

Effective Instructional Approaches in a Large Introductory Biology Classroom:

A Research Review and Illustrative Case Study

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Abstract

International students continue to outperform U.S. students in Science, Technology, Engineering, and Mathematics (STEM), while U.S. students increasingly leave these high-demand areas. To improve STEM performance and to alleviate STEM fatigue and attrition, researchers from several disciplines have been conducting studies to determine the most effective and efficient instructional and organizational practices in these courses. This thesis identifies best practices in structuring a STEM course to promote transformation to comprehension-based learning, while fostering student success. Best practices fall within three clusters: (a) structuring a course; (b) focusing on *how* to teach; and (c) assessing student performance. An illustrative case study in a large introductory biology classroom is highlighted as each cluster is described. Further, recommendations are provided related to effective instructional practices to be used in STEM classes. This combined research review and case study aims to provide new or inquiring instructors with the evidence-based strategies they may need to help reduce STEM fatigue and attrition in their classes.

Keywords: best practices, STEM education, effective instruction, active learning

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A Research Review and Illustrative Case Study

Introduction

The Importance of STEM

We are at the forefront of an advancing and ever-changing world. Scientific and technological innovations have led to vast changes in the way we navigate our environments. For example, medical advances, such as replacing parts of a human skull with 3D-printed plastic (Eng, 2014), have saved people's lives and broadened the ways in which medical issues are addressed. Genetic engineering is another important tool with the potential to contribute, for example, to meeting the future food demand of a growing human population (Okigbo, Iwube, & Putheti, 2011). Finally, the products developed at *Apple*, such as the iPhone, have led to alterations in human communication (Kelly, 2012); we now are able to keep in touch with people anytime we desire via texting, emailing, calling, or using Facetime or Skype. The myriad of inventions and discoveries made in the U.S. and other countries have largely been the result of efforts focused on science, technology, engineering, and mathematics (STEM). According to the U.S. Department of Commerce (2011),

the greatest advancements in our society from medicine to mechanics have come from the minds of those interested in or studied in the areas of STEM. Although still relatively small in number, the STEM workforce has an outsized impact on a nation's competitiveness, economic growth, and overall standard of living. (p. 6)

Occupations in STEM fields not only provide avenues that lead to discoveries but also offer higher wages, require further schooling, and are projected to increase by 17% from 2008 to 2018 (U.S. Department of Commerce, 2011).

In addition to fostering STEM contributions and job prosperity, a strong background in areas such as science and mathematics is a prerequisite for developing citizens who can think critically. Scientific and mathematical literacy can enhance people's reasoning skills and is critical for helping them make informed decisions (Wieman, 2012). Children raised in the 21st century will be called upon to address challenges, such as climate change, overpopulation, and economic disparities, and will thus need sufficient preparation to problem-solve and to devise solutions to many of life's challenges (National Education Association, 2014). Furthermore, in a world filled with vast amounts of information, citizens will need to have the skills necessary to examine evidence, compare claims, and draw logical conclusions to make informed decisions (National Education Association, 2014).

The Problem

Despite the skills STEM fields offer to students and the demand for STEM workers, “economic projections point to a need for approximately 1 million more STEM professionals than the U.S. will produce at the current rate over the next decade if the country is to retain its historical preeminence in science and technology” (President's Council of Advisors on Science and Technology [PCAST], 2012, p. i). Unfortunately, U.S. students consistently lag behind their international peers in science and mathematics. In fact, high school students in the U.S. ranked 27th in mathematics and 20th in science out of 34 countries that are members of the Organization for Economic Cooperation and Development as assessed by the Program for International Student Assessment in 2012 (Organisation for Economic Co-operation and Development [OECD], 2012). The poor performance in science and mathematics of U.S. students is also reflected in high school graduates' college readiness. Only 44% of high school graduates are prepared for college-level mathematics courses, and only 36% of these graduates are prepared

for college-level science courses (National Math + Science Initiative, 2015). These issues with college readiness are also reflected in the college-level STEM fatigue and attrition statistics. Between 2003 and 2009, nearly 50% of bachelor's degree students and approximately 70% of those seeking associate's degrees in STEM left these fields (National Center for Education Statistics, 2013). Even more concerning is that, while the U.S. spends more money on average per student per year than most other industrialized countries, student performance does not reflect this educational investment (OECD, 2012).

When examining characteristics of individuals in the STEM workforce and those in STEM classes, we learn that females (Office of Science and Technology Policy, 2013), first-generation college students, and culturally diverse population are underrepresented (National Center for Education Statistics, 2013). African Americans, Hispanics, and American Indians comprise the population that trails other racial and ethnic groups in degree and employment statistics (National Center for Science and Engineering Statistics, 2013). When large populations are underrepresented in these important fields, meeting the future demand for STEM talent will be more difficult to achieve (Joint Economic Committee Chairman's Staff, 2012). Thus, improving STEM performance and alleviating attrition has become a national priority (STEM Education Coalition, 2013).

Solutions

To address these national challenges, President Obama included numerous investments in the 2015 budget to improve STEM education (U.S. Department of Education, 2015). These investments target multiple areas, such as "Recruiting, preparing, and supporting excellent STEM teachers," "Supporting more STEM-focused school districts", and "Investing in breakthrough research on STEM teaching and learning" (White House Office of Science and

Technology, 2014, p. 1). With support from the federal government, many educators have begun adopting innovative teaching strategies and techniques to encourage students to develop skills in and a love for science and mathematics.

The power of strong instruction cannot be overstated. In the Federal Science, Technology, Engineering, and Mathematics (STEM) Education Strategic Plan from the Committee on STEM Education National Science and Technology Council (2013), the first-listed national goal is to improve STEM instruction. According to Bhowmik, Banerjee, and Banerjee (2013), “pedagogy is the art (and science) of teaching” (p. 01). In order for instructors to promote STEM learning, understanding, and generalization, their pedagogy should be based on evidence-based teaching practices. Evidence-based teaching is the “conscientious, explicit, and judicious integration of best available research on teaching technique and expertise within the context of student, teacher, department, college, university, and community characteristics” (Groccia & Buskist, 2011, p. 8). Pedagogy that draws on research-based conclusions is rooted in empiricism as compared to opinion or intuition and should thus lead to greater learning outcomes.

The research literature contains an immense number of articles that investigate best practices in teaching and learning. These articles often examine specific teaching approaches or cognitive learning processes. Instructors wishing to transform their courses by including scientifically validated practices would likely have to read a plethora of studies to develop a comprehensive understanding of how they should go about designing and implementing their courses. Papers such as “Course Transformation Guide” from the University of British Columbia and the University of Colorado Science Education Initiatives (2014) along with books such as *How Learning Works: 7 Research-Based Principles for Smart Teaching* by Ambrose, Bridges, DiPietro, Lovett, and Norman (2010) and *Make It Stick: The Science of Successful Learning* by

Brown, Roediger, and McDaniel (2014) offer a comprehensive analysis of techniques and principles that can be used to inform our teaching in higher education.

However, research reviews are lacking that explicitly outline ways to structure STEM-focused courses based upon a synthesis of peer-reviewed journal articles. To successfully transform a STEM course, instructors should be given evidence-based suggestions on approaches ranging from writing an effective syllabus to designing effective assessments. My research questions pertain to a course transformation at the University of Colorado Boulder and include the following specific questions: (a) Which overarching clusters of teaching and learning techniques are present in one instructor's teaching/class? and (b) What research evidence is available to support the instructional elements within these overarching clusters? My goal is to identify a comprehensive range of different components (e.g., pedagogical, didactic, personal, instructor-specific and student-specific, logistical, philosophical) of such a course that could be used to synergistically support learning goals. Further, this thesis aims to bridge the gap between an exhaustive list of education-related research articles and what practices are evident in one particular course that promotes enhanced teaching and learning. Finally, given the urgent need for improved STEM education, this thesis offers illustrative examples of practical teaching/learning instructional and organizational practices found in a large biology college course.

Methods

Instructor

Dr. Barbara Demmig-Adams served as the targeted instructor in my investigation. She is a full professor at the University of Colorado Boulder (CU Boulder) and has been teaching at CU Boulder for 26 years. She began teaching the introductory biology course that serves as a general

science requirement for STEM and non-STEM majors in the early 1990s. She taught the course for three fall semesters in the 1990s and, subsequently, each fall semester since 2007. Students who have taken her general biology course rate her positively. For example, her average teaching rating for this course is 5.5 ± 0.1 (mean and standard deviation) and for her additional Honors seminar is 5.9 on a scale ranging from 1 to 6. As a popular teaching professor, Dr. Demmig-Adams has received the Marinus Smith Award from the CU Parents Association for services to CU undergraduates (2014), the Chancellor's Award for Excellence in STEM Education (2013), the Boulder Faculty Assembly Excellence in Teaching Award (2010-2011), a Certificate of Appreciation for her work with students with disabilities from Disabilities Services at CU (2008), and the CU LEAD Scholar Award to honor faculty recognized by traditionally underrepresented CU-LEAD students for having a significant influence on their success at CU Boulder (2008). In addition to her recognition as an influential professor, she is a productive researcher with recognition for influential papers and scholarly pursuits and for being highly cited. Finally, she has had 29 grants funded, has published over 160 scholarly articles, and has given over 80 invited talks and conference presentations.

Course

The course that served as the inspiration for this best-practices investigation is an introductory biology course entitled Ecology and Evolutionary Biology (EBIO) 1210: General Biology I. As stated previously, this course is required by various science departments on campus including EBIO, Integrative Physiology, Psychology, and Engineering and fulfills the core science requirement for any major at CU. General Biology I is offered each fall semester, and General Biology II is offered each spring semester. Approximately 1400 students enroll in General Biology I each fall semester; Dr. Demmig-Adams is typically responsible for 700

students in two parallel sections. The course is designed to have two professors team-teach during the semester; Dr. Demmig-Adams teaches two sections over the first half of the course, and another EBIO faculty member teaches the same sections over the second half of the course. The course is generally held in a large, 400-seat lecture hall where the instructor stands at the front of the room and students sit in stadium seating with theater-like chairs and attached desks. Finally, the course textbook used in fall 2015 was the first edition of *Campbell Biology in Focus* by Urry et al. (2013) published by Benjamin Cummings.

I chose to use this course as a model in response to a request from Dr. Demmig-Adams to help her choose video clips suitable for showing instructors of other introductory biology courses real-world examples of specific pedagogical techniques that they could use in their own classes. Dr. Demmig-Adams was co-principal investigator for a grant funded by the Science Education Initiative at the University of Colorado Boulder from 2011-2015 entitled, “Increasing Teaching Effectiveness in Ecology and Evolutionary Biology.” A targeted objective of this grant was to transform teaching approaches to foster student participation and critical thinking skills. With the aid of a videographer, Dr. Demmig-Adams had each of her lectures video-recorded during the Fall 2015 semester.

As I began to collaborate with Dr. Demmig-Adams on identifying the techniques she utilized in the course, I became interested in developing categories, into which particular instructional and organization practices could fit as part of my Honors thesis. Due to the high teaching evaluations Dr. Demmig-Adams received from her students in General Biology I, I thought it would be important to classify the various instructional and organizational practices she implemented throughout the first half of the semester. As both a previous General Biology I student and a previous undergraduate teaching assistant for the same course taught by Dr.

Demmig-Adams, I can personally speak to the ways in which the course inspired me to pursue an EBIO major. By examining the research literature on these general practices, instructors wishing to adopt new techniques would be able to choose from those that are evidence based. My goal for this Honors thesis was to become better acquainted with the research literature on effective teaching practices in STEM courses and to illustrate these teaching practices with illustrative video clips of one selected instructor who received positive feedback for her teaching.

Category Development

To develop categories into which to place Dr. Demmig-Adams' pedagogical techniques, I took the following steps. First, I met with Dr. Demmig-Adams multiple times before the video recordings of her course had been completed to discuss her course structure and teaching philosophy. We discussed how she generally structures her course, such as preparing a syllabus and deciding which material to cover and when to cover it. We also discussed her teaching philosophy, which centers on wanting to create an engaging and comfortable atmosphere, where students can be guided through the learning process with careful scaffolding. I compiled instructional and organizational practices I remembered from when I took the course and when I served as a teaching assistant, such as clicker questions (see below for further detail) interspersed during lecture. Finally, we discussed how she assessed students' understanding of the material.

