom spaces, technology-enhanced classrooms, social learning environments, outdoor spaces and learning environments, and place-based instruction such as that delivered at the University of Idaho's McCall Outdoor Science School. –All of these learning environments should be considered in terms of multiple administrative, faculty, and student learning outcomes and begin with estimations of G and $\acute{K}_r$ as we've done. While the work presented here provides an important contribution to the body of science education research, we investigated only two student learning outcomes in a single learning environment and created more questions than we answered; clearly much work remains.

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APPENDIX A INSTITUTIONAL REVIEW BOARD APPROVAL LETTERS

College of Western Idaho Institutional Review Board Approval Letter

April 23, 2014

Dear Steve:

Thank you for submitting your IRB review application for your research, "Evaluating Long-term Retention of Knowledge-Gains by Undergraduate Biology Students."

In reviewing your application, the committee has determined that your study qualifies for "exempt" status.

All the best,

Regards,

Dr. Mary E. Rohlfing

Assistant Dean, School of Social Sciences and Public Affairs
Mailing address:
College of Western Idaho
MS 5000
PO Box 3010
Nampa, ID 83653

cc: Melissa Bechaver

University of Idaho Institutional Review Board Approval Letter

University *of* Idaho
Office of Research Assurances
Institutional Review Board
875 Perimeter Drive, MS 3010
Moscow ID 83844-3010
Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

To:	Brant Miller
From:	Traci Craig, Ph.D., Chair, University of Idaho Institutional Review Board University Research Office Moscow, ID 83844-3010
Date:	8/7/2014 2:10:44 PM
Title:	Evaluating the long-term retention of knowledge gains by undergraduate biology students.
Project:	14-126
Certified:	Certified as exempt under category 1 at 45 CFR 46.101(b)(1).

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the above-named research project has been certified as exempt under category 1 at 45 CFR 46.101(b)(1). This study may be conducted according to the protocol described in the Application without further review by the IRB. As specific instruments are developed, modify the protocol and upload the instruments in the portal. Every effort should be made to ensure that the project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice. It is important to note that certification of exemption is NOT approval by the IRB. Do not include the statement that the UI IRB has reviewed and approved the study for human subject participation. Remove all statements of IRB Approval and IRB contact information from study materials that will be disseminated to participants. Instead please indicate, 'The University of Idaho Institutional Review Board has Certified this project as Exempt.'

Certification of exemption is not to be construed as authorization to recruit participants or conduct research in schools or other institutions, including on Native Reserved lands or within Native Institutions, which have their own policies that require approvals before Human Subjects Research Projects can begin. This authorization must be obtained from the appropriate Tribal Government (or equivalent) and/or Institutional Administration. This may include independent review by a tribal or institutional IRB or equivalent. It is the investigator's responsibility to obtain all such necessary approvals and provide copies of these approvals to ORA, in order to allow the IRB to maintain current records. As Principal Investigator, you are responsible for ensuring compliance with all applicable FERPA regulations, University of Idaho policies, state and federal regulations. This certification is valid only for the study protocol as it was submitted to the ORA. Studies certified as Exempt are not subject to continuing review (this Certification does not expire). If any changes are made to the study protocol, you must submit the changes to the ORA for determination that the study remains Exempt before implementing the changes. Should there be significant changes in the protocol for this project, it will be necessary for you to submit an amendment to this protocol for review by the Committee using the Portal. If you have any additional questions about this process, please contact me through the portal's messaging system by clicking the Reply button at either the top or bottom of this message.

Traci Craig, Ph.D.

Appendix B Permissions to Re-print in Dissertation

Permission Letter #1 (Chapters 2 & 4)

From: Caroline Barnes [mailto:cbarnes@nsta.org]
Sent: Wednesday, April 29, 2015 6:46 AM
To: Steve Lysne
Subject: RE: Permission to Reprint

We do allow authors to reprint articles as part of their dissertation. Would you be using the formatted, printed version for the published article? If so, I can provide a PDF with the NSTA copyright line. Regarding the accepted article that is not yet in print, as long as you identify it that way, it is OK to use as well.

Caroline

From: Steve Lysne [mailto:stevelysne@cwidaho.cc]
Sent: Friday, April 24, 2015 12:19 PM
To: Caroline Barnes
Cc: Steve Lysne
Subject: RE: Permission to Reprint

Dear Dr. Barnes,

I apologize for the second correspondence… I also request permission to reprint the manuscript presently accepted for publication but not yet in print [2014-Jul-2YC-JCST-0020].

Sincerely,

Steve

From: Steve Lysne
Sent: Thursday, April 23, 2015 10:21 PM
To: Caroline Barnes
Cc: Steve Lysne
Subject: Permission to Reprint

Dear Dr. Barnes,

I'm nearing the end of my doctoral program at the University of Idaho and I am requesting permission to reprint an article I published in the *Journal* [EXPLORING

STUDENT ENGAGEMENT IN AN UNDERGRADUATE BIOLOGY COURSE, Vol 43(2)] as a chapter in my dissertation. At UI we have a dissertation option whereby you can present articles published or under consideration as opposed to the five or six chapter model.

If the *Journal* will grant this request I would need from you a letter of authorization to reprint. Thank you for your consideration and I look forward to our future collaborations.

My very best regards,

Steve

Steven J. Lysne
Asst. Prof. of Biology
Dept. of Life Sciences
College of Western Idaho
5500 E. Opportunity Dr.
Nampa, ID 83687
208.562.3360
stevelysne@cwidaho.cc

Permission Letter #2 (Chapter 3)

From: Gene Stuffle
Sent: Saturday, May 9, 2015 9:29 AM
To: Steve Lysne
Cc: Gene Stuffle; Jennifer Chase
Subject: Permission to Reprint

Steve:

We don't have a formal procedure but, since it's your work, you may reprint it as you see fit. Congratulations on "nearing the end"!

Gene

--

R. E. "Gene" Stuffle, Ph.D., M.S.B.A., P.E.
Professor and Chair [Gene.Stuffle@isu.edu]
Department of Electrical Engineering

Idaho State University
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Executive Director & Historian, Idaho Academy of Science and Engineering
[ED@Idaho.Academy]

(208) 282-3950 [office]
(208) 317-1477 [cell]
Email works best!

From: Steve Lysne
Sent: Friday, May 8, 2015 9:07 PM
To: Gene Stuffle
Subject: Permission to Reprint

Hello Gene,

I'm writing to follow up on Jennifer's question to you regarding permission to reprint an article I published in our journal. I'm nearing the end of my doctoral program and I'd like to include the article in my dissertation but I require the Academy's permission.

Jennifer may not have had this question previously and we were both uncertain of a process for permission granting. I've received permissions from two other journals and they both just wrote emails expressing permission.

If there is a process for permissions, will you please share that with Jennifer and I. If there is not, will you, as Executive Director, grant Jennifer, as editor of the *Journal*, authority to grant permissions.

Thank you Gene, have a good weekend.

Steve

From: Steve Lysne
Sent: Thursday, April 23, 2015 9:54 PM
To: Jennifer Chase
Subject: Permission to Reprint

Hello Jennifer,

I'm nearing the end of my doctoral program and I would like permission to re-print in my dissertation the article I published along with my major professor in the June 2014 (v50) issue of the *Journal*. At the University of Idaho we have a dissertation option whereby you can present articles published or under consideration as opposed to the five or six chapter model.

If the Academy will grant this request I would need a letter of authorization to reprint. Thanks so much Jennifer!

My best,

Steve

Steven J. Lysne
Asst. Prof. of Biology
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APPENDIX C ADDITIONAL CHAPTER 5 METHODS

This appendix provides a detailed description of both the treatment and control curriculum models that were used in Chapter 5, A COMPARISON OF LONG-TERM KNOWLEDGE RETENTION BETWEEN TWO TEACHING APPROACHES IN AN UNDERGRADUATE BIOLOGY COURSE. As with Chapters 2, 3, and 4, Chapter 5 is intended for publication and I endeavored to write a submission-ready manuscript within common constraints for published research (e.g. 4,000 words). Table 5.1 in Chapter 5 compares the treatment and control in terms of general course structure but I have provided here the curricular framework for each group as delivered during the fall of the 2014. Included are descriptions of the content covered, how each group will be taught, the assignments to be completed by students, and tentative dates (i.e. academic weeks) of assessments. The purpose of this detailed curriculum plan is to support an openness in the research process, openness to critique and improvement, and to allow others to adopt, modify, and/or validate the research model.

Instructional Setting

In the *Methods* section of Chapter 5 I discuss the study area and sampling frame for this research a mostly administrative context; “who is CWI, what is their study body like” and *et cetera*. Here I describe in greater detail the academic context of the classrooms involved in the study.

Biology is the largest declared major in the School of Science, Technology, Engineering, and Math at CWI and the second largest declared major in the college. Almost 1,400 students are enrolled in one of CWI’s four programs in biology and to graduate they must complete the year-long sequence of introductory biology for majors: Biology 1 and Biology 2. Our intention was to solicit participation from students in Biology 1 knowing that we would have a reasonably large sample size and that the same students may return to CWI the following spring for Biology 2. In the fall of 2014, CWI offered five face-to-face sections of Biology 1 to students; three were taught by myself, one by a colleague that participated in the study, and one by a colleague that did not. My committee members debated the merits of I teaching all of the sections in the study or only one or some other arrangement. It was suggested that I should not teach all of the sections in the study and that other faculty members be asked to participate. However the logistics of scheduling classes at CWI took ultimate precedence and in the end, only one other faculty member was able to teach a section under investigation. Four sections of Biology 1 were used; three taught by myself and one was taught by Dr. Andrew Jensen, Assistant Professor of Biology. I used a random number generator in Microsoft Excel to assign sections of Biology 1 to either the treatment (active) or control (lecture) teaching approaches. The two sections assigned to the treatment group were BIOL 201001 taught by Dr. Jensen on Monday and Wednesday at 2:30pm and BIOL 201002 taught by me on Tuesday and Thursday at 11:30am. Both sections assigned to the control group were taught by me; BIOL 201004 on Monday and Wednesday at 8:30am and BIOL 201007 on Saturday at 10:00am.