Second, I developed a tentative list of the main practices present in her course based upon our discussions and my experiences in the class, and solicited feedback from Dr. Demmig-Adams. Third, as I was choosing video clips of the course to showcase, I recorded any additional teaching practices used on a consistent basis. Finally, we met to discuss any additional elements we noted while either watching the video clips or reflecting on the course and furthered refined my list. After assembling the main elements present in the first half of General Biology I, I

sorted these into categories based on connections among the elements. Three clusters emerged: (1) structuring a course, (2) focusing on *how* to teach, and (3) assessing student performance. With these three clusters and specified organizational and instructional practices identified for each cluster, I conducted a research review on the identified instructional and organizational practices.

My search included ProQuest, Academic Search Premier, JSTOR, and Google Scholar to find research articles on effective teaching practices in STEM and effective teaching in general. Search terms included, but were not limited to, the following: *STEM, active learning, active engagement, modeling, guided practice, syllabus, organization, effective teaching practices, explicit instruction, think/thinking aloud(s), engagement, humor, clickers, opportunities to respond, assessment, background knowledge, positive atmosphere, positive and corrective feedback, test preparation, and study guides*; further articles were found based searching for articles citing or cited by articles located via the aforementioned searches. Located articles were placed in the context of Dr. Demmig-Adams' general instructional and organizational practices; illustrative examples were used to highlight these practices.

Results and Discussion

I conducted a review of the peer-reviewed research for each of the three clusters: (1) structuring a course; (2) focusing on *how* to teach; and (3) assessing student performance. I provide an overview of each cluster and include specific sub-clusters with corresponding supportive research and illustrative examples from Dr. Demmig-Adams' class.

Structuring a Course

Course organization and structure serve as foundational elements to teaching and learning. When a course is well structured, student learning can be enhanced (Eddy & Hogan, 2014).

Course organization includes a well-designed syllabus, an intentional scope and sequence of topic coverage, and the use of a learning management system.

Syllabus. Development and use of a syllabus is a common practice at colleges and universities across the country (Ludwig, Bentz, & Fynewever, 2011). A syllabus generally includes basic information such as the instructor's name and office hours, a course description, course objectives, materials, course requirements, grading policies, a course schedule, and recommendations for course success (Carnegie Mellon University Eberly Center, 2016; University of California Berkeley Center for Teaching and Learning, 2016). Syllabus distribution commonly occurs on the first day of class and provides students with an introduction to the course and how it will be conducted. Syllabi are often considered contracts between instructors and students (Parks & Harris, 2002 as cited in Habanek, 2005); students typically consult course syllabi on a weekly basis (Appling, Gancar, Hughes, & Saad, 2012).

Given that a syllabus provides an early introduction to a course, it contributes to students' first impressions regarding the instructor and the course itself (Harnish & Bridges, 2011). To establish a positive tone of both the instructor and course and to promote effective communication between instructor and students, the design of a syllabus should be taken into careful consideration. Harnish and Bridges (2011) investigated students' perceptions of their instructor and the course based upon varying syllabi tones. Through the manipulation of syllabus tone (i.e., friendly or unfriendly), these researchers found that students who read the "friendly" syllabus rated the instructor as being warmer, more approachable, and more motivated. A friendly tone can be achieved through the use of positive or friendly language (e.g., "I look forward to"), a rationale for assignments (e.g., link course objectives to course work), self-disclosure (e.g., share personal experiences), humor (e.g., attach a cartoon), compassion (e.g.,

acknowledge the reality of missing class), and enthusiasm (e.g., link course objectives with your excitement for the subject matter) (Harnish & Bridges, 2011; Harnish et al., 2011). Further, students who received friendly syllabi rated their courses as less difficult (Harnish & Bridges, 2011).

In addition to creating a positive first impression through the use of a friendlier syllabus, students in a study by Appling et al. (2012) specified that the syllabus is important for planning and should include assessment dates and assignment information. Further, when a syllabus includes specific information such as learning objectives for each chapter; ways to use assignments, assessments, and other evaluations tools to monitor learning; and information on how course activities will be used by the instructor to inform his/her teaching, instructors can encourage open communication in the classroom (Ludwig et al., 2011). This communication is labeled assessment for learning (AfL) and includes any assessment that helps instructors and students to critically examine their own teaching/learning and make modifications if necessary. The inclusion of detailed information pertinent to the course such as required readings and exam logistics is often more preferable to students than less detailed information (Habanek, 2005; Ludwig et al., 2011). Improved communication between the instructor and the students can occur through the use of concise syllabi that provide students with the necessary information to successfully navigate the course and their own learning.

Illustrative example. Appendix A provides Dr. Barbara Demmig-Adams' syllabus and supporting materials (including course schedule, course policy, learning goals, and PowerPoint slides containing helpful tips) presented on the first and second days of class for EBIO 1210 General Biology I. These materials are designed to support students' success. Beyond course logistics, Dr. Demmig-Adams provides tips on how to do well in the course, the course learning

goals, and a list of chapters/sections in the textbook that correspond to her lectures. Dr. Demmig-Adams includes friendly language in her syllabus. For example, she includes a section describing how students can prepare for success in the course.

Scope and sequence. An essential task to consider when designing a course and course syllabus is the schedule of topics. Over the quarter or semester, instructors need to cover certain information to provide their students with a strong background in and knowledge of the subject matter. Instructors may follow the chapter sequence presented in the course textbook or may create their own sequence. To provide students with strong foundational skills in a particular content area, the scope and sequence of the covered material should be carefully investigated. Building background knowledge and skills in one course often serves as a foundation or platform for developing more advanced knowledge and skills in another course (Gregory, Lending, Orenstein, & Ellis, 2011); this seamless progression is often seen in coursework with prerequisites (e.g., Biology I and II).

As STEM fields progress, the content taught in college courses may become more expansive and intricate. For example, courses in the biological sciences have experienced an increase in the amount of presented material but a decrease in the time allotted to promote students' depth of knowledge of this material (Gregory et al., 2011). Unfortunately, quantity does not equal quality when it comes to education. A well-known comment that captures the depth versus breadth dilemma in the U.S. is that curricula in our country are often "a mile wide and an inch deep" (Schmidt, Houang, & Cogan, 2002, p. 3). When compared to other countries, we tend to emphasize breadth of knowledge over depth of knowledge; this tendency can easily be observed in the width of U.S. textbooks (Schmidt et al., 2002). The benefits of learning less

information on a deeper level instead of learning more information on a surface level cannot be overstated.

Schwartz, Sadler, Sonnert, and Tai (2008) examined depth versus breadth of topic coverage. High school students who achieved higher grades in their college science class covered a minimum of one major concept in depth for at least 1 month. In fact, students who reported more breadth-based learning in their high school science class performed less well in college biology. Covering a topic in depth may involve more active-learning activities that go beyond rote memorization and encourage students to develop critical thinking skills (Gregory et al., 2011; Luckie et al., 2012).

With an immense amount of information instructors could cover over the course of several weeks, it is critical to determine the most essential biological concepts that should be emphasized in introductory courses to promote depth-based learning. Gregory et al. (2011) identified 23 essential topics that undergraduate students in introductory biology courses should learn; these included such topics as mitosis and meiosis, respiration, and photosynthesis. Narrowing biological topics to only include those that are most essential to educate students can mitigate breadth-based learning.

In addition to teaching fewer concepts at a higher level, topics in STEM should have logical connections to each other to enhance learning progression. Prerequisite skills must be in place before students can move on to more rigorous or multifaceted material. For example, the teaching of mathematics in the United States often does not connect topics, making the collection of information seem random and unstructured (Schmidt et al., 2002). To move toward a systematic approach to curriculum design, backward planning has been recommended. Allen and Tanner (2007) described backward planning as beginning with the end in mind; that is, the

destination is determined first and the route toward that destination follows suit. While this route may follow the order of topics found in the course textbook, instructors may also choose to sequence topics in a way that seems more connected based on their interests or consideration of courses that follow at their college/university (Allen & Tanner, 2007; Rissing, 2013). This sequencing may also be conducted by curriculum development committees within departments; these committees often discuss topic coverage, order, student outcomes, and sequencing within and across courses (Voet et al., 2003).

Illustrative example. Dr. Barbara Demmig-Adams provides a detailed list of the topics required for each exam (see Appendix A). She chooses the chapters in the textbook based upon her own order of topics as opposed to following the specific order of chapters/topics in the required textbook. Concepts visited early in the course build a foundation for more complex topics; no detail is included that would not be integrated into the more complex concepts. For example, Dr. Demmig-Adams first teaches her students about active and passive transport; these concepts are later used to form an understanding of muscle and neuron function as well as Adenosine Triphosphate (ATP) formation in photosynthesis and respiration.

Learning management system. The advancement of technology has led to online opportunities for instructors to organize their classes. One such opportunity is the learning management system (LMS), which allows students to access class materials and assignments online throughout the quarter or semester. Learning can be facilitated through the use of such an online class component by allowing instructors to give immediate feedback on assignments or assessments, to promote online discussions of class material, to record lectures, and to post useful class information and materials (Coates, James, & Baldwin, 2005; Martin, 2008). Given their advanced technological skills, many students have come to expect online resources in their

classes (Coates et al., 2005). The most helpful aspects of any LMS for students include posting of syllabi (Appling et al., 2012), accessibility of course materials, immediate feedback on quizzes, and organization of the learning environment (Martin, 2008). “This technology builds bridges between knowledge and learners and helps these learners construct meaningful understandings” (Falvo & Johnson, 2007, p. 45).

Illustrative example. Dr. Barbara Demmig-Adams uses the LMS *Desire2Learn* that has been adopted by the University of Colorado Boulder. This online environment includes course materials such as the syllabus, PowerPoint lecture slides, course handouts, exam review slides, exam answer keys, and a course grade book.

Focusing on *How* to Teach

Besides examining course organization, instructors should focus on *how* they teach. According to Archer and Hughes (2011), “how well you teach = how well they learn” (p. ix). Focusing on *how* to teach includes a learning-conducive atmosphere (with humor, relevant course content, and polling) and the effective teaching model.

Learning-conducive atmosphere. The learning atmosphere in college classes can be enhanced in several ways. The addition of humor, relevant course content (with multimedia), and polling help promote engagement and a more positive experience. Enhancing the learning atmosphere with these additions may be an effective way to develop, maintain, and/or further promote students’ interests in and feelings toward STEM courses.

Humor. Class distractions are ever-present for today’s students in classes with texting, emails, and Facebook at their fingertips; thus, it is of the utmost importance to capture students’ attention and to maintain their engagement when they are in class. One way to reduce student boredom and to spark their interest and maintain their attention is through the use of humor

(Hackathorn, Garcyzynski, Blankmeyer, Tennial, & Solomon, 2011). Humor can be defined as “a situation that stimulates laughter or amusement upon cerebral evaluation of it” (Wandersee, 1982, p. 212). The use of humor in the classroom has been investigated. For example, Wanzer, Frymier, and Irwin (2010) proposed and tested the Instructional Processing Theory (IHPT), which was useful in predicting the types of humor and contexts where humor would be most and least beneficial for student learning. Results indicated that humor tied to course relevance was positively associated with learning. Further, when class constructs were taught using humor (e.g., jokes, riddles, and multimedia), college students performed higher on quiz questions that were at the first two levels (i.e., knowledge and comprehension) of Bloom’s Taxonomy (Hackathorn et al., 2011). In addition to increased academic performance, Garner (2006) found support for the benefits of humor on statistics content retention; students who were in the humor condition retained more information while also reporting more positive opinions of the class and the instructor.

Humor is also an effective way to reduce students’ stress and anxiety (Flowers, 2001) and to create a more relaxed atmosphere (Chabeli, 2008). Humor may reduce stress levels through the anticipation of laughter; this anticipation can decrease levels of cortisol, 3,4-Dihydroxyphenylacetic acid (DOPAC), and epinephrine in the blood stream (Berk, Tan, & Berk, 2008). Interestingly, when students were exposed to funny cartoons before they took a difficult math test, they reported a decrease in anxiety and an increase in their test performance (Ford, Ford, Boxer, & Armstrong, 2012). Stress and anxiety can be reduced in an environment that is made more comfortable by adding jokes or other humorous remarks; these outlets can create connections to students’ lives and encourage interpersonal involvement (Slater, Levis, & Levis, 2015). Webb and Barrett (2014) found that college students voiced high levels of comfort when

their instructor incorporated humor in the lesson and found their instructors to be more approachable and less intimidating.

There are certain forms of humor that can be effective for student learning and engagement, while others can be counterproductive (Flowers, 2001). In general, humor is counterproductive when it belittles students, encourages negativity, and creates a hostile learning environment (Chabeli, 2008; Flowers, 2001). Further, instructor credibility can be lost if the instructors use self-incriminating humor (Wandersee, 1982) such as telling jokes about their own weaknesses, insecurities, or faults. Conversely, self-disparaging humor can also be positively correlated with student learning because it can grab students' attention with its unexpectedness (Wanzer et al., 2010). However, due to the potential negative consequences of inappropriate humor, framing humor in a positive, inclusive, and content-relevant way remains the most beneficial.

Illustrative example. Humor is often used by Dr. Demmig-Adams to create a more laid-back environment and to promote student interest in and understanding of the course material. Several examples showcase the ways in which she adds humor to the course material. First, Dr. Demmig Adams takes a humorous approach in describing the process by which motor molecules move vesicles across the cytoskeletal track of the cell. Taken verbatim from her lecture on September 16, 2015, Dr. Barbara Demmig Adams stated,

The movement of vesicles across the skeletal tracks is facilitated/performed by a motor protein that is fueled by ATP. The motor protein just has two little hands that—well two little things that attach to the vesicles. Then it just has something in between and then two little feet that march along the cytoskeletal track, and it's the same principle as motor molecules in muscle movement or with the sodium potassium pump where we get shape

changes by ATP stabbing something with an energy-rich phosphate group. So the feet get stabbed here. So the motor protein stands on the cytoskeleton track, and here comes ATP. And it sticks one of the little feet with a phosphate group. The motor protein goes ‘ouch’ [Dr. Demmig-Adams lifts one of her legs as if in pain]; well, without the ‘ouch’ [she laughs]. And so the leg’s up and then down again [Dr. Demmig-Adams puts down her leg]. Then the other foot gets stabbed— ‘ouch’ [Dr. Demmig-Adams lifts her other leg and then puts it down]. So every step costs us one ATP.

After stating this, she provided a humorous demonstration; she showed a video (see <https://www.youtube.com/watch?v=y-uuk4Pr2i8>) and narrated the part where the motor protein “struggles” to carry the vesicle across the track. She said, “awwwwwwe, it is so endearing to see that little motor molecule move through there.” The students laughed as they watched the video because she made the motor protein seem like a small person struggling to carry a huge item instead of a protein in a cell.

Another example of humor involves the following. When discussing the constant cycling of carbon and oxygen molecules between consumers and producers, Dr. Demmig-Adams noted the following during her lecture on October 5, 2015,

Somebody once said that in a living ecosystem, everybody’s waste is somebody’s lunch. That sounds icky but it’s true. So we exhale CO₂ and the plants say ‘give me that, that’s my food.’ And then they make sugars and they make extra Oxygen, more than they need, and we say ‘Oh, give me that, I need that!’ So it’s this intertwined cycle.

Student laughter was heard following her aforementioned remarks.

Relevant course content. Linking course content to relevant examples is one way to increase students’ engagement with and understanding of presented material. Relevancy can be

achieved by “including discussion of applications to real-world issues and societal challenges (Ueckert, Adams, & Lock, 2011, p. 168). Connections can be made between course information and everyday experiences through the addition of related examples and analogies (Ambrose et al., 2010). “For example, students’ experiences with cooking can be enlisted to help them understand scientific processes such as chemical synthesis (just as in cooking, when you mix or heat chemicals, you need to know when precision is and is not critical)” (Ambrose et al., 2010, p. 33). Connections can also be made through case studies (Ueckert et al., 2011). For example, The National Center for Case Study Teaching in Science (see <http://sciencecases.lib.buffalo.edu/cs/collection/>) provides a myriad of case studies that provide students with real-world examples of specific concepts, controversies, ethical issues, etc. related to science. These activities provide students with the opportunity to interact with the material and to engage in critical thinking (Majeed, 2014).

Class topics can also be “introduced in the context of exciting and interdisciplinary questions, such as understanding the possibility of synthetic life, the biology and treatment of AIDS and cancer, human population genetics, and malaria” (Labov, Reid, & Yamamoto, 2010, p. 14). By drawing on student experiences and general facts, background knowledge can be connected to new knowledge (Ambrose et al., 2010). Significant learning can take place when meaningful associations are made among ideas, subjects, and people (Allen & Tanner, 2007). For example, Hulleman and Harackiewicz (2009) found that students with low success expectancies who were encouraged “to make connections between their lives and what they were learning in their science classes” (p. 1410) earned better grades in their classes.

Tying a concept to its practical implication(s) can also promote an improvement in students’ motivation for and interest in the course content. When students in science courses

make these connections, they may be more interested in the subject matter (Hulleman & Harackiewicz, 2009). In fact, Krajcik and Sutherland (2010) recommended five educational techniques to promote scientific literacy in students that relate to forming meaningful connections; these techniques included:

- (i) linking new ideas to prior knowledge and experiences, (ii) anchoring learning in questions that are meaningful in the lives of students, (iii) connecting multiple representations, (iv) providing opportunities for students to use science ideas, and (v) supporting students' engagement with the discourse of science. (p. 456)

In addition to linking information in science, Hulleman, Godes, Hendricks, and Harackiewicz, (2010) found that, when lower performing students wrote about how the math or psychology material they were learning was personally relevant, their perceptions of utility value and interest increased. Finding meaning in one's education is an important and practical way to enrich students' motivation and academic achievement (Harackiewicz & Hulleman, 2010).

Connections between or among concepts and the real world can be made through words, pictures, and videos—learning through the use of words and pictures is known as multimedia learning (Mayer, 2008). A pioneer in multimedia research and the founder of the cognitive theory of multimedia learning is Dr. Richard Mayer (Mayer, 2001, 2009). Through a plethora of studies, Dr. Mayer and his colleagues have developed several principles to aid instructors in their creation of multimedia lessons. These principles generally refer to reducing extraneous processing, managing essential processing, and fostering generative processing (Mayer, 2008). In other words, these principles should help to create more effective multimedia designs that “help learners attend to relevant information, organize it into a coherent mental representation, and integrate it with prior knowledge” instead of overwhelming and confusing them (Issa et al., 2013,

p. 389). When used in ways that are consistent with the learning process, the integration of words and pictures can help students learn material at deeper levels (Mayer, 2003).

Providing students with pictures to reinforce or explain course concepts can increase their understanding and comprehension. Bean, Searles, Singer, and Cowen (1990) investigated the effects of providing pictorial representations to encourage students in their learning of biology concepts. They found that the incorporation of these pictures during a lesson on cell structure and function improved students' performance on a short answer test. In addition to pictures, videos are another outlet by which to enhance students' knowledge. Based upon a literature review by Berk (2009), there are eight steps to follow when adding videos to a course lecture. These steps include:

- (1) Pick a particular clip to provide the content or illustrate a concept or principle; (2) Prepare specific guidelines for students or discussion questions so they have directions on what to see, hear, and look for; (3) Introduce the video briefly to reinforce purpose; (4) Play the clip; (5) Stop the clip at any scene to highlight a point or replay the clip for a specific in-class exercise; (6) Set a time for reflection on what was scene; (7) Assign an active learning activity to interact on specific questions, issues, or concepts in a clip; and (8) Structure a discussion around those questions in small and/or large group format. (p. 10)

Finally, multimedia presentations can be effective in other STEM courses such as a calculus-based introductory electricity and magnetism physics course (Stelzer, Gladding, Mestre, & Brookes, 2008). Students who received a multimedia learning module to learn Coulomb's Law, electric fields, electric flux, and Gauss' Law had higher exam scores and retention of the information than students who learned via the textbook. The multimedia learning modules

consisted of dynamic animations synchronized with audio narration. Based upon the research on multimedia learning, connecting course material to relevant examples in the form of pictures or videos can prove to be useful in promoting deeper understanding and retention of the information.

Illustrative example. One of Dr. Demmig-Adams' strengths as a professor is her refined skill of placing the general biology material in the context of students' lives. The following example highlights the way in which she uses images (see Appendix B) to help students understand potential energy and active/passive transport. These images help to connect real-world examples to biological concepts by drawing on student experiences (e.g., sledding) or student knowledge (e.g., water accumulation and subsequent electricity generation via a hydroelectric dam). The images depict a rock on the edge of the cliff, a girl dropping the book, and children sledding downhill that are familiar to students and can help them to understand how potential energy can go from high to low energy states.

Dr. Demmig-Adams also uses videos to help students visualize certain processes such as water transfer from plant roots to the leaves (see http://www.colorado.edu/ebio/genbio/03_03WaterTransport_A.html), the inner workings of a cell (see <http://multimedia.mcb.harvard.edu>), or to engage students with the material through interesting renditions, such as a rap about DNA replication and protein synthesis (see <https://www.youtube.com/watch?v=d1UPf7lXeO8>).

Polling. Increasing student engagement and learning during class can be accomplished through the use of real-time polling systems. Real-time polling systems include clickers (i.e., hand-held devices that allow students to click buttons that correspond with multiple choice answers), cell phones, laptops, and tablets (Stover, McNutt, & Heilmann, 2015). Stover et al. (2015) investigated the effects of real-time polling on students' perceptions of how this

interactive system influenced their understanding, satisfaction, participation, and engagement. An analysis of student responses regarding polling provided insight into its perceived benefits. Students generally enjoyed the anonymous nature of this response system, felt they improved in their understanding of course material and had deeper discussions, believed they were more accountable for the information and could compare their performance to their peers, and indicated they were more engaged and attentive during class. The body of research further demonstrating the efficacy of polling systems in the form of clickers will be discussed in the third cluster “Assessing Student Performance.”

Illustrative example. Dr. Demmig-Adams uses clickers as her classroom polling system. She typically incorporates at least five clicker questions during her 50-minute lecture and utilizes the polling information to gauge how well her students understand the information. Students receive participation points for answering these questions as well as points for getting the correct answers. Some of the questions (polling questions on class composition and student interests as well as repeat questions from earlier lectures) are to be answered independently, whereas most questions are to be answered in a “pair-discuss-vote” (also termed “think-pair-share” in CU’s introductory General Biology I course) format, where students discuss the questions with those around them before answering. The time given per question varies depending on the length and complexity of the questions.

Effective teaching model. Perhaps the most important element of an effective course is the actual instructional approach to student learning. The need to improve teaching using evidence-based instructional approaches has led to a highly contested debate in education. At the heart of this debate is how strongly guided instruction should be for students (Clark, Kirschner, & Sweller, 2012; Cobern et al., 2012). Upon careful examination of the scientific research

literature, fully guided, scaffolded instruction has been shown to be an effective approach (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Clark et al., 2012; Klahr & Nigam, 2004; Mayer, 2004; Rosenshine, 2012). This approach can be summarized as “I do, we do, you do” (Archer & Hughes, 2011).