Teaching Approach

Each learning module consisted of two or three chapters of content from Reece et al. (2011), a popular textbook for biology majors. Each learning module covered five 75 minute class periods and 2 ½ weeks of class time. Both the treatment and control sections of Biology 1 used CWI's learning management system for the course (Blackboard Learn) to administer quizzes or low-stakes assessments. In addition to quizzes, the treatment group used the Journal application in Blackboard Learn to reflect on each learning module regarding their prior content knowledge, what was new or interesting to them, and how this information pertained to their lives or career paths.

Guided question-and-answer sessions were the principle intervention that differentiated the treatment group from the control group. Students are provided a set of questions to answer before coming to class and then during class students are called on to share their responses to the questions. The questions were written by me, covered the necessary disciplinary content, and followed the characteristics of and inquiry-based approach (NRC, 2000). For example, questions were scientifically oriented, they were based on evidence, students were asked to provide explanations to the questions in their own words, and they were asked to justify these explanations to the class and the instructor.

The activities used in each module were designed to support the content covered in the assigned readings and guided discussions. I have used numerous active learning exercises in the re-branding of my instructional approach; just a sample of active-learning exercises that I've used were provided in Chapter 4.

The control group covered the same 16 chapters as the treatment group. However information was presented as lecture via Power Point presentations with expanded explanations by the instructor and clarifying or procedural diagrams on the whiteboard. Detailed exposition was interspersed with examples and contemporary issues pertaining to the course content. Animations and videos from commercial sources were used to conceptualize difficult cellular or systematic processes. Student questions were accepted and expanded explanations provided but the course could not be described as "discussion-based." Table C1 below lists the curriculum included in both the treatment and control models of the current study. The curriculum used is consistent with the published course description (CWI, 2014) and met program, department, and institutional requirements for degree-seeking students.

Table C.1 Alignment of curriculum included in both the treatment (Active) and control (Lecture) groups during the present study.

	Treatment (Active) Model	Control (Lecture) Model
Week 1	Chapter 1	Chapter 1 – Introduction & themes in biology
Week 2	Chapters 1	Chapter 2 – The chemical context of life
Week 3	Chapters 2, 3, 4	Chapter 3 – The chemistry of carbon
Week 4	Chapters 2, 3, 4	Chapter 4 – The chemistry of water
Week 5	Chapters 2, 3, 4	Chapter 5 – Large biological molecules
Week 6	Chapters 5, 6, 7	Chapter 6 – Cells and the basic unit of life
Week 7	Chapters 5, 6, 7	Chapter 7 – The working cell
Week 8	Chapters 5, 6, 7	Chapter 8 – An introduction to metabolism
Week 9	Chapters 8, 9, 10	Chapter 9 – Energy transformations in cells
Week 10	Chapters 8, 9, 10	Chapter 10 – Photosynthesis
Week 11	Chapters 14, 15, 16	Chapter 14 – Mendel and the idea of the gene
Week 12	Chapters 14, 15, 16	Chapter 15 – The structure and function of DNA
Week 13	Chapters 14, 15, 16	Chapter 16 – DNA replication
Week 14	Chapters 17, 18, 20	Chapter 17 – Protein synthesis
Week 15	Chapters 17, 18, 20	Chapter 18 – Control of gene expression
Week 16	Chapters 17, 18, 20	Chapter 20 - Biotechnology

Appendix D Testing Instruments

Pre-Test Directions and Researcher Statement to Students

Directions: Please administer during the first week of class, Fall Term, 2014. Please read the “Researcher Statement” below to the class before administering. There are two copies of the pre-test, a research instrument and a placebo. I have collated these exams so that every other one is the instrument. Please ask students to take the copy on top and pass the exams along. After completing the exam (which should take no more than 20 minutes), please collect both hard copy exams. Students may indicate their answers directly on the exam copy, I will transfer to an electronic database. If you need additional copies, please let me know. THANK YOU!

Researcher Statement: “Hello. You are being asked to participate in a study investigating science education at community colleges. Your participation is optional but would be very greatly appreciated. This pre-test will have absolutely no impact on your course grade and your responses will be kept confidential. Your participation will help us understand students’ basic science knowledge and will help us develop quality science instruction at the College of Western Idaho. Please read the directions on the pre-test, print your name on the top, and sign on the bottom. Thank you very, very much.”

Pre-Test Instrument and Consent Form

Following is the test instrument that was presented to students on the first day of the fall 2014 academic term. It contains a statement of consent and required a student’s signature to authorize use in the research. There are 18 questions that were carefully drafted to address key concepts in CWI’s student learning outcomes for Biology 1 and also in the AAAS Vision & Change framework. For each question below, there is listed the correct response, the question’s difficulty level (on a modified Bloom’s Taxonomy), and the Vision & Change Core Concept (VCCC) that the question addresses.

“Statement of Consent: I ________________________________ give my consent to have my (Please Print)

responses included in the research study described below.

1. The purpose of the study is to investigate student learning in the context of a community college science program. Participation will in no way affect your grade. But please do try to answer the questions because it will help me understand aspects of science education at CWI.
2. Nothing will be asked of you aside from this pre-test and you're welcome to opt out.
3. The risks associated with participation in this project are minimal to non-existent.
4. The benefits of your participation include a better understanding of student's content knowledge when entering a science program, suggesting new approaches or tools for science education faculty to use in the classroom, a meaningful engagement with scholarly research, and the satisfaction of contributing to the advancement of knowledge.
5. If at any time you would like to discontinue the survey, you are free to do so without question.
6. Your confidentiality will be strictly protected. Any analysis, distribution, or publication of information obtained from your participation will not be linked to you in any way. Your responses to the questions in the pre-test will be known only by me and only until the data is entered into an electronic database. After that, each set of responses will be identified by a number and impossible to link back to any particular individual. The information learned is important and will be used to guide future instruction at the College of Western Idaho. Thanks for helping!

7. If you have additional questions regarding this study, please contact: stevelysne@cwidaho.cc

8. Principle Investigator
Steven Lysne
University of Idaho
Department of Curriculum & Instruction
University of Idaho
Moscow, Idaho 84844

9. Faculty Sponsor
Brant G. Miller
University of Idaho
Department of Curriculum & Instruction
Moscow, Idaho 84844

I have reviewed this consent form and understand and agree to participate freely. I reserve the right to withhold my responses from the research process and I may do so at any time by providing written notification to the principle investigator.

Participant Signature:

Date:

THANK YOU!

Directions: Please use a pencil. I have some if you do not. Choose the single response that best answer the following questions. If you're unsure of a word or concept, please feel free to ask me.

1. Once labor begins in childbirth, contractions increase in intensity and frequency until delivery. The increasing labor contractions of childbirth are an example of which type of regulation?
A) a bioinformatic system
B) positive feedback
C) negative feedback
D) feedback inhibition
E) enzymatic catalysis
Answer: B
Skill: Understanding
VCCC[5]: IV OR V

2. When the body's blood glucose level rises, the pancreas secretes insulin and, as a result, the blood glucose level declines. When the blood glucose level is low, the pancreas secretes glucagon and, as a result, the blood glucose level rises. Such regulation of the blood glucose level is the result of
A) catalytic feedback.
B) positive feedback.
C) negative feedback.
D) bioinformatic regulation.
E) protein-protein interactions.
Answer: C
Skill: Understanding
VCCC: IV OR V

3. Which of the following best demonstrates the unity among all organisms?
A) matching DNA nucleotide sequences
B) descent with modification
C) the structure and function of DNA
D) natural selection
E) emergent properties
Answer: C
Skill: Synthesis
VCCC: IV

[5] *Vision and Change* Core Concept

4. There are 20 different amino acids. What makes one amino acid different from another?
A) different side chains (R groups) attached to a carboxyl carbon
B) different side chains (R groups) attached to the amino groups
C) different side chains (R groups) attached to the middle carbon
D) different structural and optical isomers
E) different asymmetric carbons
Answer: C
Skill: Knowledge
VCCC: IV

5. If cells are grown in a medium containing radioactive ^{32}P-labeled phosphate, which of these molecules will be labeled?
A) phospholipids
B) nucleic acids
C) proteins
D) amylose
E) both phospholipids and nucleic acids
Answer: E
Skill: Application/Synthesis
VCCC: IV

6. Large numbers of ribosomes are present in cells that specialize in producing which of the following molecules?
A) lipids
B) glycogen
C) proteins
D) cellulose
E) nucleic acids
Answer: C
Skill: Knowledge/Understanding
VCCC: IV

7. You are a cell biologist for the state of Idaho looking at possible causes of a water-borne illness in the Treasure Valley. You've identified a suspect organism that has the following molecules and structures: enzymes, DNA, ribosomes, plasma membrane, and mitochondria. You determine that this cell could be from
A) a bacterium.
B) an animal, but not a plant.
C) nearly any eukaryotic organism.
D) any multicellular organism, like a plant or an animal.
E) any kind of organism.
Answer: C
Skill: Application
VCCC: IV

8. Why is glycolysis considered to be one of the first metabolic pathways to have evolved?
A) It produces much less ATP than does oxidative phosphorylation.
B) It does not involve organelles or specialized structures, does not require oxygen, and is present in most organisms.
C) It is found in prokaryotic cells but not in eukaryotic cells.
D) It relies on chemiosmosis, which is a metabolic mechanism present only in the first cells' prokaryotic cells.
E) It requires the presence of membrane-enclosed cell organelles found only in eukaryotic cells.
Answer: B
Skill: Synthesis
VCCC: I OR II

9. If a photosynthesizing green algae is provided with CO_2 containing the oxygen isotope ^{18}O, later analysis will show that all but one of the following compounds produced by the algae contain the ^{18}O label. Which compound is it?
A) G3P.
B) fructose.
C) glucose.
D) RuBP.
E) O_2.
Answer: E
Skill: Synthesis
VCCC: II

10. Which of the following statements best describes the relationship between photosynthesis and cellular respiration?
A) Respiration runs the biochemical pathways of photosynthesis in reverse.
B) Photosynthesis stores energy in complex organic molecules, whereas respiration releases it.
C) Photosynthesis occurs only in plants and respiration occurs only in animals.
D) ATP molecules are produced in photosynthesis and used up in respiration.
E) Respiration is anabolic and photosynthesis is catabolic.
Answer: B
Skill: Understanding
VCCC: II

11. The frequency of heterozygosity for the sickle-cell anemia allele in tropical regions is unusually high, presumably because this reduces the frequency of malaria (which can be fatal). Such a relationship is related to which of the following?
A) Mendel's law of independent assortment
B) Mendel's law of segregation
C) Darwin's explanation of natural selection
D) Darwin's observations of competition
E) the malarial parasite changing the allele
Answer: C

12. Red-green color blindness is a sex-linked recessive trait in humans. Two people with normal color vision have a color-blind son. What are the genotypes of the parents?
Let: C = allele for normal color vision and c = allele for colorblindness

A) $X^c X^c$ and X^CY
B) X^cX^c and X^cY
C) X^CX^C and X^cY
D) X^CX^C and X^CY
E) X^CX^c and X^CY
Answer: E
Skill: Application
VCCC: III

13. IF: Telomeres protect the information at the end of linear chromosomes AND: The DNA of telomeres has been found to be *highly conserved* throughout the evolution of eukaryotes THEN: What does this most probably reflect?
A) the inactivity of this DNA
B) the low frequency of mutations occurring in this DNA
C) that new evolution of telomeres continues
D) that mutations in telomeres are relatively advantageous
E) that the critical function of telomeres must be maintained
Answer: E
Skill: Synthesis
VCCC: I OR III

14. Which of the following regarding DNA replication and DNA transcription is false?
A) DNA replication and DNA transcription use slightly different nitrogenous bases.
B) DNA replication results in a double-stranded molecule while DNA transcription results in a single-stranded molecule.
C) DNA replication and DNA transcription use slightly different polymerases.
D) DNA replication and DNA transcription occur in different locations in the cell.
E) DNA replication and DNA transcription have different regulatory mechanisms.
Answer: D
Skill: Knowledge
VCCC: III

15. Which of the following provides some evidence that RNA probably evolved before DNA?
A) RNA polymerase uses DNA as a template.
B) RNA polymerase makes a single-stranded molecule.
C) RNA polymerase does not require localized unwinding of the DNA.
D) DNA polymerase uses a primer, usually made of RNA.
E) DNA polymerase has proofreading function.
Answer: D
Skill: Synthesis
VCCC: I

16. GIVEN: A part of the promoter region of a gene, called the TATA box, has been *highly conserved* in the course of evolution. Which of the following might this illustrate?
A) The sequence evolves very rapidly.
B) The sequence does not mutate.
C) Any mutation in the sequence is selected against.
D) The sequence is found in many but not all promoters.
E) The sequence is transcribed at the start of every gene.
Answer: C
Skill: Understanding
VCCC: I OR III

17. A mutation that inactivates the regulatory gene of a repressible operon in an *E. coli* cell would result in
A) continuous transcription of the gene.
B) complete inhibition of transcription.
C) irreversible binding of the repressor to the operator.
D) inactivation of RNA polymerase by alteration of its active site.
E) continuous translation of the mRNA because of alteration of its structure.
Answer: A
Skill: Knowledge/Understanding
VCCC: III

18. What would occur if the repressor of an inducible operon were mutated so it could not bind the operator?
A) irreversible binding of the repressor to the promoter
B) reduced transcription of the operon's genes
C) buildup of a substrate for the pathway controlled by the operon
D) continuous transcription of the operon's genes
E) overproduction of catabolite activator protein (CAP)
Answer: D
Skill: Knowledge/Understanding
VCCC: III

Pre-Test Placebo and Consent Form

Following is the placebo instrument that was presented to students on the first day of the fall 2014 academic term. It contains a statement of consent and required a student's signature to authorize use in the research. There are 18 questions that were selected from publisher-provided test banks and unmodified for this research instrument. Below each question is the correct response, the question's difficulty level (on a modified Bloom's Taxonomy), and the Vision & Change Core Concept (VCCC) that the question addresses.

"Statement of Consent: I ________________________________ give my consent to have my responses

(Please Print)

included in the research study described below.

1. The purpose of the study is to investigate student learning in the context of a community college science program. Participation will in no way affect your grade. But please do try to answer the questions because it will help me understand aspects of science education at CWI.

2. Nothing will be asked of you aside from this pre-test and you're welcome to opt out.

3. The risks associated with participation in this project are minimal to non-existent.

4. The benefits of your participation include a better understanding of student's content knowledge when entering a science program, suggesting new approaches or tools for science education faculty to use in the classroom, a meaningful engagement with scholarly research, and the satisfaction of contributing to the advancement of knowledge.

5. If at any time you would like to discontinue the survey, you are free to do so without question.

6. Your confidentiality will be strictly protected. Any analysis, distribution, or publication of information obtained from your participation will not be linked to you in any way. Your responses to the questions in the pre-test will be known only by me and only until the data is entered into an electronic database. After that, each set of responses will be identified by a number and impossible to link back to any particular individual. The information learned is important and will be used to guide future instruction at the College of Western Idaho. Thanks for helping. Steve

7. If you have additional questions regarding this study, please contact: stevelysne@cwidaho.cc

8. Principle Investigator
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[6] Primary address: College of Western Idaho, Department of Life Sciences, PO Box 3010, Nampa, ID 83653

9. Faculty Sponsor
Brant G. Miller
University of Idaho
Department of Curriculum & Instruction
Moscow, Idaho 84844

I have reviewed this consent form and understand and agree to participate freely. I reserve the right to withhold my responses from the research process and I may do so at any time by providing written notification to the principle investigator.

Participant Signature:

Date:

THANK YOU!

Directions: Please use a pencil. I have some if you do not. Choose the single response that best answer the following questions. If you're unsure of a word or concept, please feel free to ask me.

1) A localized group of organisms that belong to the same species is called a
A) biosystem.
B) community.
C) population.
D) ecosystem.
E) family.
Answer: C
Topic: Concept 1.1
Skill: Knowledge/Comprehension

2) About 25 of the 92 natural elements are known to be essential to life. Which four of these 25 elements make up approximately 96% of living matter?
A) carbon, sodium, hydrogen, nitrogen
B) carbon, oxygen, phosphorus, hydrogen
C) oxygen, hydrogen, calcium, nitrogen
D) carbon, hydrogen, nitrogen, oxygen
E) carbon, oxygen, nitrogen, calcium
Answer: D
Topic: Concept 2.1
Skill: Knowledge/Comprehension

3) The main source of energy for producers in an ecosystem is
A) light energy.
B) kinetic energy.
C) thermal energy.
D) chemical energy.
E) ATP.
Answer: A
Topic: Concept 1.1
Skill: Knowledge/Comprehension

4) Which of the following types of cells utilize deoxyribonucleic acid (DNA) as their genetic material but do not have their DNA encased within a nuclear envelope?
A) animal
B) plant
C) archaea
D) fungi
E) protists
Answer: C
Topic: Concept 1.1
Skill: Application/Analysis

5) Why is each element unique and different from other elements in chemical properties?
A) Each element has a unique atomic mass.
B) Each element has a unique atomic weight.
C) Each element has a unique number of protons in its nucleus.
D) Each element has a unique number of neutrons in its nucleus.
E) Each element has different radioactive properties.
Answer: C
Topic: Concept 2.2
Skill: Knowledge/Comprehension

6) One difference between carbon-12 ($^{12}_{6}C$) and carbon-14 ($^{14}_{6}C$) is that carbon-14 has
A) two more protons than carbon-12.
B) two more electrons than carbon-12.
C) two more neutrons than carbon-12.
D) two more protons and two more neutrons than carbon-12.
E) two more electrons and two more neutrons than carbon-12.
Answer: C
Topic: Concept 2.2
Skill: Knowledge/Comprehension

7) Which branch of biology is concerned with the naming and classifying of organisms?
A) informatics
B) schematic biology
C) taxonomy
D) genomics
E) evolution
Answer: C
Topic: Concept 1.1
Skill: Knowledge/Comprehension

8) Prokaryotes are classified as belonging to two different domains. What are the domains?
A) Bacteria and Eukarya
B) Archaea and Monera
C) Eukarya and Monera
D) Bacteria and Protista
E) Bacteria and Archaea
Answer: E
Topic: Concept 1.1
Skill: Knowledge/Comprehension