To understand how an instructional approach can impact student learning, the tenets of cognitive science should first be discussed. “The relations between working and long-term memory, in conjunction with the cognitive processes that support learning, are of critical importance to developing effective instruction” (Clark et al., 2012, p. 8). Atkinson and Shiffrin (1968) developed the foundational model of memory that described the possible flow of information from sensory memory to short-term (working) memory (WM) to long-term (LTM) memory (as cited in Matlin, 2013). LTM can be thought of as a storage house for information that may be minutes to decades old (Matlin, 2013). On the other hand, WM contains information a person is actively using (Matlin, 2013) and is where conscious processing occurs (Clark et al., 2012). Information in WM can move to LTM, and information stored in LTM can be pulled back into WM. Thus,

WM represents both the activated portion of LTM and the set of control processes that act on those activated representations in order to bring them into a heightened state of activation and actively maintain them in the face of distraction. (Unsworth, 2010, p. 26)

When it comes to learning, students should have related information stored in LTM to pull from when solving novel or complex problems (Clark et al., 2012). If students do not have prior knowledge from which to pull to solve these problems, they place a larger burden on their WM. This burden prevents learning from taking place because WM is unable to contribute to the learning process while it is searching for solutions (Kirschner, Sweller, & Clark, 2006). Thus, it

is important to teach students in a way that allows significant concepts and procedures to be stored in LTM for future use when solving novel or complex problems. To promote effective and efficient learning, students should be fully guided through the learning process with careful modeling, guided practice, and subsequent opportunities to perform the skill independently (Marchand-Martella, Martella, & Martella, 2014).

Instructor modeling is an essential element of the effective teaching model that includes instructor demonstrations and think-alouds (Rosenshine, 2008). For example, to show students how to solve a math problem, an instructor could show and tell students each step of the algorithm used to solve the problem. Instructors can then check for student understanding by asking questions to eliminate student misconceptions as they present new problems (Marchand-Martella & Martella, 2013; Rosenshine, 2008). Instructors can break the material into manageable steps that mitigate WM overload and can solidify prerequisite skills needed to advance student knowledge. If students are required to “discover” the target information completely on their own without instructor guidance, “they may fail to come into contact with the to-be-learned material” and “no amount of activity or discussion will be able to help the learner makes sense of it” (Mayer, 2004, p. 17). Showing students how to perform a skill before asking students to practice it on their own is an effective and efficient way to promote student understanding (Archer & Hughes, 2011) and ensure the learned information moves to LTM.

For example, instructor modeling was a key component of the “control of variables” strategy (CVS) (Klahr & Nigam, 2004). This strategy is a way to conduct experiments, where only a single variable differentiates the experimental conditions. Klahr and Nigam (2004) found that instructional guidance, including modeling, and feedback helped students design “unconfounded” (i.e., high internal validity) experiments and created more CVS masters (i.e.,

students who designed an unconfounded experiment on three out of four attempts) than when no guidance and feedback were provided by the instructor. This instructional support also led to a large percentage of students being able to engage in higher-order cognitive skills such as evaluation. For students to make valid inferences during an experiment, instructional guidance should thus be provided during the teaching of experimental designs (Lazonder & Egberink, 2014).

As part of instructional guidance, active-learning strategies can be critical in the progression from “I do” (i.e., lecture) to “we do” (i.e., student practice in class with feedback). For example, in an introductory physics class, a combination of instructor guidance and feedback with active-learning strategies (e.g., use of clicker questions) resulted in better exam performance (Deslauriers, Schelew, & Wieman, 2011). Active-learning strategies have a growing body of research support, as summarized in several research reviews and evidenced in experimental studies (see Armbruster, Patel, Johnson, & Weiss, 2009; Cotner, Loper, Walker, & Brooks, 2013; Freeman et al., 2014; Freeman et al., 2007; Gavalcova, 2008; Gardner & Belland, 2012; Jensen, Kummer, & Godoy, 2015; Kim, Sharma, Land, & Furlong, 2013; Marbach-Ad & Sokolove, 2000; Michael, 2006; Zepke & Leach, 2010) and often include problem solving, collaboration and discussion, animations, and technology-enhanced activities (Gardner & Belland, 2012). Student participation can be encouraged in large lecture courses through the use of probing questions (Allen & Tanner, 2005) that can be answered via clickers; these questions may require analysis or evaluation and can promote student discussion.

Student discussion can be effective in promoting student learning and was found to enhance understanding in an undergraduate genetics course (Smith et al., 2009); this finding may be the result of students constructing their own explanations for why answers may be correct or

incorrect and the opportunity to listen to the justifications of other group members. The think-pair-share strategies can also help students develop higher-order cognitive skills (Bamiro, 2015). In think-pair-share, questions are posed to students who have time to think about their answers. They then pair up with a fellow student to answer these questions. Following this scheduled brainstorming, students are asked to share what they found. Importantly, the “we do” element of the effective teaching model should include positive and constructive feedback, such that students can improve their learning and develop a firmer understanding of the material (Marchand-Martella, Martella, & Lambert, 2015; Rosenshine, 2008). As stated by Hattie and Timperley (2007), “Feedback is one of the most powerful influences on learning and achievement, but this impact can be either positive or negative” (p. 81). To create positive and effective feedback, the feedback should be immediate, constructive, explicit, and specific to the task (Hattie & Timperley, 2007).

Finally, students should be given opportunities to practice skills independently (in the “you do” part). Students who receive homework, for example, have opportunities to solidify their skills on their own (Archer & Hughes, 2011) and to store the information in LTM. The goal of the effective teaching model is to have students become independent learners (Rosenhine, 2008) who have gained ownership of their learning. Students should be prepared for independent practice opportunities such as homework assignments or clicker questions based upon the scaffolding they received throughout the course lesson; these independent practice opportunities should be aligned with future assessments such as quizzes, tests, and/or exams. This guided approach should reduce errors (as advocated by Hattie, 2009) during this independent “you do” step and should only occur once students reach mastery (80% success rate) during guided practice (Hofmeister & Lubke, 1990). The benefits of the effective teaching model cannot be

overstated as they relate to improved student understanding and achievement as well as to decreased student frustration and error rates.

Illustrative example. The effective teaching model is well used by Dr. Demmig-Adams in the General Biology I course. She uses PowerPoint slides to present new material and provides explanations, elaborations, examples, and demonstrations as she presents the information on each slide. She guides students through each step of complex processes while describing not only the “how” but also the “why” of each step. When students have questions, they are allowed to raise their hand, and she responds to their inquiries. Given her expertise, Dr. Demmig-Adams often uses additional information and stories related to the material to both broaden and deepen students’ understanding. Multimedia such as videos is also incorporated during her lectures to expose students to different and/or additional explanations and examples.

Clicker questions are used throughout her lectures to give students an opportunity to state on their own what was just modeled by the instructor and to extend these insights to new situations. Students are typically allowed to talk with their fellow students and then are required to select an answer with their clickers. After each question, Dr. Demmig-Adams provides explanations for why each answer choice was either correct or incorrect. Students may also be called upon to voice their own thinking on these questions. To encourage students to continue to review the course material, repeat clicker questions from past lectures may be used during later lectures. These questions also represent the types of questions students must answer on the course exams.

Independent practice opportunities occur when clicker questions require students to answer questions without peer discussion; the weekly online homework assignments provide

additional independent practice. Students receive feedback on both the clicker questions and the homework assignments, ensuring students do not practice errors or develop misconceptions.

Assessing Student Performance

Assessment informs instructional practices. If students are struggling with class material, instructors can reteach difficult concepts; if students are learning at high levels, instructors can progress to new topics. To promote students' knowledge, planned test preparation activities including review/help sessions can be incorporated into classes. Further, to test students' knowledge, several types of assessments can be utilized including clicker questions, homework, and exams.

Test preparation. Forms of assessments such as quizzes and exams typically comprise a large proportion of total course points. Course grades may be entirely based upon midterm and final exams or may be dependent on both assessments and other factors such as attendance or group activities. Multiple-choice tests are quite common in introductory science classes, particularly those offered by research universities (Stanger-Hall, 2012). Due to the importance of testing students to inform one's teaching and to designate course grades, preparing students for these evaluations of their learning can help them to experience greater academic success.

Review/help sessions. Beyond regularly scheduled lectures and labs that comprise the foundational aspects of the course, many instructors offer additional opportunities for students to master the course material. One such opportunity commonly found in introductory courses is the review/help session. Leaders of these sessions are generally teaching assistants (Jensen & Moore, 2009), or such sessions can be led by the instructors themselves. Exam content is not revealed during the review/help session; student questions are answered and course content is reviewed (Jensen & Moore, 2009). Approximately 30 to 40% of students attend review/help sessions at

any one time during a course, and those with lower grades attended disproportionately fewer of these sessions than those who received higher grades (Jensen & Moore, 2009; Moore, 2008). Unfortunately, students who need to improve their grades in the course generally do not take advantage of extra opportunities to practice the material (Moore, 2008).

If instructors offer the review/help sessions during class, students with lower grades may be helped with the course material. Unfortunately, students with “D” and “F” grades typically have excessive absences (Jensen & Moore, 2009) and thus would not necessarily benefit from in-class review/help sessions either. These sessions are beneficial for “A,” “B,” and “C” students because they receive extra practice with the material, can have their questions answered, and are provided with additional explanations (Jensen & Moore, 2009; King, 2010). Clicker questions can be an effective way to engage students during these review sessions (King, 2010). Finally, Hackathorn et al. (2012) found that when students attended more traditional (i.e., question and answer) or trivia-based (e.g., *Jeopardy*) review/help sessions, they experienced an increase in their exam scores. Whether review/help sessions result in higher exam grades due to the sessions themselves or based upon the types of students who attend these sessions, researchers generally conclude that time spent reviewing material is an important way to help students refine their understanding of the course content.

Illustrative example. Dr. Demmig-Adams has offered a review/help session, consisting of a question-and-answer period, where students offer questions and are provided with detailed explanations from her, during the lecture day before the scheduled exam. However, she found that this session is typically attended by the already well-prepared students rather than those who need help. For that reason, Dr. Demmig-Adams provides a series of practice-exam questions as in-class clicker questions a week before the exam for students to answer without discussing with

fellow students. These clicker questions may prompt further class-content questions from the students in the lecture, which Dr. Demmig-Adams answers. After each question, Dr. Demmig-Adams points out which of her previous lecture slides (available to the students in the online course content) and associated explanations (available in her recorded lectures posted as online course content) presented in class covers the concepts needed to answer the respective clicker question.

Types of assessments. When it comes to assessment, there are two main feedback mechanisms. The first feedback mechanism is immediate and the second feedback mechanism is less immediate (Ludwig et al., 2011). *Immediate* feedback comes from clicker questions and small group activities. *Less immediate* feedback comes from quizzes and tests.

Clicker questions. As previously discussed, real-time polling can be beneficial in promoting student engagement and learning. A popular version of these student response systems in college classes is clickers (Herreid, 2006). As stated above, clickers are handheld keypad devices that allow students to answer questions posed during class. These questions increase students' opportunities to respond (OTR), which have been shown to improve on-task behavior, increase academic success, and decrease off-task behaviors (e.g., Haydon, MacSuga-Gage, Simonsen, & Hawkins, 2012; Moore Partin, Robertson, Maggin, Oliver, & Wehby, 2010; Sutherland, Alder, & Gunter, 2003; Sutherland & Wehby, 2001). The clicker package includes the handheld keypad, a receiver that accepts signals from the clickers, and a clicker program for the instructor's computer (Hatch, Jensen, & Moore, 2005). Instructors can lecture on a particular topic and intermittently check student understanding by asking questions, allowing all students to click-in their answers. After a pre-determined amount of time passes to answer a question, the question "closes," and instructors can see the class's data on their computers. This response data

can also be displayed for the class, allowing students to compare their understanding to their peers' understanding (Zhu, 2007). Importantly, no more than 20 minutes per instructional session should be devoted to the use of clickers (Society for Advancement of Education, 2008).

Large classrooms can be a challenge when it comes to gauging how well each student understands the material. When relying on individual student responses, instructors may receive a skewed view of how well their students are doing in the class based upon the few select students who typically respond to their questions posed during class. However, clickers can provide insight into the understanding of the class as a whole by collecting responses from all of the students present. Further, these devices provide anonymity, likely leading to more honest responses from students (Herreid, 2006). When instructors receive the clicker data, they can use the information to decide whether or not to reteach material, provide further examples and explanations, or progress with the lesson; thus, student performance informs instruction (Chih-Yuan Sun, Martinez, & Seli, 2014). This immediate feedback aspect of clickers is crucial to students' learning experiences. Given the vast amounts of information that clickers can provide, the questions can be designed with specific goals in mind. For example, questions could be used to assess students' knowledge, locate misconceptions, and test generalization or even to garner student opinions (Caldwell, 2007).