9) Which of the following is (are) true of natural selection?
A) It requires genetic variation.
B) It results in descent with modification.
C) It involves differential reproductive success.
D) It results in descent with modification and involves differential reproductive success.
E) It requires genetic variation, results in descent with modification, and involves differential reproductive success.
Answer: E
Topic: Concept 1.2
Skill: Knowledge/Comprehension

10) Why is Darwin considered original in his thinking?
A) He provided examples of organisms that had evolved over time.
B) He demonstrated that evolution is continuing to occur now.
C) He described the relationship between genes and evolution.
D) He proposed the mechanism that explained how evolution takes place.
E) He observed that organisms produce large numbers of offspring.
Answer: D
Topic: Concept 1.2

11) What is the major distinguishing characteristic of fungi?
A) gaining nutrition through ingestion
B) being sedentary
C) being prokaryotic
D) absorbing dissolved nutrients
E) being decomposers of dead organisms
Answer: D
Topic: Concept 1.2
Skill: Knowledge/Comprehension

12) Atoms whose outer electron shells contain 8 electrons tend to
A) form ions in aqueous solutions.
B) form hydrogen bonds in aqueous solutions.
C) be stable and chemically nonreactive, or inert.
D) be gaseous at room temperature.
E) be both chemically inert and gaseous at room temperature.
Answer: E
Topic: Concept 2.2
Skill: Knowledge/Comprehension

13) The method of scientific inquiry that describes natural structures and processes as accurately as possible through careful observation and the analysis of data is known as
A) hypothesis-based science.
B) discovery science.
C) experimental science.
D) quantitative science.
E) qualitative science.
Answer: B
Topic: Concept 1.3
Skill: Knowledge/Comprehension

14) When applying the process of science, which of these is tested?
A) a question
B) a result
C) an observation
D) a prediction
E) a hypothesis
Answer: E
Topic: Concept 1.3
Skill: Knowledge/Comprehension

15) Which of the following best describes a model organism?
A) It is often pictured in textbooks and easy for students to imagine.
B) It lends itself to many studies that are useful to beginning students.
C) It is well studied, easy to grow, and results are widely applicable.
D) It is small, inexpensive to raise, and lives a long time.
E) It has been chosen for study by the earliest biologists.
Answer: C
Topic: Concept 1.4
Skill: Knowledge/Comprehension

16) All the organisms on your campus make up
A) an ecosystem.
B) a community.
C) a population.
D) an experimental group.
E) a taxonomic domain.
Answer: B
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension

17) Which of the following is a correct sequence of levels in life's hierarchy, proceeding downward from an individual animal?
A) brain, organ system, nerve cell, nervous tissue
B) organ system, nervous tissue, brain
C) organism, organ system, tissue, cell, organ
D) nervous system, brain, nervous tissue, nerve cell
E) organ system, tissue, molecule, cell
Answer: D
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension

18) Protists and bacteria are grouped into different domains because
A) protists eat bacteria.
B) bacteria are not made of cells.
C) protists have a membrane-bounded nucleus, which bacterial cells lack.
D) bacteria decompose protists.
E) protists are photosynthetic.
Answer: C
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension

Post-Test Instrument

Following is the test instrument that was presented to students on the final day of the fall 2014 academic term. The same 18 questions from the pre-test are embedded in this final examination.

BIOL 201 *Biochemistry to Genetics* December, 2014
Final Examination Part 2

Directions: Use a pencil. Write your name on your SCANTRON scorecard. Multiple Choice; completely fill in the bar on your scorecard corresponding to the letter of the single best answer. (50 pts)

1. Once labor begins in childbirth, contractions increase in intensity and frequency until delivery. The increasing labor contractions of childbirth are an example of which type of regulation?
A) a bioinformatic system
B) positive feedback
C) negative feedback
D) feedback inhibition
E) enzymatic catalysis
Answer: B

2. When the body's blood glucose level rises, the pancreas secretes insulin and, as a result, the blood glucose level declines. When the blood glucose level is low, the pancreas secretes glucagon and, as a result, the blood glucose level rises. Such regulation of the blood glucose level is the result of
A) catalytic feedback.
B) positive feedback.
C) negative feedback.
D) bioinformatic regulation.
E) protein-protein interactions.
Answer: C

3. Which of the following best demonstrates the unity among all organisms?
A) matching DNA nucleotide sequences
B) descent with modification
C) the structure and function of DNA
D) natural selection
E) emergent properties
Answer: C

4. A water sample from a hot thermal vent contained a single-celled organism that had a cell wall but lacked a nucleus. What is its most likely classification?
A) Eukarya
B) Archaea
C) Animalia
D) Protista
E) Fungi
Answer: B

5. Why is the theme of evolution considered to be the core theme of biology by biologists?
A) It provides a well-supported framework that makes sense out of a great deal of biological research.
B) It is recognized as the core theme of biology by organizations such as the National Science Foundation.
C) Controversy about this theory provides a basis for a great deal of experimental research.
D) Since it cannot be proven, biologists will be able to study evolutionary possibilities for many years.
E) Biologists do not subscribe to alternative models.
Answer: A

6. There are 20 different amino acids. What makes one amino acid different from another?
A) different side chains (R groups) attached to a carboxyl carbon
B) different side chains (R groups) attached to the amino groups
C) different side chains (R groups) attached to the middle carbon
D) different structural and optical isomers
E) different asymmetric carbons
Answer: C

7. Which of the following best describes the structure of the monomer unit known as nucleotides?
A) a nitrogenous base and a phosphate group
B) a nitrogenous base and a pentose sugar
C) a nitrogenous base, a phosphate group, and a pentose sugar
D) a phosphate group and an adenine or uracil
E) a pentose sugar and a purine or pyrimidine
Answer: C

8. One of the primary functions of RNA molecules is to
A) transmit genetic information to offspring.
B) serve as a copy of DNA which cannot leave the nucleus.
C) make a copy of itself, thus ensuring genetic continuity.
D) act as a pattern or blueprint to form DNA.
E) form the genes of higher organisms.
Answer: B

9. A new organism is discovered in the deserts of southern Idaho. CWI scientists determine that the polypeptide sequence of hemolymph from the new organism has 72 amino acid differences from humans, 49 differences from a lancelet, and 5 differences from an earthworm. These data suggest that the new organism
A) is more closely related to humans than to earthworms.
B) is more closely related to earthworms than to humans.
C) evolved at about the same time as earthworms, which is much earlier than lancelets and mammals.
D) is more closely related to humans than to lancelets.
E) is more closely related to earthworms than to humans and also evolved at about the same time as earthworms, which is much earlier than lancelets or mammals.
Answer: B

10. If cells are grown in a medium containing radioactive ^{32}P-labeled phosphate, which of these molecules will be labeled?
A) phospholipids
B) nucleic acids
C) proteins
D) amylose
E) both phospholipids and nucleic acids
Answer: E

Large Biological Molecules

11. *Part 1*

A. The four classes of large biological molecules include the carbohydrates, proteins, fats, and nucleic acids.

B. The four classes of large biological molecules include the carbohydrates, proteins, lipids, and nucleic acids.

C. The four classes of large biological molecules include the carbohydrates, amino acids, fats, and nucleic acids.

D. The four classes of large biological molecules include the carbohydrates, amino acids, lipids, and DNA.

Answer B

12. *Part 2*

A. The carbohydrates include sugars such as fats, waxes, phospholipids, and steroids and are the building blocks for more complex biological molecules such starch, cellulose, and chitin. The trademark of sugars is the presence of both a carbonyl and multiple hydroxyl groups. The proteins are large and complex polymers that are constructed of monomer units called amino acids. Proteins are responsible for numerous functions in cells including copying genetic information, speeding up chemical reactions, defense against foreign substances, and transmitting signals and solutes across the plasma membrane.

B. The carbohydrates include sugars such as various monosacharrides, disacharrides, and polysacharrides and are the building blocks for more complex biological molecules such starch, cellulose, and chitin. The trademark of sugars is the presence of both a methyl group and multiple amino groups. The proteins are large and complex polymers that are constructed of monomer units called polypeptides. Proteins are responsible for numerous functions in cells including copying genetic information, speeding up chemical reactions, defense against foreign substances, and transmitting signals and solutes across the plasma membrane.

C. The carbohydrates include sugars such as various monosacharrides, disacharrides, and polysacharrides and are the building blocks for more complex biological molecules such starch, cellulose, and chitin. The trademark of sugars is the presence of both a carbonyl and multiple hydroxyl groups. The proteins are large and complex polymers that are constructed of monomer units called amino acids. Proteins are responsible for numerous functions in cells including copying genetic information, speeding up chemical reactions, defense against foreign substances, and transmitting signals and solutes across the plasma membrane.

D. The carbohydrates include sugars such as various monosacharrides, disacharrides, and polysacharrides and are the building blocks for more complex biological molecules such starch, cellulose, and chitin. The trademark of sugars is the presence of both a carbonyl and multiple hydroxyl groups. The proteins are large and complex polymers that are constructed of monomer units called nucleotides. Proteins are responsible for numerous functions in cells including copying genetic information, speeding up chemical reactions, defense against foreign substances, and transmitting signals and solutes across the plasma membrane.

Answer C

13. _Part 3_

A. The lipids are large biological molecules that share a single conspicuous characteristic, they do not mix with water. There are many types of lipids including various monosacharrides, disacharrides, and polysacharrides. Nucleic acids are polymers of monomer units called nucleotides. Nucleotides are composed of a pentose sugar, a phosphate group, and one of five nitrogen-containing bases. Nucleic acids are important biological molecules because they store and transmit hereditary information in all forms of life.