Numerous studies support the use of clickers to enhance learning for students (e.g., Haydon et al., 2012; Kenwright, 2009; Keough, 2012; Moore Partin et al., 2010; Pollock & Perkins, 2004; Salemi, 2009; Sevan & Robinson, 2011; Sutherland et al., 2003; Sutherland & Wehby, 2001). In fact, students overwhelmingly reported that they had a better understanding of the class material after using the technology (Stover et al., 2015). Further, students report being more engaged and motivated (Condon, 2013; Oigara & Keengwe, 2013; Trees & Jackson, 2007)

and have more opportunities to participate with the use of this technology (Caldwell, 2007). Student discussions can also occur during clicker questions; these discussions may provide an avenue for students to use reasoning skills and to exchange ideas (Knight, Wise, & Southard, 2013) and can make students feel like a more active member of the class (Stover et al., 2015).

Illustrative example. As stated previously in the illustrative example for “polling,” Dr. Barbara Demmig-Adams provides students with at least 5 clicker questions during each 50 min lecture. After each clicker question, she discusses why the correct answer was correct and why the incorrect answers were incorrect. She also may ask the class if anyone would like to explain why he/she chose a particular answer. Any clicker questions that received low percentages of correct answers in previous years have been broken down by Dr. Demmig-Adams into a series of questions that first individually address the thinking that needs to go into each step of a more complex process, followed by a culminating question that requires the students to combine several simple arguments into a complex outcome.

Each clicker question has been created with a particular goal in mind. In other words, Dr. Demmig-Adams identifies the material she wants to ensure students understand before progressing in the lecture and turns this information into clicker questions. She uses her knowledge of how to sequence material to design clicker questions that build one another, leading students to perform well on the ultimate, highly complex clicker question that requires higher-order cognitive skills such as analysis, synthesis, and evaluation.

Homework. The updated saying “practice makes permanent” speaks to the importance of providing students with assignments such as homework to promote mastery through practice and review. The effectiveness of homework generally relates to the opportunities by which students receive “additional opportunities to apply and generalize skills and knowledge outside of school”

(Archer & Hughes, 2011, p. 233). Homework should align with instruction be used to firm and extend skills. As stated by Archer and Hughes (2011),

Practice, practice, practice. This is not always the first choice of human beings. And yet if instruction is not yoked to judicious practice, skills will not be retained. Too often this is exactly what occurs: Initial instruction is not followed by well-designed distributed and cumulative practice, which results in exposure to content rather than mastery. (p. 243)

While homework can benefit students by helping them to master skills, assigning these additional activities when students do not have the skills to independently complete their work can discourage them (Vatterott, 2010) and lead to frustration (Protheroe, 2009). Hattie (2009) warned against homework that leads to students internalizing incorrect routines. The effects of homework are highest when students practice or rehearse information/skills at high levels (Hattie, 2009) and when “students practice getting it right” (Lemov, Woolway, & Yezzi, 2012, p. 25). Homework questions should only involve previously learned skills (Martella, 2010) and “will not be used to teach complex skills. It will generally focus on simple skills and material or on the integration of skills already possessed by the students” (Cooper, 1989, p. 90). However, when used correctly, homework can be a valuable tool to reinforce students’ learning (Carr, 2013). It can also be used to promote self-regulation in students, giving them more responsibility to reach their goals (Bembenutty, 2011). The effectiveness of homework applies not only to students in K-12 but to students at the college level as well.

Opportunities for students to practice skills within college course material can increase student achievement and competence. Online homework assignments are becoming more common in face-to-face courses (Bonham, Deardorff, & Beichner, 2003) and provide a unique avenue by which to foster student mastery and provide immediate feedback (Richards-Babb,

Drelick, Henry, & Robertson-Honecker, 2011). The positive aspects and appropriate use of homework have been outlined by Cooper (1989) for print-based homework assignments. Online homework is now popular; studies examining online homework have been conducted as have studies comparing print-based versus online homework at the college level. Dillard-Eggers, Wooten, Childs, and Coker (2008) found a positive association between the completion of online homework assignments and course grades. Further, when students in a college chemistry course spent more time on each online homework question and attempted these questions fewer times, they were found to have higher course grades than students who spent less time on each question and accessed the questions several times (Bowman, Gulacar, & King, 2014). Online homework may also be an effective way to help lower-performing students (Wooten & Dillard-Eggers, 2013) because it provides practice for these students and motivates them to engage with the course material.

When investigating online homework assignments in large introductory science courses, Dufresne, Mestre, Hart, and Rath (2002) found that online versions of the homework assignments led to higher exam performance than the paper-and-pencil versions of these homework assignments; Arasasingham, Martorell, and McIntire (2011) also found that online homework assignments resulted in higher final exam scores. In contrast, Bonham et al. (2003) showed that online forms of homework do not always lead to higher levels of learning and performance as compared to other formats of homework. Nevertheless, online homework performance can be a useful predictor of how students will score on tests that measure problem-solving skills (Lazarova, 2015). Regardless of the homework format (online or print-based), the benefits of practice cannot be overstated and, when implemented correctly, can lead to increases in student achievement (Williams, 2012).

Finally, to increase the number of students who complete homework assignments, course points can be attached to each practice activity. Ryan and Hemmes (2005) found that when points were provided for homework assignments, the number of assignments submitted was higher than the group of students who did not receive this incentive. Credit can be a powerful motivating factor for students to complete their homework (Planchard, Daniel, Maroo, Mishra, & McLean, 2015). Further, when homework credit was based on accuracy instead of simple question completion, students had higher accuracy, more detailed answers, and greater exam performance (Galyon, Voils, Blondin, & Williams, 2014).

Illustrative example. The online biology site *MasteringBiology* (see <http://www.pearsonmylabandmastering.com/northamerica/masteringbiology/>) provides students with assigned homework assignments that account for 1/6 of their biology course grades. As stated in Dr. Demmig-Adams' syllabus, "All answers to the homework questions can be derived from the material presented in class and the lecture PDFs." One homework assignment is assigned each week, and students receive feedback on their answers after the homework is due. Instead of offering makeup homework, Dr. Demmig-Adams allows students to drop 10% of the total available homework points.

Exams. One of the most common strategies to assess student learning is through exams. Exams are important for assessing students' knowledge and for helping students to have enhanced learning and retention opportunities (Rohrer, Taylor, & Sholar, 2010). The practice of retrieval promoted by exams is a key element in strengthening long-term memory (Brame & Biel, 2015). Exams are typically comprised of multiple-choice questions (Simkin & Kuechler, 2005), especially in introductory science courses (Stanger-Hall, 2012). Simkin and Kuechler (2005) reviewed the literature on multiple-choice tests and found several advantages and disadvantages.

Advantages of using these types of questions include efficiency (i.e., easy to grade when teaching large courses), objectivity (i.e., each question has a correct answer and thus does not need a rubric), more immediate feedback (i.e., grading is quicker), and longer tests (i.e., more questions can be asked and on a wider range of topics). Brame and Biel (2015) discussed several studies that found multiple-choice questions improved recall.

Disadvantages of multiple-choice exams typically revolve around the limitations of such questions in assessing higher order thinking skills (Simkin & Kuechler, 2005; Stanger-Hall, 2012). When instructors use multiple-choice questions, the questions often assess lower level thinking skills such as recall and identification. Despite the importance of students developing critical thinking skills, the development of test questions to assess these skills has been difficult for faculty (Bissell & Lemons, 2006). Writing questions that assess critical thinking can also be more time consuming than giving constructed-response questions such as fill-in-the-blank. When traditional multiple-choice tests were compared to multiple choice/constructed-response question tests (“nontraditional” test) in an introductory science course, students exhibited improved learning and critical thinking with nontraditional tests (Stanger-Hall, 2012). One way to aid instructors in creating multiple-choice questions that assess varying levels of cognitive skills is through Bloom’s Taxonomy.

Bloom’s Taxonomy is a framework consisting of six categories that categorize particular goals of education; these categories include (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, and (6) Evaluation (Armstrong, 2016). These different levels of cognitive skills can be collapsed into two overarching cognitive-skill categories—lower-order and higher-order cognitive skills (Crowe, Dirks, & Wenderoth, 2008). Levels 1 and 2 of Bloom’s Taxonomy are considered lower-order cognitive skills; Level 3 consists of lower and higher-

order cognitive skills; and Levels 4, 5, and 6 are said to include higher-order cognitive skills. Crowe et al. (2008) created an assessment tool based on Bloom's Taxonomy called the Blooming Biology Tool. By using this tool, these researchers were able to evaluate 600 science questions and provide examples of activities and questions that could be used to meet each of the six taxonomy levels. Multiple-choice questions could be created for each level except for the fifth and last level "Synthesis." The reason for this limitation is that being provided with possible answers for each question removes the opportunity for students to independently develop a novel response.

Multiple-choice exams can be created to assess both lower and higher-order cognitive skills as shown by Crowe et al. (2008). Unfortunately, these exams typically contain questions that require more memorization and less analysis or evaluation, and they may provide a skewed representation of students' understanding (Simkin & Kuechler, 2005). For example, after an evaluation of an introductory biology course and an introductory physics course, Momsen et al. (2013) concluded that questions on both courses' assessments were primarily testing lower-order cognitive skills. These findings are concerning due to the importance of ensuring that students develop critical thinking skills in STEM courses. Using Bloom's Taxonomy to evaluate exam questions and to create new exam questions can be a positive way to design exams that are more accurate in assessing actual student understanding. Finally, in addition to aiming for higher level of Bloom's Taxonomy, the questions should assess student mastery by including questions that assess fundamentals (i.e., prerequisite skills) and key concepts and that put students at a disadvantage when they have not attended class lectures/discussions (Diegelman-Parente, 2011).

Illustrative example. Dr. Demmig-Adams has experienced great success with designing the "Un-Google-able" question, such that General Biology exams can be given online. Most of

her exam questions are at least at Level 3 of Bloom's Taxonomy and are geared more toward assessing higher-order cognitive skills as compared to lower-order cognitive skills. In Appendix C, questions from her past exams are provided to illustrate the assessment of higher-order cognitive skills.

Conclusions and Recommendations

To provide U.S. students with the skills they need to do well in STEM disciplines and to reduce the fatigue and attrition in these areas, it is essential to implement effective and efficient instructional practices in our courses. The research literature has an expansive number of articles that focus on evidence-based educational practices; however, choosing from among these practices to redesign courses may be rather challenging for new or inquiring instructors. This thesis offered a practical example of how an introductory course in biology could be structured and taught in ways that are evidence based and promote student understanding and achievement in STEM.

After examining Dr. Demmig-Adams' section of General Biology I, three overarching clusters emerged related to her organizational and instructional practices. These clusters included: (1) structuring a course, (2) focusing on *how* to teach, and (3) assessing student performance. Structuring a course included three specific elements: (1) syllabus, (2) scope and sequence, and (3) learning management system. Focusing on *how* to teach included two specific elements; the first element included three sub-elements: (1) learning-conducive atmosphere that included (a) humor, (b) relevant course content, and (c) polling; and (2) effective teaching model. Assessing student performance included two specific elements; each element included sub-elements: (1) test preparation that involved (a) review/help sessions; (2) types of assessments that involved (a) clicker questions, (b) homework, and (c) exams. Each individual

practice/approach was supported by the research literature and was illustrated with real examples from Dr. Demmig-Adams' section of General Biology I.

Practical/Teaching Recommendations

The organizational and instructional practices researched in this thesis provide instructors with evidence-based practices that they may choose to adopt in their own courses. Further, illustrative examples of how Dr. Demmig-Adams uses these strategies in her own teaching may prove helpful to other instructors. However, the overarching clusters identified in this thesis do not contain every research-validated educational practice that could be incorporated into a college-level class. After reviewing a large portion of the research literature on ways to improve STEM education specifically and education in general, a few additional practices emerged as being highly effective. These included the use of frequent quizzes, practice exams, and study guides—each will be briefly discussed next.