B. The lipids are large biological molecules that share a single conspicuous characteristic, they do not mix with water. There are many types of lipids including fats, waxes, phospholipids, and steroids. Nucleic acids are polymers of monomer units called nucleotides. Nucleotides are composed of a pentose sugar, a phosphate group, and one of five nitrogen-containing bases. Nucleic acids are important biological molecules because they store and transmit hereditary information in all forms of life.

C. The lipids are large biological molecules that share a single conspicuous characteristic, they easily mix with water. There are many types of lipids including fats, waxes, phospholipids, and steroids. Nucleic acids are polymers of monomer units called nucleoli. Nucleoli are composed of a pentose sugar, a phosphate group, and one of five nitrogen-containing bases. Nucleic acids are important biological molecules because they store and transmit hereditary information in all forms of life.

D. The lipids are large biological molecules that share a single conspicuous characteristic, they do not mix with water. There are many types of lipids including fats, waxes, phospholipids, and steroids. Nucleic acids are polymers of monomer units made of nitrogen. These monomers are composed of a pentose sugar, a methyl group, and one of five nitrogen-containing bases. Nucleic acids are important biological molecules because they because they are easily broken down and used as energy in cells.

Answer B

14. The evolution of eukaryotic cells most likely involved
A) endosymbiosis of an aerobic bacterium in a larger host cell–the endosymbiont evolved into mitochondria.
B) anaerobic archaea taking up residence inside a larger bacterial host cell to escape toxic oxygen–the anaerobic bacterium evolved into chloroplasts.
C) an endosymbiotic fungal cell evolved into the nucleus.
D) acquisition of an endomembrane system, and subsequent evolution of mitochondria from a portion of the Golgi.
Answer: A

15. If radioactive deoxythymidine triphosphate (dTTP) is added to a culture of rapidly growing bacterial cells, where in the cell would you expect to find the greatest concentration of radioactivity?
A) nucleus
B) cytoplasm
C) endoplasmic reticulum
D) nucleoid region
E) mitochondrion
Answer: D

16. Large numbers of ribosomes are present in cells that specialize in producing which of the following molecules?
A) lipids
B) glycogen
C) proteins
D) cellulose
E) nucleic acids
Answer: C

17. IF: the chemical reactions involved in respiration are virtually identical between prokaryotic and eukaryotic cells AND: In eukaryotic cells, ATP is synthesized primarily on the inner membrane of the mitochondria. THEN: knowing what you do regarding the endosymbiont theory for the evolutionary origin of mitochondria, where is most ATP synthesis likely to occur in prokaryotic cells?
A) in the cytoplasm
B) on the inner mitochondrial membrane
C) on the endoplasmic reticulum
D) on the plasma membrane
E) on the inner nuclear envelope
Answer: D

18. You are a cell biologist for the state of Idaho looking at possible causes of a water-borne illness in the Treasure Valley. You've identified a suspect organism that has the following molecules and structures: enzymes, DNA, ribosomes, plasma membrane, and mitochondria. You determine that this cell could be from
A) a bacterium.
B) an animal, but not a plant.
C) nearly any eukaryotic organism.
D) any multicellular organism, like a plant or an animal.
E) any kind of organism.
Answer: C

19. If an enzyme in solution is saturated with substrate, the most effective way to obtain a faster yield of products is to
A) add more of the enzyme.
B) heat the solution to 90°C.
C) add more substrate.
D) add an allosteric inhibitor.
E) add a noncompetitive inhibitor.
Answer: A

20. Which of the following is true of metabolism in all organisms?
A) Metabolism depends on a constant supply of energy from food.
B) Metabolism depends on an organism's adequate hydration.
C) Metabolism uses all of an organism's resources.
D) Metabolism consists of all the energy transformation reactions in an organism.
E) Metabolism manages the increase of entropy in an organism.
Answer: D

21. Which of the following statements is true about enzyme-catalyzed reactions?
A) The reaction is faster than the same reaction in the absence of the enzyme.
B) The free energy change of the reaction is opposite from the reaction that occurs in the absence of the enzyme.
C) The reaction always goes in the direction toward chemical equilibrium.
D) Enzyme-catalyzed reactions require energy to activate the enzyme.
E) Enzyme-catalyzed reactions release more free energy than noncatalyzed reactions.
Answer: A

22. Which metabolic pathway is common to both fermentation and cellular respiration of a glucose molecule?
A) the citric acid cycle
B) the electron transport chain
C) glycolysis
D) synthesis of acetyl CoA from pyruvate
E) reduction of pyruvate to lactate
Answer: C

23. Why is glycolysis considered to be one of the first metabolic pathways to have evolved?
A) It produces much less ATP than does oxidative phosphorylation.
B) It does not involve organelles or specialized structures, does not require oxygen, and is present in most organisms.
C) It is found in prokaryotic cells but not in eukaryotic cells.
D) It relies on chemiosmosis, which is a metabolic mechanism present only in the first cells' prokaryotic cells.
E) It requires the presence of membrane-enclosed cell organelles found only in eukaryotic cells.
Answer: B

24. Which of the following statements best describes the relationship between photosynthesis and cellular respiration?
A) Respiration runs the biochemical pathways of photosynthesis in reverse.
B) Photosynthesis stores energy in complex organic molecules, whereas respiration releases it.
C) Photosynthesis occurs only in plants and respiration occurs only in animals.
D) ATP molecules are produced in photosynthesis and used up in respiration.
E) Respiration is anabolic and photosynthesis is catabolic.
Answer: B

Directions: Multiple choice/Essay. Choose the single paragraph for EACH PART that, when combined, best completes the essay.

For this essay, assume a eukaryotic animal cell in mitosis.

25. *Part 1*

A. The *cell cycle* is a concept used to describe and discuss the behavior of chromosomes and other processes within a cell. The cell cycle consists of two primary phases, the D-phase and interphase. Interphase is the period between one cell division and the next where the cell is growing larger, copying all of the sub-cellular material, and doing its normal cell functions whatever those may be. A cell will spend approximately 90% of the cell cycle in interphase.

B. The *cell cycle* is a concept used to describe and discuss the behavior of chromosomes and other processes within a cell. The cell cycle consists of two primary phases, the M-phase and interphase. Interphase is the period between one cell division and the next where the cell is growing larger, copying all of the sub-cellular material, and doing its normal cell functions whatever those may be. A cell will spend approximately 90% of the cell cycle in interphase.

C. The *cell cycle* is a concept used to describe and discuss the behavior of chromosomes and other processes within a cell. The cell cycle consists of two primary phases, the M-phase and interphase. Interphase is the period between one cell division and the next where the cell is growing larger, copying all of the sub-cellular material, and doing its normal cell functions whatever those may be. A cell will spend approximately 50% of the cell cycle in interphase.

Ans. B

26. *Part 2*

A. Interphase is separated into three shorter phases; the G_1, S, and G_2 phases. During each of these phases, the cell is making new proteins and sub-cellular organelles such as mitochondria and endoplasmic reticulum to name just a couple. However only during the S phase is the genetic material copied. The M-phase is the part of the cell cycle where the cell is actively dividing and includes four shorter phases, or stages, that are part of a continuum of cell division. A cell will spend approximately 10% of the cell cycle in M-phase.
B. Interphase is separated into three shorter phases; the G_1, C, and G_2 phases. During each of these phases, the cell is making new proteins and sub-cellular organelles such as mitochondria and endoplasmic reticulum to name just a couple. However only during the C phase is the genetic material copied. The D-phase is the part of the cell cycle where the cell is actively dividing and includes four shorter phases, or stages, that are part of a continuum of cell division. A cell will spend approximately 10% of the cell cycle in M-phase.
C. Interphase is separated into four shorter phases; the P, M, A, and T phases. During each of these phases, the cell is making new proteins and sub-cellular organelles such as mitochondria and endoplasmic reticulum to name just a couple. However only during the M phase is the genetic material made. The M-phase is the part of the cell cycle where the cell is actively dividing and includes three shorter phases, or stages, that are part of a continuum of cell division. A cell will spend approximately 50% of the cell cycle in M-phase.

Ans. A

27. *Part 3*

A. The four phases of D-phase include, in order, Prophase, Metaphase, Anaphase, and Telophase (which is generally combined with Cytokinesis). During the D-phase, the genetic material, now called chromatin and existing in triplicated sets (having been copied in the S phase of interphase), begins to condense into structures called alleles. These alleles wiggle back and forth as microtubules from the centrosome region push and pull them, eventually lining them up across an imaginary line called the anaphase plate. The alleles next are pulled apart toward separate ends of the cell (also called poles) and the cell cytoplasm begins to divide, a process called cytokinesis, ultimately giving rise to two genetically identical daughter cells.

B. The three phases of M-phase include, in order, Metaphase, Anaphase, and Prephase (which is generally combined with Cytokinesis). During the M-phase, the genetic material, now called chromalux and existing in duplicated sets (having been copied in the S phase of interphase), begins to condense into structures called chromosomes. These chromosomes wiggle back and forth as microtubules from the centrosome region push and pull them, eventually lining them up across an imaginary line called the metaphase plate. The chromosomes next are pulled apart toward separate ends of the cell (also called poles) and the cell cytoplasm begins to divide, a process called segregation, ultimately giving rise to two genetically unique daughter cells.

C. The four phases of M-phase include, in order, Prophase, Metaphase, Anaphase, and Telophase (which is generally combined with Cytokinesis). During the M-phase, the genetic material, now called chromatin and existing in duplicated sets (having been copied in the S phase of interphase), begins to condense into structures called chromosomes. These chromosomes wiggle back and forth as microtubules from the centrosome region push and pull them, eventually lining them up across an imaginary line called the metaphase plate. The chromosomes next are pulled apart toward separate ends of the cell (also called poles) and the cell cytoplasm begins to divide, a process called cytokinesis, ultimately giving rise to two genetically identical daughter cells.

Ans. C

For this essay, compare and contrast the purpose, process, and products of mitosis and meiosis.

28. *Part 1*

A. *Meiosis* and *Mitosis* are both forms of cellular division but are very different when we look at what they are for and how they work. The purpose of meiosis is for growth and repair of cells and tissues in an organism. Meiosis conserves chromosome numbers. For example, all animals begin as a single cell called a zygote that subsequently divides many times to become the millions to trillions of cells in the adult form. Meiosis is the process responsible for this growth. Similarly, meiosis is responsible for the replacement and repair of cells or tissues, for example, when cells are lost by abrasion or damaged by exposure to viruses. By contrast, the purpose of mitosis is strictly for reproduction in sexually reproducing organisms. Mitosis reduces chromosome numbers in half such that when haploid gametes are united during fertilization, the result is once again a diploid organism with a full complement of chromosomes.

B. *Mitosis* and *Meiosis* are both forms of cellular division but are very different when we look at what they are for and how they work. The purpose of mitosis is for growth and sexual reproduction. Mitosis reduces chromosome numbers. For example, all animals begin as a single cell called a zygote that subsequently divides many times to become the millions to trillions of cells in the adult form.

Mitosis is the process responsible for this growth. Similarly, mitosis is responsible for the replacement and repair of cells or tissues, for example, when cells are lost by abrasion or damaged by exposure to viruses. By contrast, the purpose of meiosis is strictly for repair of cells and tissues in organisms. Meiosis conserves chromosome numbers such that when cells and tissues are repaired, the result is an exact copy of the parent cell.

C. *Mitosis* and *Meiosis* are both forms of cellular division but are very different when we look at what they are for and how they work. The purpose of mitosis is for growth and repair of cells and tissues in an organism. Mitosis conserves chromosome numbers. For example, all animals begin as a single cell called a zygote that subsequently divides many times to become the millions to trillions of cells in the adult form. Mitosis is the process responsible for this growth. Similarly, mitosis is responsible for the replacement and repair of cells or tissues, for example, when cells are lost by abrasion or damaged by exposure to viruses. By contrast, the purpose of meiosis is strictly for reproduction in sexually reproducing organisms. Meiosis reduces chromosome numbers in half such that when haploid gametes are united during fertilization, the result is once again a diploid organism with a full complement of chromosomes.

Ans. C

29. *Part 2*

A. The process by which mitosis occurs in animals is divided into four steps, or phases, where the genetic material, now called chromatin and existing in duplicated sets, begins to condense into structures called chromosomes. These chromosome pairs, called sister chromatids, wiggle back and forth as microtubules from the centrosome region push and pull them, eventually lining them up across an imaginary line called the metaphase plate. The chromosome pairs next are pulled apart toward separate ends of the cell and the cell cytoplasm begins to divide, a process called cytokinesis. The process of meiosis, by comparison, follows a similar set of steps, or phases, but two rounds of division proceed. In the first round of division, the homologous pairs of chromosomes are separated and in the second round, the sister chromatids are separated.

B. The process by which mitosis occurs in animals is divided into three steps, or phases, where the genetic material, now called chromatin and existing in duplicated sets, begins to condense into structures called chromophores. These chromophore pairs, called sister chromatids, wiggle back and forth as microtubules from the centrosome region push and pull them, eventually lining them up across an imaginary line called the metaphase plate. The chromophore pairs next are pulled apart toward separate ends of the cell and the cell cytoplasm begins to divide, a process called glycokinesis. The process of meiosis, by comparison, follows a similar set of steps, or phases, but two rounds of division proceed. In the first round of division, the homologous pairs of chromosomes are separated and in the second round, the sister chromatids are separated.

C. The process by which mitosis occurs in animals is divided into four steps, or phases, where the genetic material, now called chromatin and existing in duplicated sets, begins to condense into structures called chromosomes. These chromosome pairs, called sister chromatids, wiggle back and forth as microtubules from the centrosome region push and pull them, eventually lining them up across an imaginary line called the metaphase plate. The chromosome pairs next are pulled apart toward separate ends of the cell and the cell cytoplasm begins to divide, a process called cytokinesis. The process of meiosis, by comparison, follows a similar set of steps, or phases, but two rounds of division proceed. In the first round of division, the sister chromatids are separated and in the second round, the homologous pairs of chromosomes are separated.

Ans. A

30. *Part 3*

A. The products of mitosis are called daughter cells, there are two of them, and they are genetically identical to the parent cell that started the process of cellular division. The products of meiosis are also called daughter cells but in this case there are four of them. They are also genetically unique due to independent assortment and crossing over; two processes that occur only in meiosis and contribute to the variation evident in the offspring of organisms.
B. The products of mitosis are called filial cells, there are two of them, and they are genetically identical to the parent cell that started the process of cellular division. The products of meiosis are also called filial cells but in this case there are three of them. They are also genetically unique due to independent assortment and crossing over; two processes that occur only in meiosis and contribute to the variation evident in the offspring of organisms.
C. The products of mitosis are called daughter cells, there are two of them, and they are genetically identical to the parent cell that started the process of cellular division. The products of meiosis are also called daughter cells but in this case there are four of them. They are also genetically unique due to segregation and random fertilization; two processes that occur only in meiosis and contribute to the variation evident in the offspring of organisms. Ans. A

31. How many unique gametes could be produced through independent assortment by an individual with the genotype *AaBbCCDdEE*?
A) 4
B) 8
C) 16
D) 32
E) 64
Answer: B

32. Why did Mendel continue some of his experiments to the F_2 or F_3 generation?
A) to obtain a larger number of offspring on which to base statistics
B) to observe whether or not a recessive trait would reappear
C) to observe whether or not the dominant trait would reappear
D) to distinguish which alleles were segregating
E) to be able to describe the frequency of recombination
Answer: B
33. A CWI scientist discovers a DNA-based test for one allele of a particular gene. This and only this allele, if homozygous, produces an effect that results in death at or about the time of birth. Of the following, which is the best use of this discovery?
A) Screen all newborns of an at-risk population.
B) Design a test for identifying heterozygous carriers of the allele.
C) Introduce a normal allele into deficient newborns.
D) Follow the segregation of the allele during meiosis.
E) Test school-age children for the disorder.
Answer: B
34. The frequency of heterozygosity for the sickle-cell anemia allele in tropical regions is unusually high, presumably because this reduces the frequency of malaria (which can be fatal). Such a relationship is related to which of the following?
A) Mendel's law of independent assortment
B) Mendel's law of segregation
C) Darwin's explanation of natural selection
D) Darwin's observations of competition
E) the malarial parasite changing the allele
Answer: C
35. Males are more often affected by sex-linked traits than females because
A) male hormones such as testosterone often alter the effects of mutations on the X chromosome.
B) female hormones such as estrogen often compensate for the effects of mutations on the X chromosome.
C) X chromosomes in males generally have more mutations than X chromosomes in females.
D) males have only one copy of the X chromosome.
E) mutations on the Y chromosome often worsen the effects of X-linked mutations.
Answer: D

36. In cats there are two alleles on the X chromosome that influence fur color. One causes black fur color, the other allele at this locus causes orange color. The heterozygote is tortoiseshell. What kinds of offspring would you expect from the cross of a black female and an orange male?
A) tortoiseshell females; tortoiseshell males
B) black females; orange males
C) orange females; orange males
D) tortoiseshell females; black males
E) orange females; black males
Answer: D

37. Red-green color blindness is a sex-linked recessive trait in humans. Two people with normal color vision have a color-blind son. What are the genotypes of the parents?
Let: C = allele for normal color vision and c = allele for colorblindness

A) $X^c X^c$ and $X^C Y$
B) $X^c X^c$ and $X^c Y$
C) $X^C X^C$ and $X^c Y$
D) $X^C X^C$ and $X^C Y$
E) $X^C X^c$ and $X^C Y$
Answer: E

38. IF: Cytosine makes up 42% of the nucleotides in a sample of DNA from an organism THEN: Approximately what percentage of the nucleotides in this sample will be thymine?
A) 8%
B) 16%
C) 31%
D) 42%
E) It cannot be determined from the information provided.
Answer: A

39. IF: Telomeres protect the information at the end of linear chromosomes AND: The DNA of telomeres has been found to be *highly conserved* throughout the evolution of eukaryotes THEN: What does this most probably reflect?
A) the inactivity of this DNA
B) the low frequency of mutations occurring in this DNA
C) that new evolution of telomeres continues
D) that mutations in telomeres are relatively advantageous
E) that the critical function of telomeres must be maintained
Answer: E

40. Which of the following regarding DNA replication and DNA transcription is false?
A) DNA replication and DNA transcription use slightly different nitrogenous bases.
B) DNA replication results in a double-stranded molecule while DNA transcription results in a single-stranded molecule.
C) DNA replication and DNA transcription use slightly different polymerases.
D) DNA replication and DNA transcription occur in different locations in the cell.
E) DNA replication and DNA transcription have different regulatory mechanisms.
Answer: D

41. Which of the following provides some evidence that RNA probably evolved before DNA?
A) RNA polymerase uses DNA as a template.
B) RNA polymerase makes a single-stranded molecule.
C) RNA polymerase does not require localized unwinding of the DNA.
D) DNA polymerase uses a primer, usually made of RNA.
E) DNA polymerase has proofreading function.
Answer: D

42. GIVEN: A part of the promoter region of a gene, called the TATA box, has been *highly conserved* in the course of evolution. Which of the following might this illustrate?
A) The sequence evolves very rapidly.
B) The sequence does not mutate.
C) Any mutation in the sequence is selected against.
D) The sequence is found in many but not all promoters.
E) The sequence is transcribed at the start of every gene.
Answer: C

43. A mutation that inactivates the regulatory gene of a repressible operon in an *E. coli* cell would result in
A) continuous transcription of the gene.
B) complete inhibition of transcription.
C) irreversible binding of the repressor to the operator.
D) inactivation of RNA polymerase by alteration of its active site.
E) continuous translation of the mRNA because of alteration of its structure.
Answer: A

44. What would occur if the repressor of an inducible operon were mutated so it could not bind the operator?
A) irreversible binding of the repressor to the promoter
B) reduced transcription of the operon's genes
C) buildup of a substrate for the pathway controlled by the operon
D) continuous transcription of the operon's genes
E) overproduction of catabolite activator protein (CAP)
Answer: D

45. If a photosynthesizing green algae is provided with CO_2 containing the oxygen isotope ^{18}O, later analysis will show that all but one of the following compounds produced by the algae contain the ^{18}O label. Which compound is it?
A) G3P.
B) fructose.
C) glucose.
D) RuBP.
E) O_2.
Answer: E

Second Post-Test Instrument

Following is the test instrument that was presented to students on the final day of the spring 2015 academic term. The same 18 questions from the pre-test are embedded in this final examination.