Incorporating several opportunities for students to be tested on course material can be an effective way to enhance student learning. Several researchers have examined the effects of frequently assessing students and have found that weekly quizzes improved students' performance on tests and exams (McDaniel, Anderson, Derbish, & Morrisette, 2007; McDaniel & Agarwal, 2011); repeated testing led to greater retention than studying (Roediger, & Karpicke, 2006), and “testing potentiates further study” (Brame & Biel, 2015, p. 8). Relatedly, practice exams that mirror actual exams allow students to actively retrieve information from their long-term memory, strengthening this information in the process (Dunlosky, 2013). Practice exams help simulate conditions of actual exams, increasing student confidence and overall learning (Brown et al., 2014). These practice exams can help students identify where they may be struggling and what they should focus on when they study for actual exams (Dunlosky, 2013).

Finally in a major research synthesis, Dunlosky, Rawson, Marsh, Nathan, and Willingham (2013) concluded the following:

On the basis of the evidence described above, we rate practice testing as having high utility. Testing effects have been demonstrated across an impressive range of practice-test formats, kinds of material, learner ages, outcome measures, and retention intervals. Thus, practice testing has broad applicability. Practice testing is not particularly time intensive relative to other techniques, and it can be implemented with minimal training. (p. 35)

Dr. Demmig-Adams has given practice tests in the past when she used a mix of lower-order and high-order exam questions and found that students who scored increasingly highly on the practice exams were still unable to demonstrate higher-order thinking skills during an oral follow-up exam with her. They appeared to have learned to “take the test” rather than actually deepening their understanding. Dr. Demmig-Adams started administering exams consisting entirely of higher-order questions for her first online exams in the fall of 2015. These exams consisted of 30 questions corresponding to her exam topics on the study guide, each represented by 4-7 alternative higher-order questions randomly rotated in for the respective exam topic, thus providing a “unique” online exam for each student. Development of over 100 higher-order exam questions for an exam is no trivial task, but Dr. Demmig-Adams plans to develop a large bank of similar higher-order questions to use for future practice exams. She hopes these practice exams will prompt students to return to working on their higher-order skills after taking the practice exam rather than merely learning “to take the test”.

Traditional study guides typically accompany the textbook (Vandsburger & Duncan-Daston, 2011) and may help students on their exam performance (Dickson, Miller, & Devoley, 2005) due to the opportunity these study tools provide students to interact with the material and

become more self directed in their learning (Mafinejad et al., 2014). “Study guides have three roles in facilitating learning: (1) assisting in the management of student learning; (2) providing a focus for student activities relating to the learning; (3) providing information on the subject or topic of study” (Harden, Laidlaw, & Hesketh, 1999, p. 248). A review sheet can also be provided to students that includes a list of exam topics as well as practice exam items beyond the textbook (Nilson, 2010). Dr. Demmig-Adams provides students with a list of exam topics as well as practice exam questions (see pages 75-81 in Appendix A for the list of exam topics).

Future Research Directions

The importance of teaching students in the most effective and efficient ways possible cannot be overstated. To ensure the efficacy of educational practices, scientific rigor cannot be abandoned. Unfortunately, after reviewing the research literature on educational practices, I often found there to be a lack of operational definitions when describing variables of interest. To be able to replicate a study, it is imperative that clear definitions are provided for teaching practices studied, and that methodology is precise and carefully described. Klahr (2013) emphasized the need to define experimental variables by creating a table in which he removed the names of the instructional practices and instead characterized them based on what they did and did not do (see Appendix D). Miscommunication can arise and staunch disagreements ensue over terms such as *direct instruction* or *inquiry-based learning* when variation exists for terminology (Klahr, 2013). The same term may be used with multiple definitions. Further, categorizing specific teaching approaches in consistent ways can help to improve instructional fidelity and can create better clarity in pedagogical approaches. In fact, teaching practices inventories and classroom observation protocols have been created by several researchers to reliably characterize specific approaches implemented in college courses (Smith, Jones, Gilbert, & Wieman, 2013; Wieman &

Gilbert, 2014). Faculty can use these tools to evaluate their own or their colleagues' teaching practices. These tools can improve the scientific rigor of educational research and of our educational practices.

One particular term that needs to be operationally defined and furthered studied is *active learning*. Active learning has been shown to enhance student learning; however, the specific aspects of active learning that promote student understanding are rather ambiguous. Active learning seems to be on a spectrum from traditional lecture with a few class clicker questions to student-centered learning in the form of group work with no instructor guidance or instruction. To conclude that active learning encourages student achievement, researchers need to operationally define active learning and compare varying forms of this procedure.

Mayer (2008) discussed the need to apply the science of learning and instruction when designing multimedia instruction, for example. Instructional methods should be “consistent with research-based theories of how people learn (i.e., the science of learning) and evidence-based principles of how to design instruction (i.e., the science of instruction)” (Mayer, 2008, p. 760). Psychology offers a unique avenue by which to improve math and science education through cognitive psychology, developmental psychology, cognitive science, and the learning sciences (Newcombe et al., 2009). In fact, “Collaborations between cognitive scientists and STEM education developers would not only improve teaching and learning in STEM undergraduate sources but also help identify causal mechanisms for improved learning” (Henderson, Mestre, & Slakey, 2015, p. 51). Interdisciplinary research such as collaboration among psychologists, educators, and STEM researchers can offer exciting new ways to improve STEM education because each researcher can contribute his/her own unique expertise. Unfortunately,

the connections between psychological data and educational practice have often been difficult to forge. This is unfortunate, not only because psychological research has the potential to enrich and ground educational practice but also because educational practice has the potential to enrich and ground psychological research. (Newcombe et al., 2009, p. 539)

Based upon the need to make educational research more rigorous through operational definitions and interdisciplinary research, future researchers should be cognizant of how they define their independent variables and should collaborate with researchers from other disciplines and/or with other areas of expertise. To encourage faculty to adopt the practices found to be effective through scientific validation and to critically examine their own teaching, universities may need to provide faculty with the resources, time, and incentives necessary to make important changes and facilitate a change in thinking that views teaching as a scholarly and important endeavor (Brownell & Tanner, 2012). A positive development in higher education is the hiring of science faculty who specialize in education (Allen, 2013); these instructors can provide beneficial insights and can support them in their pedagogical approaches.

The goal of improving U.S. student performance on international assessments and reducing the STEM fatigue and attrition is a realistic goal. However, to reach this goal, several steps must be taken. First, the scientific rigor of educational research must be improved through operationally defining the variables of interest in a study, through instructional fidelity checks, and through the application of the science of learning and instruction to educational methods. Second, researchers from different disciplines should collaborate to address STEM education questions. Finally, faculty should be encouraged to adopt research-based teaching principles and

to evaluate their own teaching in the process. By treating educational research as an essential and rigorous endeavor, researchers can better address issues in STEM fatigue and attrition.

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Appendices

Appendix A

Course Syllabus and Supporting Materials

EBIO 1210 GENERAL BIOLOGY – FALL 2015

Lecture Professor weeks 1 through 8: Dr. Barbara Demmig-Adams

Office hrs: Ramaley C434; Monday & Wednesday 3:30-4:30 pm. Phone: (303) 492-5541

Lecture Professor weeks 9 through 15: Dr. Sam Flaxman

Office hrs: Ramaley N211; Mondays noon to 1 pm; Tuesdays 9-10 am; other times by appointment. Phone: (303) 492-7184

Course Meets: MWF 10-10:50 am (sect. 001) *or* 11-11:50 am (sect. 002) in MUEN E050

Lecture Coordinator: Mr. Derek Sweeney

Help Room/Tutoring Center: Ramaley N197

Course email address: genbiohelpMWF@colorado.edu (will be answered by Mr. Sweeney; for questions about registering for and using *iClickers* and the online homework, first use the contact information below)

This course is intended for students in pre-health, professional, science, and other programs for which biology is a requirement. Students wishing to satisfy the Natural Sciences Core Requirement can take EBIO 1030/1040 for **non-science** majors. For biology-related majors, EBIO 1210 establishes the foundations for many upper division courses. The first half of the semester focuses on life's key molecules and cellular processes, and their roles in human health or energy. The second half of the semester focuses on genetics and evolution, and current topics related to these important areas. A separate laboratory course, EBIO 1230, is a co-requirement for some majors (see departmental requirements and/or advisor). **Testing out of the course:** If you already have a background in biology equivalent to the material covered in this course, you can test out of this course by taking the College Level Examination Program (CLEP) test (contact Career Services <http://careerservices.colorado.edu/testing/CLEP.aspx>).

MATERIALS AND ACTIONS REQUIRED FOR ALL STUDENTS:

1. Textbook: Campbell Biology in Focus (note: choose either the electronic version OR a hard copy; you do not need both).

2. An Access Code for *MasteringBiology.com*: Credit is given in this class for online homework. You need to purchase access to ***MasteringBiology*** to be able to do the homework assignments. An access code for *MasteringBiology* may come bundled with the textbook. Otherwise, you may purchase *MasteringBiology*, alone or with an eBook version of the text (Campbell Biology in Focus), for a special discounted price through this website http://www.pearsoncustom.com/co/uc_ebio1210/. To access the homework site on future visits, you can log in to <http://www.masteringbiology.com>.

Essential information for registering and enrolling: the zip code for the University of Colorado is **80309**; select the **Campbell Biology in Focus textbook**; **your *MasteringBiology* Course ID is EBIO1210MWF2015**. You may use any login name and

password when initially registering for *MasteringBiology*. However, **when you enroll in our specific course (after registering), you must provide your official University of Colorado IdentiKey login name** when prompted, which is the only way we can give you credit for your homework (see: “What is an Identikey login name?”

<http://www.colorado.edu/oit/services/identity-access-management/identikkey>). Each homework assignment will be available for credit for a limited time (see deadlines in *MasteringBiology*); the correct answers will be visible after the deadlines for completion of each assignment. 1/6 of your final grade will be based on the *MasteringBiology* homework assignments over the whole semester. For questions about how to log into and use *MasteringBiology*, contact the support staff via one of multiple avenues.

Access Customer Support at <http://247pearsoned.custhelp.com/app/ask>, where you will find: System Requirements, Answers to Frequently Asked Questions, and additional contact information for Customer Support, including 24/7 Live Chat, email, and phone support at 844-292-7017. If your *MasteringBiology* questions cannot be resolved by any of the means above, email Erin.Daubenmire@pearson.com. If applicable, please provide Erin with your Incident Number (that will look something like this: 120819-004421).

3. i>Clicker: To receive credit for your answers to questions posed in class, you also need to purchase the university-supported *i>Clicker* remote and register it. To register your clicker online, you can go through your own portal in MyCUInfo (see <http://www.colorado.edu/oit/tutorial/cuclickers-iclicker-remote-registration>). **Please note that you must enter your CU IdentiKey Login Name in the Student ID field (and NOT your CU student ID number!) during this registration process – if you fail to use your IdentiKey Login Name, the clicker points that you earn will not show up in Desire2Learn (D2L) and will not contribute to your grade.** Please also note that you must register your clicker at the beginning of each academic year. You are responsible for bringing your clicker to class every day! 1/6 of your final grade will be based on the points earned from *i>Clicker* responses to questions in class over the whole semester. To make it easier for students who have to miss a few class periods due to illness and other circumstances beyond their control, the full (maximum possible) *i>Clicker* credit will be given for 90% of the *i>Clicker* questions offered over the semester. For the occasional polling question you will receive full credit for participation, and for most other questions (with one correct answer) you will receive credit for answering correctly. The *i>Clicker* questions that involve credit for the correct answer are included in the lecture PowerPoints posted on D2L no later than the day before each class. For problems with the functioning of your *iClicker*, please seek assistance from the Office of Information Technology Service Center staff (see <http://www.colorado.edu/oit/support-training/it-service-center>).