BIOL 202 – *Biodiversity & Evolution*
Final Examination – Part 2

Directions: Please write your name on your SCANTRON scorecard. Completely fill in the bar associated with the single best answer for each question. Use a pencil.

1. Why is glycolysis considered to be one of the first metabolic pathways to have evolved?
A) It produces much less ATP than does oxidative phosphorylation.
B) It does not involve organelles or specialized structures, does not require oxygen, and is present in most organisms.
C) It is found in prokaryotic cells but not in eukaryotic cells.
D) It relies on chemiosmosis, which is a metabolic mechanism present only in the first cells' prokaryotic cells.
E) It requires the presence of membrane-enclosed cell organelles found only in eukaryotic cells.
Answer: B
Skill:
VCCC: I OR II

2. Which statement about natural selection is *most* correct?
A) Adaptations beneficial in one habitat should generally be beneficial in all other habitats as well.
B) Different species that occupy the same habitat will adapt to that habitat by undergoing the same genetic changes.
C) Adaptations beneficial at one time should generally be beneficial during all other times as well.

D) Well-adapted individuals leave more offspring, and thus contribute more to the next generation's gene pool, than do poorly adapted individuals.
E) Natural selection is the sole means by which populations can evolve.
Answer: D
Topic:
Concept 22.2
Skill:
Synthesis/Evaluation

3. Which of the following provides some evidence that RNA probably evolved before DNA?
A) RNA polymerase uses DNA as a template.
B) RNA polymerase makes a single-stranded molecule.
C) RNA polymerase does not require localized unwinding of the DNA.
D) DNA polymerase uses a primer, usually made of RNA.
E) DNA polymerase has proofreading function.
Answer: D
Skill:
VCCC: I

4. Which statement best describes the evolution of pesticide resistance in a population of insects?
A) Individual members of the population slowly adapt to the presence of the chemical by striving to meet the new challenge.
B) All insects exposed to the insecticide begin to use a formerly silent gene to make a new enzyme that breaks down the insecticide molecules.
C) Insects observe the behavior of other insects that survive pesticide application, and adjust their own behaviors to copy those of the survivors.
D) Offspring of insects that are genetically resistant to the pesticide become more abundant as the susceptible insects die off.
Answer: D
Topic: Concept 22.3
Skill: Application/Analysis

5. If two modern organisms are *distantly* related in an evolutionary sense, then one should expect that
A) they live in very different habitats.
B) they should share fewer homologous structures than two more closely related organisms.
C) their chromosomes should be very similar.
D) they shared a common ancestor relatively recently.
E) they should be members of the same genus.

Answer: B
Topic:
Concept 22.3
Skill:
Application/Analysis

6. In a hypothetical population of rabbits, you observe the allele frequency of a potentially fatal gene changing dramatically. Which of the following assumptions of Hardy-Weinberg equilibrium is the hypothetical population most likely violating?
A) No mutation
B) No gene flow
C) No Natural Selection
D) Large population size
E) Random mating
Answer: C
Topic: Concept 23.1
Skill: Application/Analysis

7. The frequency of heterozygosity for the sickle-cell anemia allele in tropical regions is unusually high, presumably because this reduces the frequency of malaria (which can be fatal). Such a relationship is related to which of the following?
A) Mendel's law of independent assortment
B) Mendel's law of segregation
C) Darwin's explanation of natural selection
D) Darwin's observations of competition
E) the malarial parasite changing the allele
Answer: C
Skill:
VCCC: I OR III

8. Red-green color blindness is a sex-linked recessive trait in humans. Two people with normal color vision have a color-blind son. What are the genotypes of the parents?
Let: C = allele for normal color vision and c = allele for colorblindness

A) $X^c X^c$ and $X^C Y$
B) $X^c X^c$ and $X^c Y$
C) $X^C X^C$ and $X^c Y$
D) $X^C X^C$ and $X^C Y$
E) $X^C X^c$ and $X^C Y$
Answer: E
Skill:
VCCC: III

9. Both animals and fungi are heterotrophic. What distinguishes animal heterotrophy from fungal heterotrophy is that only animals derive their nutrition
A) from organic matter.

B) by preying on animals.

C) by ingesting it.

D) by consuming living, rather than dead, prey.

E) by using enzymes to digest their food.

Answer: C

Topic: Concept 32.1

Skill: Knowledge/Comprehension

10. Large numbers of ribosomes are present in cells that specialize in producing which of the following molecules?
A) lipids
B) glycogen
C) proteins
D) cellulose
E) nucleic acids
Answer: C
Skill:
VCCC: IV

11. There are 20 different amino acids. What makes one amino acid different from another?
A) different side chains (R groups) attached to a carboxyl carbon
B) different side chains (R groups) attached to the amino groups
C) different side chains (R groups) attached to the middle carbon
D) different structural and optical isomers
E) different asymmetric carbons
Answer: C
Skill:
VCCC: IV

12. Phylogenetic trees are best described as

A) true and inerrant statements about evolutionary relationships.

B) hypotheses regarding evolutionary relationships.

C) the most accurate representations possible of genetic relationships among taxa.

D) theories of evolution.

E) the closest things to absolute certainty that modern systematics can produce.

Answer: B

Topic: Concept 26.?

Skill: Knowledge/Comprehension

13. If a photosynthesizing green algae is provided with CO_2 containing the oxygen isotope ^{18}O, later analysis will show that all but one of the following compounds produced by the algae contain the ^{18}O label. Which compound is it?
A) G3P.

B) fructose.
C) glucose.
D) RuBP.
E) O_2.
Answer: E
Skill:
VCCC: II

14. Which of the following statements best describes the relationship between photosynthesis and cellular respiration?
A) Respiration runs the biochemical pathways of photosynthesis in reverse.
B) Photosynthesis stores energy in complex organic molecules, whereas respiration releases it.
C) Photosynthesis occurs only in plants and respiration occurs only in animals.
D) ATP molecules are produced in photosynthesis and used up in respiration.
E) Respiration is anabolic and photosynthesis is catabolic.
Answer: B
Skill:
VCCC: II

15. The most recent common ancestor of all land plants was probably similar to modern-day members of which group?
A) pterophytes
B) red algae
C) charophytes
D) brown algae
E) angiosperms
Answer: C
Topic: Concept 29.1
Skill: Knowledge/Comprehension

16. A biologist from CWI on sabbatical in Cost Rica discovers a new species of plant. After observing its anatomy and life cycle, the following characteristics are noted: flagellated sperm, xylem with tracheids, separate gametophyte and sporophyte generations with the sporophyte dominant, and no seeds. This plant is probably most closely related to
A) mosses.
B) charophytes.
C) ferns.
D) gymnosperms.
E) flowering plants.
Answer: C
Topic: Concept 29.3
Skill: Application/Analysis

17. Over human history, which process has been most important in improving the features of plants that have long been used by humans as staple foods?
A) genetic engineering
B) artificial selection
C) natural selection
D) sexual selection
E) pesticide and herbicide application
Answer: B
Topic: Concept 30.4
Skill: Knowledge/Synthesis

18. The common ancestor of all animals was probably a
A) bacteria
B) unicellular yeast.
C) plant.
D) multicellular fungus.
E) flagellated protist.
Answer: E
Topic: Concept 32. 2 Skill: Knowledge/Comprehension

19. Which of the following best demonstrates the unity among all organisms?
A) matching DNA nucleotide sequences
B) descent with modification
C) the structure and function of DNA
D) natural selection
E) emergent properties
Answer: C
Skill:
VCCC: IV