4. Desire2Learn (D2L), <https://learn.colorado.edu/>: Students are required to check D2L for important class announcements several times a week. We will use D2L to post all information relevant to the course, including announcements, syllabus, course policy, textbook units corresponding to lectures, PowerPoint presentations (including Exam Topics and *iClicker* questions), and points that you have earned (e.g., from Clicker responses, exams, etc.).

5. Additional Expectations and Requirements: Students are responsible for all information presented in lecture, information posted on D2L, homework assignments, announcements, etc. If book chapters or sections are assigned as required reading, this

material, along with designated lecture material, is eligible for inclusion on the exams. Students are expected to check their University of Colorado email account and D2L regularly for important communication from the course instructors.

FORMAT OF EXAMINATIONS: There will be four midterm exams and one cumulative final exam, each consisting of 30 multiple-choice questions, and all administered through D2L. Wi-fi/Ethernet connectivity and a working computer with a D2L-compatible browser are required for participation in the exams, and are the student's responsibility. Using smartphones or tablets to take the exam is NOT recommended. The first three midterms will be given on Monday evenings (Sept. 21, Oct. 19, Nov. 16) from 7-9 pm, whereas the fourth midterm exam plus the cumulative final exam will be administered during the final exam time scheduled by the University (Tuesday, December 15, from 10:30 am to 1 pm). The fourth midterm exam will focus on material presented in the last quarter of the semester. The cumulative final covering the whole semester will contain questions on the material for all four midterms (15 questions from the first half of the semester and 15 questions from the second half), and is offered as a make-up exam for anyone who was unable to take one of the previous midterm exams. The cumulative final can also be taken optionally by anyone who would like the chance to drop his or her lowest midterm exam score by earning a higher score on the cumulative final. In addition, exam 2 is cumulative over the first half of the semester. For our policy on missed exams, see the next section. Put all exam dates on your calendar at the beginning of the semester! Each exam is worth a maximum of 100 points, and the exams will constitute 4/6 of your final grade.

CALCULATION OF YOUR FINAL GRADE: Your final grade is calculated based upon three sources:

1. Homework assignments on MasteringBiology (1/6 of your grade): the total points toward your final grade from homework will be calculated with the following formula, and will not exceed 100%:

$$(100 * \text{raw homework points earned}) / (0.9 * \text{total available raw homework points})$$

The "0.9" in the formula equates to *dropping 10%*. This is a 10% forgiveness for missing (parts of) homework assignments for any reason. We do NOT offer makeup homework assignments.

2. Points earned from using your i>Clicker in class (1/6 of your grade): the total points toward your final grade from i>Clicker usage in class will be calculated with the following formula, and will not exceed 100%:

$$(100 * \text{raw clicker points earned}) / (0.9 * \text{total available raw clicker points})$$

The "0.9" in the formula equates to *dropping 10%*. This is a 10% forgiveness for missing clicker points for any reason. We do NOT offer makeups for clicker points.

3. Points earned on examinations (4/6 of your final grade): Four of the five exams offered will be counted for the final grade. For students who miss one of the first three midterms, the cumulative final will serve as their makeup exam (this is the only option we offer for a makeup). For students who take all five exams, we will automatically drop the lowest exam grade of the five (i.e., your four best exams will count). Any students forced to miss the fourth midterm/cumulative final due to circumstances beyond their control (illness, death in the immediate family, unavoidable emergencies) should contact us **immediately** with documentation to schedule a make-up cumulative final.

From the above three sources of points, your final percentage will be calculated as your earned points out of the maximum possible (you can think of that as 100 points from

each exam as 4/6 of the credit, plus 1/6 of the credit for *iClickers* and 1/6 of the credit for homework, for an overall total of 600 points). At the end of the semester, we will then use the following scale to determine your final course letter grade: 94%-100% = A, 90%-93% = A-, 87%-89% = B+, 84%-86% = B, 80%-83% = B-, etc. However, the actual grade cut-offs are sometimes more favorable than this point scale would indicate. The cut-offs for the semester are only set **after** all of the adjusted final scores have been reported from all sections. ***NO letter grades will be assigned to the individual exams. Numeric grades are NOT rounded (you get what you get).***

Preparing for Success: General Biology can be a demanding course and students are sometimes overwhelmed with the details of the subject. We post our lecture PowerPoints BEFORE our lectures to allow students to prepare for the *iClicker* questions as well as review the “Exam Topics” before coming to each lecture. All answers to the homework questions can be derived from the material presented in class and the lecture PowerPoints. For one-on-one help from a TA, and regular tutoring on a weekly basis, visit the Help Room (free Tutoring Center in Ramaley N197; open most hours of the week). For questions about the biology, typically approach the TAs first, and if your question is not fully addressed, write to the course email address (<genbiohelpMWF@colorado.edu>) or go to the professor’s office hours. ***Those who cram just before the exams are typically disappointed with their grade.*** To evaluate your understanding of the material, try explaining to the TA WHY the correct answers to particular clicker questions are correct (and why each of the others is incorrect!) and ask the TA for feedback. Meeting regularly with a study group of classmates is also helpful.

Policy on Acceptable Use of Email: Responses to queries submitted to the course email address <genbiohelpMWF@colorado.edu> will be answered by your lecture coordinator Mr. Derek Sweeney and/or the graduate and undergraduate Teaching Assistants for this course. Email messages should be professional, concise, courteous like a formal letter, and to the point. Since your lecture professors (Drs. Demmig-Adams and Flaxman) are each responsible for approximately 700 students, they are unable to answer email queries about any procedural matters already detailed in lecture and available in the material posted on Desire2Learn (exam dates and time, any required readings, what material is covered on exams, anything in this Course Policy, etc.).

University Policies: Campus Policies will be enforced and students are expected to be aware of these policies (<<http://www.colorado.edu/catalog/2015-16/campuspolicies>>). We want to foster a positive learning and working environment for everyone and will enforce the relevant policies below (Honor code, classroom behavior, and sexual harassment policy).

Special Accommodations

Disability: We are sincerely committed to assisting you in any way possible! If you qualify for exam accommodations because of a disability, please submit a letter to us from Disability Services in a timely manner (***at least one week before the first exam***) so that we have time to find reasonable means of accommodation. Disability Services (303-492-8671, DSInfo@colorado.edu, and <http://disabilityservices.colorado.edu/>) determines accommodations based on documented disabilities. You must contact us prior to each

exam to ensure that exam accommodations are arranged. Please also let us know if there are any accommodations we can make for you during lectures or for other aspects of the class.

If you have a temporary medical condition or injury, see [Temporary Injuries guidelines](#) under Quick Links at the [Disability Services website](#) and discuss your needs with your professor.

Religious Observances: Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments, or required attendance. In this class, we will try to accommodate religious conflicts in a reasonable manner. Please check the syllabus at the beginning of the semester to identify possible conflicts. ***Requests for adjustments must be made during the first two weeks of the class.*** Our generous policy on credit for in-class clicker responses, homework assignments, and exams (see above) should accommodate most individuals. Additional information can be found at http://www.colorado.edu/policies/fac_relig.html.

Honor Code: All students of the University of Colorado at Boulder are responsible for knowing and adhering to [the academic integrity policy](#) of this institution. Violations of this policy may include: cheating, plagiarism, aid of academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct shall be reported to the Honor Code Council (honor@colorado.edu; 303-735-2273). Students who are found to be in violation of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion). Additional information regarding the Honor Code can be found at <http://www.colorado.edu/policies/honor.html> and at <http://honorcode.colorado.edu>.

Classroom Behavior: Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, color, culture, religion, creed, politics, veteran's status, sexual orientation, gender, gender identity and gender expression, age, disability, and nationalities. Class rosters are provided to the instructor with the student's legal name. We will gladly honor your request to address you by an alternate name or gender pronoun. Please advise us of this preference early in the semester so that we may make appropriate changes to my records. See policies at <http://www.colorado.edu/policies/classbehavior.html> and at http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code.

Discrimination and Sexual Harassment: The University of Colorado Boulder (CU-Boulder) is committed to maintaining a positive learning, working, and living environment. CU-Boulder will not tolerate acts of discrimination or harassment based upon Protected Classes or related retaliation against or by any employee or student. For purposes of this CU-Boulder policy, "Protected Classes" refers to race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Individuals who believe they have been discriminated against should contact the Office of Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Student Conduct (OSC) at 303-492-5550. Information about the ODH, the above referenced policies, and the campus resources

available to assist individuals regarding discrimination or harassment can be found at the [OIEC website](#). The [full policy on discrimination and harassment](#) contains additional information.

LEARNING GOALS

General process-related learning goals

- Practice critical thinking and evidence-based reasoning
- Apply critical thinking and evidence-based reasoning skills to science

Alignment with departmental process-related learning goals

- Interact with peers, share information, and make succinct, persuasive, evidence-based arguments during in-class iClicker discussions and use these skills in study groups
- Begin to decipher, assess the validity, and gauge the uncertainty of scientific claims, identify social influences on scientific pursuits or acceptance of science, and judge and critique the reliability and authenticity of information (will be visited in lecture presentations and during in-class iClicker discussions)
- Correctly interpret graphical, tabular, and text-based descriptions of data

The above process-related learning goals will be practiced using the content below

General topic-related goals for the first half of EBIO1210

- Make connections between the molecules of life and their functions within organisms as well as in the interaction of organisms with their environment
- Follow information flow through biological cells; identify indispensable cell features
- Follow energy flow through biological systems
- Make connections between the above processes and human health and/or human society

Specific topic-related goals (= Exam Topics) for the first half of EBIO1210

Exam 1

Lipids 1: Fats and their link to energy metabolism and health

- Know the four classes of large biological molecules and their building blocks.
- Know the three sub-groups of lipids and their function.
- Know the building blocks of a fat.
- Relate structural differences between saturated and unsaturated fatty acids to their differences in shape, in fluidity, in energy content, and in their health effects.
- Compare the properties of nonpolar and polar bonds, and predict from its bonds whether a molecule is an energy source.
- Identify and use the common principles underlying structure, formation, and breakdown of the four classes of large biological molecules.

Lipids 2: Phospholipids & polarity; cholesterol & steroids

- Relate the properties of oxygen (O), hydrogen (H), and carbon (C) to molecules they form.
- Relate the hydrogen bond to the properties of water that support life.
- Use polarity to predict whether a substance is hydrophilic or hydrophobic.
- Relate nonpolar covalent bonds, polar covalent bonds, and electrically charged substances to solubility.

- Know the building blocks of a phospholipid.
- Relate the structure of phospholipids to their function in biological membranes.
- Relate the structures of fats and phospholipids to their relative energy content.
- Classify cholesterol as a steroid and a precursor in the synthesis of important hormones.

Membranes 1: Structure & function; links to ecology

- Relate the basic structure of biological membranes to their principal functions.
- Relate phospholipids made from saturated, monounsaturated, and polyunsaturated fatty acids to membrane fluidity and the ecology of organisms.
- Identify the role of cholesterol in membrane fluidity.
- Use the solubility of molecules to predict their passage through biological membranes.
- Predict where hydrophilic versus hydrophobic components are found in various transport proteins.

Membranes 2: Principles of active and passive transport across membranes

- Predict when a protein is needed for movement of substances across membranes.
- Predict when energy (in the form of ATP) is needed to fuel transport across membranes.
- Explain the connection between potential energy and the movement of substances across membranes.
- Apply the principal features and functions of an ATP-fueled pump to the Na^+/K^+ pump.
- Relate the structure of ATP to its energy content and its function in fueling the 3 major kinds of cellular work.
- Place ATP at the intersection between energy-providing and energy-requiring pathways.

Membranes 3: application to nerves & muscles; links to nutrition

- Identify the involvement of active and passive transport in nerve function.
- Relate the function of omega-3 fatty acids to their role in the prevention of disorders.
- Identify the involvement of active and passive transport in muscle function.