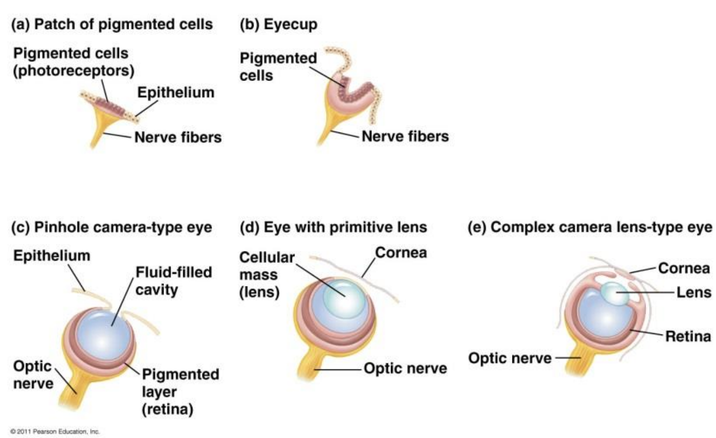
20. GIVEN: A part of the promoter region of a gene, called the TATA box, has been *highly conserved* in the course of evolution. Which of the following might this illustrate?
A) The sequence evolves very rapidly.
B) The sequence does not mutate.
C) Any mutation in the sequence is selected against.
D) The sequence is found in many but not all promoters.
E) The sequence is transcribed at the start of every gene.
Answer: C
Skill:
VCCC: I OR III

21. A mutation that inactivates the regulatory gene of a repressible operon in an *E. coli*

cell would result in
A) continuous transcription of the gene.
B) complete inhibition of transcription.
C) irreversible binding of the repressor to the operator.
D) inactivation of RNA polymerase by alteration of its active site.
E) continuous translation of the mRNA because of alteration of its structure.
Answer: A
Skill:
VCCC: III

22. What would occur if the repressor of an inducible operon were mutated so it could not bind the operator?
A) irreversible binding of the repressor to the promoter
B) reduced transcription of the operon's genes
C) buildup of a substrate for the pathway controlled by the operon
D) continuous transcription of the operon's genes
E) overproduction of catabolite activator protein (CAP)
Answer: D
Skill:
VCCC: III

Use the information below for Question #23
All animals with eyes or eyespots that have been studied so far share a gene in common. When mutated, the gene *Pax-6* causes lack of eyes in fruit flies, tiny eyes in mice, and missing irises (and other eye parts) in humans. The sequence of *Pax-6* in humans and mice is identical. There are so few sequence differences with fruit fly *Pax-6* that the human/mouse version can cause eye formation in eyeless fruit flies, even though vertebrates and invertebrates last shared a common ancestor more than 500 million years ago.



23. The appearance of *Pax-6* in all animals with eyes can be explained in multiple ways. Based on the information above, which explanation is most likely?
A) *Pax-6* in all of these animals is not homologous; it arose independently in many different animal phyla due to intense selective pressure favoring vision.

B) The *Pax-6* gene is really not "one" gene. It is many different genes that, over evolutionary time and due to convergence, have come to have a similar nucleotide sequence and function.
C) The *Pax-6* gene was an innovation of an ancestral animal of the early Cambrian. Animals with eyes or eyespots are descendants of this ancestor.
D) The *Pax-6* gene appeared instantaneously in all animals created to have eyes or eyespots.
Answer: C
Topic: Concept 25.4
Skill: Synthesis/Evaluation

24. You are a cell biologist for the state of Idaho looking at possible causes of a water-borne illness in the Treasure Valley. You've identified a suspect organism that has the following molecules and structures: enzymes, DNA, ribosomes, plasma membrane, and mitochondria. You determine that this cell could be from
A) a bacterium.
B) an animal, but not a plant.
C) nearly any eukaryotic organism.
D) any multicellular organism, like a plant or an animal.
E) any kind of organism.
Answer: C
Skill:
VCCC: IV

25. What do animals as diverse as sponges and monkeys have in common?
A) body cavity between body wall and digestive system
B) type of body symmetry
C) degree of cephalization
D) number of embryonic tissue layers
E) presence of homeobox genes
Answer: E
Topic: Concept 32.1
Skill: Factual/Recall

26. If cells are grown in a medium containing radioactive ^{32}P-labeled phosphate, which of these molecules will be labeled?
A) phospholipids
B) nucleic acids
C) proteins
D) amylose
E) both phospholipids and nucleic acids
Answer: E
Skill:

27. IF: Telomeres protect the information at the end of linear chromosomes AND: The DNA of telomeres has been found to be *highly conserved* throughout the evolution of eukaryotes THEN: What does this most probably reflect?
A) the inactivity of this DNA
B) the low frequency of mutations occurring in this DNA
C) that new evolution of telomeres continues
D) that mutations in telomeres are relatively advantageous
E) that the critical function of telomeres must be maintained
Answer: E
Skill: Synthesis
VCCC: I OR III

28. Which of the following regarding DNA replication and DNA transcription is false?
A) DNA replication and DNA transcription use slightly different nitrogenous bases.
B) DNA replication results in a double-stranded molecule while DNA transcription results in a single-stranded molecule.
C) DNA replication and DNA transcription use slightly different polymerases.
D) DNA replication and DNA transcription occur in different locations in the cell.
E) DNA replication and DNA transcription have different regulatory mechanisms.
Answer: D
Skill: Understanding
VCCC: III

29. Beetle pollinators of a particular plant are attracted to its flowers' bright orange color. The beetles not only pollinate the flowers, but they mate while inside of the flowers. A mutant version of the plant with red flowers becomes more common with the passage of time. A particular variant of the beetle prefers the red flowers to the orange flowers. Over time, these two beetle variants diverge from each other to such an extent that interbreeding is no longer possible. What kind of speciation has occurred in this example, and what has driven it?
A) allopatric speciation with ecological isolation
B) sympatric speciation with habitat differentiation
C) allopatric speciation with behavioral isolation
D) sympatric speciation with sexual selection
E) sympatric speciation with allopolyploidy
Answer: B
Topic: Concept 24.2
Skill: Application/Analysis

30. An ectotherm is more likely to survive an extended period of food deprivation than would an equally-sized endotherm because
A) the ectotherm maintains a higher basal metabolic rate.
B) the ectotherm expends more energy/kg body weight than the endotherm.
C) the ectotherm invests little energy in temperature regulation.
D) the ectotherm metabolizes its stored energy more readily than can the endotherm.
E) the ectotherm has greater insulation on its body surface.
Answer: C
Topic: Concept 40.3
Skill: Application/Analysis

31. An example of a properly functioning homeostatic control system is seen when
A) the core body temperature of a runner rises gradually from 37°C to 45°C.
B) the kidneys excrete salt into the urine when dietary salt levels rise.
C) a blood cell shrinks when placed in a solution of salt and water.
D) appetite suppressing hormones are not released when food reaches the small intestine.
E) the level of glucose in the blood is abnormally high whether or not a meal has been eaten.
Answer: B
Topic: Concept 40.2
Skill: Application/Analysis

32. Once labor begins in childbirth, contractions increase in intensity and frequency until delivery. The increasing labor contractions of childbirth are an example of which type of regulation?
A) a bioinformatic system
B) positive feedback
C) negative feedback
D) feedback inhibition
E) enzymatic catalysis
Answer: B
Skill:
VCCC: IV OR V

33. When the body's blood glucose level rises, the pancreas secretes insulin and, as a result, the blood glucose level declines. When the blood glucose level is low, the pancreas secretes glucagon and, as a result, the blood glucose level rises. Such regulation of the blood glucose level is the result of
A) catalytic feedback.
B) positive feedback.
C) negative feedback.
D) bioinformatic regulation.
E) protein-protein interactions.
Answer: C
Skill:
VCCC: IV OR V

34. Which of these observations gives the most support to the endosymbiotic theory for the origin of eukaryotic cells?
A) the existence of structural and molecular differences between the plasma membranes of prokaryotes and the internal membranes of mitochondria and chloroplasts
B) the similarity in size between the cytosolic ribosomes of prokaryotes and the ribosomes within mitochondria and chloroplasts
C) the size disparity between most prokaryotic cells and most eukaryotic cells
D) the observation that some eukaryotic cells lack mitochondria
Answer: B
Topic: Concept 25.3
Skill: Synthesis/Evaluation

35. The oxygen revolution changed Earth's environment dramatically. Which of the following took advantage of the presence of free oxygen in the oceans and atmosphere?
A) the evolution of cellular respiration, which used oxygen to help harvest energy from organic molecules
B) the persistence of some animal groups in anaerobic habitats
C) the evolution of photosynthetic pigments that protected early algae from the corrosive effects of oxygen
D) the evolution of chloroplasts after early protists incorporated photosynthetic cyanobacteria
E) the evolution of multicellular eukaryotic colonies from communities of prokaryotes
Answer: A
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension

36. A genetic change that caused a certain *Hox* gene to be expressed along the tip of a vertebrate limb bud instead of farther back helped make possible the evolution of the tetrapod limb. This type of change is illustrative of
A) the influence of environment on development.
B) paedomorphosis.
C) a change in a developmental gene or its regulation that altered the spatial organization of body parts.
D) heterochrony.
E) gene duplication.
Answer: C
Topic: End-of-Chapter Questions
Skill: Application/Analysis

37. Which of the following is *not* a characteristic that distinguishes gymnosperms and angiosperms from other plants?
A) alternation of generations
B) ovules
C) integuments
D) pollen
E) dependent gametophytes

Answer: A
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension

38. Which of the following was probably the *least* important factor in bringing about the Cambrian explosion?
A) the emergence of predator-prey relationships among animals
B) the accumulation of diverse adaptations, such as shells and different modes of locomotion
C) the movement of animals onto land
D) the origin of *Hox* genes and other genetic changes affecting the regulation of developmental genes
E) the accumulation of sufficient atmospheric oxygen to support the more active metabolism of mobile animals
Answer: C
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension

39. Some animals that lived 530 million years ago resembled lancelets but had a brain and a skull. These animals may represent
A) the first chordates.
B) a "missing link" between urochordates and cephalochordates.
C) early craniates.
D) marsupials.
E) nontetrapod gnathostomes.
Answer: C
Topic: End-of-Chapter Questions
Skill: Knowledge/Comprehension