Proteins: hemoglobin and sickle-cell trait; synthesis, solubility, and signaling by protein and steroid hormones

- Identify the sequence of information flow from DNA to RNA to proteins.
- Relate amino acid sequence and three-dimensional protein structure to the corresponding levels of protein structure.
- Relate altered protein structure to altered protein function for the examples of hemoglobin and myoglobin.
- Relate polarity or electric charge of different amino acid side groups to protein function.
- Relate the following cell components to their respective functions: Rough and smooth ER, free and bound ribosomes, transport vesicles, cytoskeleton, and the Golgi apparatus.
- Place the components of the endomembrane system into a functional sequence.
- Differentiate the roles of endocytosis and exocytosis in bulk transport.
- Identify the role of ATP and cytoskeleton tracks in vesicle movement.
- Predict the function of specialized cells enriched in either rough or smooth ER.
- Predict solubility and signal transduction for protein hormones versus steroid hormones.

Health

- Identify genetic and dietary factors affecting LDL-receptor level, and relate this to receptor-mediated endocytosis and heart disease.
- Relate the dietary intake of different fats to the programming of human metabolism.
- Know in which major human tissue systems aquaporins play a role.

Exam 2

Cell Diversity: Cell features of different groups of organisms; links to evolution and health

- Know what features all living cells share.
- Use presence or absence of certain cell components to predict to which domain of life an organism belongs.
- Relate mitochondria and chloroplasts to their principal metabolic roles and to the organisms in which they occur.
- Relate the endosymbiont theory to the evolution of eukaryotes.
- Use cell features to predict whether a given cell is an animal cell or a plant cell.

Carbohydrates: Principles; links to energy metabolism, energy flow in ecosystems; links to health and metabolic programming

- Identify a hexose as a 6-carbon monosaccharide.
- Identify what features make sugars an energy source.
- Place sugars into the context of photosynthesis and cellular respiration.
- Follow the flow of carbon from CO₂ to sugars and back between producers and consumers.
- Follow the flow of energy between producers and consumers.
- Identify the reason why sugars (and not ATP) are used for longer-term storage of energy.
- Predict the formula of sugars composed of more than one monosaccharide.
- Know the examples of mono-, di-, and polysaccharides from lecture.
- Relate high fructose corn syrup (HFCS) to human sugar transporters and to fructose malabsorption.
- Relate differences in lactose intolerance among human populations to their diets over evolutionary history.
- Relate the structures of starch, glycogen, and cellulose to their respective digestibility, their functions, and the organisms and tissues in which they occur.
- Relate the structures of the starches amylose and amylopectin to the respective speed of their breakdown.
- Relate different carbohydrates to their roles in the programming of human metabolism.

Photosynthesis: Principles; energy flow in ecosystems

- Place photosynthesis into the context of energy and carbon flow between producers and consumers; be able to identify the overall inputs and outputs of photosynthesis.
- Identify the energy donor ATP and the H shuttle NADPH as the link between light reactions and carbon conversion reactions of the Calvin cycle in photosynthesis.
- Locate light reactions and Calvin cycle to chloroplast grana and stroma, respectively.
- Know the source of oxygen produced in photosynthesis.
- Apply the model of the hydroelectric dam to photosynthetic ATP formation by ATP synthase, and identify active and passive transport of H⁺ in chloroplasts.
- Identify the following as energy-rich states in photosynthesis: Excited electrons; H⁺ gradient; ATP and NADPH; Sugars.

-Predict the relative rates of photosynthesis and respiration in a green leaf.

Respiration: Principles; energy flow in ecosystems; aerobic cellular respiration

- Place cellular respiration into the context of energy and carbon flow between producers and consumers; identify the overall inputs and outputs of cellular respiration.
- Predict changes in the binding capacity of hemoglobin for O₂ and CO₂.
- Place cellular respiration (ATP formation) into the context of cellular work.
- Locate glycolysis, the citric acid cycle, and electron transport to cytosol, mitochondrial matrix, and inner mitochondrial membranes, respectively.
- Identify the H shuttle NADH as the link between carbon conversion reactions (glycolysis and citric acid cycle) and mitochondrial ATP formation in cellular respiration.
- Identify the terminal electron acceptor of the mitochondrial electron transport chain and its essential role in energy metabolism.
- Identify the following as energy-rich states in cellular respiration: C-H bonds in food molecules; NADH; H⁺ gradient; ATP.
- Relate the link between mitochondrial electron transport and ATP synthesis to the model of the hydroelectric dam, and identify active and passive transport of H⁺ in mitochondria.
- Relate heat loss in metabolism to energy flow through ecosystems.
- Explain why mitochondria generate heat (as a form of energy) in endothermic organisms and how the uncoupling protein enhances heat generation.
- Explain why uncouplers, cyanide, and carbon monoxide can be deadly.
- Know which macromolecules can be used as fuels in cellular respiration.

Comparisons: Comparison of photosynthesis & respiration

- Place photosynthesis and cellular respiration into the context of energy and carbon flow between producers and consumers; identify the overall inputs and outputs of photosynthesis and cellular respiration.
- Identify the roles of oxygen and water in photosynthesis and cellular respiration.
- Identify the principal roles of ATP, NADPH, and NADH in photosynthesis and mitochondrial respiration.
- Compare the mechanism of ATP formation in photosynthesis and mitochondrial respiration.
- Compare the location of the electron transport chain/ATP synthase and carbon-conversion cycles in photosynthesis and mitochondrial respiration.

Comparisons continued: Comparison of aerobic respiration with fermentation in muscles & in microbes; links to industry & health

- Compare and contrast anaerobic and aerobic respiration with respect to location, speed, energy yield and the involvement of oxygen.
- Relate fast-twitch and slow-twitch muscle fibers to anaerobic and aerobic respiration, respectively.
- Identify the role of the environment (including diet) in the regulation of energy storage versus energy utilization in cellular respiration.

Connections

- Identify the role of photosynthesis in the production of oxygen and ozone (and in the evolution of multi-cellular terrestrial life), as a CO₂ sink, and as a producer of food, fuels, and materials.

- Compare and contrast sucrose, starch, and cellulose as bases for carbohydrate-based biofuels and fats as the basis for biodiesel.
- Relate the differences between C3 and C4 plants to their ecological advantages and disadvantages.
- Relate the concepts of glycemic index of different carbohydrates and glycemic load to human health

This is a list of chapters/sections in the *Biology in Focus* textbook that match our lectures over weeks 1-8. The textbook includes additional detail that is not included in our lectures and exams, which is particularly true of the first chapters on Chemistry and Water. Conversely, our lectures include brand-new information that is not covered in the textbook. Everything that is covered on Exams 1 and 2 is covered in our lectures. We provide the list below textbook for optional reading.

Textbook: Campbell BIOLOGY IN FOCUS (by Urry, Cain, Wasserman, Minorsky, Jackson and Reece), First Edition

Introduction

Chapter 1 Read as you please for your own overview; this chapter is not covered in our lectures or exams, except for Figures 1.17, 1.9 and 1.11.

Lipids

Chapter 3: Overview

Concept 3.2 Macromolecules are polymers, built from monomers

Concept 3.4 Lipids are a diverse group of hydrophobic molecules

Chapter 2: Overview

Concept 2.2 An element's properties depend on the structure of its atoms

Introductory paragraph to 2.2

Sub-sections on "Subatomic Particles" (you do not need to know the terms "neutrons" and "daltons") and on "Electron Distribution and Chemical Properties" (you do not need to know the term "valence electrons")

Concept 2.3 The formation and function of molecules depend on chemical bonding between atoms (you are not responsible for the sub-sections on "Van der Waals Interactions" and "Molecular Shape and Function"; you also do not need to know the terms "structural formula", "molecular formula", "valence", "cation", and "anion")

Concept 2.5 Hydrogen bonding gives water properties that help make life on Earth possible (you are not responsible for the sub-sections on "Cohesion of Water Molecules", "Moderation of Temperature by Water", "Floating of Ice on Liquid Water", "Solute Concentration in Aqueous Solutions", and "Acids and Bases")

Membranes

Chapter 5: Overview

Concept 5.1 Cellular membranes are fluid mosaics of lipids and proteins (you do not need to know the terms "amphipathic" or the content of Figures 5.2 and 5.4)

Concept 5.2 Membrane structure results in selective permeability

Concept 5.3 Passive transport is diffusion of a substance across a membrane with no energy investment (only subsection “Facilitated Diffusion: Passive Transport Aided by Proteins”; you are not responsible for the terms “ion channels” and “gated channels”)

Concept 5.4 Active Transport uses energy to move solutes against their concentration gradients (only introductory paragraph and subsection “The Need for Energy in Active Transport”)

Chapter 6: Overview

Concept 6.1 Only Figures 6.2 and 6.3

Concept 6.3 ATP powers cellular work by coupling exergonic to endergonic reactions (only introductory paragraph and text associated with Figures 6.8, 6.9a and b, 6.10, and 6.11, not including the equations with the kcal values for the reactions; you do not need to know the terms “exergonic” or “endergonic”)

Chapters 37 and 39

Concept 37.1-3 on nerve function. What you need to know about the involvement of active and passive transport across membranes during nerve function is contained in the lecture slides that list “ETs” at the top. The readings in the book are optional; the book covers these concepts in considerably greater detail than is required for our exam.

Concept 39.1 on muscle function. What you need to know about the involvement of active and passive transport across membranes during muscle contraction is contained in the lecture slides that list “ET” at the top. The readings in the book are optional, but may be helpful for your understanding.

Proteins

Chapter 3

Concept 3.6 You need to know that nucleic acids are polymers consisting of nucleotides and that nucleic acids store, transmit, and help express hereditary information; you are not responsible for Figures 3.26c & 3.27b and sub-sections “Nucleotide Polymers” & “The Structures of DNA and RNA Molecules”

Concept 3.5 Proteins include a diversity of structures, resulting in a wide range of functions (you are not responsible for Figures 3.18, 3.19, 3.20, 3.23, 3.24 and the associated text)

Chapter 4

Concept 4.3 The eukaryotic cell’s genetic instructions are housed in the nucleus and carried out by the ribosomes (you do not need to know the terms “nucleolus” and “ribosomal RNA”)

Concept 4.4 The endomembrane system regulates protein traffic and performs metabolic functions in the cell (you do not need to know the terms “glycoproteins”, “cis”, or “trans” and you are not responsible for the sub-sections on “Lysosomes: Digestive Compartments” & “Vacuoles: Diverse Maintenance Compartments”)

Concept 4.6 (only introductory paragraph and subsection on “Roles of the Cytoskeleton: Support and Motility”)

Health

Chapter 5

Concept 5.6 The plasma membrane plays a key role in most cell signaling (only introductory paragraph and text associated with Figures 5.23 and 5.26)

Concept 5.5 Bulk transport across the plasma membrane occurs by exocytosis and endocytosis (you do not need to know the terms “phagocytosis”, “pinocytosis”, and “ligand”)

Cell Diversity**Chapter 4:** Overview

Concept 4.2 Eukaryotic cells have internal membranes that compartmentalize their functions (you are not responsible for Figure 4.6 or the term “nucleoid”)

Concept 4.5 Mitochondria and chloroplasts change energy from one form to another (you are not responsible for the subsection on “Peroxisomes: Oxidation”)

Carbohydrates**Chapter 3**

Concept 3.3 Carbohydrates serve as fuel and building material (you do not need to know the term “glycosidic”)

Photosynthesis

Chapter 8: Overview (you do not need to know the terms “heterotrophs” and “autotrophs”)

Concept 8.1 Photosynthesis converts light energy to the chemical energy of food (you are not responsible for the details in “The Splitting of Water”, for the sub-section on “Photosynthesis as a Redox Process”, or for the term “photophosphorylation”)

Concept 8.2 The light reactions convert solar energy to the chemical energy of ATP and NADPH (only the sub-section “A Comparison of Chemiosmosis in Chloroplasts and Mitochondria”)

Concept 8.3 The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO₂ to sugar (only the paragraph on “Phase 1: Carbon fixation”)

Respiration**Chapter 7:** Overview

Concept 7.1 Catabolic pathways yield energy by oxidizing organic fuels; only the subsection “The Stages of Cellular Respiration” with Fig. 7.6 (you do not need to know the terms/concepts “pyruvate oxidation” or “substrate-level phosphorylation”)

Concept 7.2 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate; only the subsection “Chemiosmosis: The Energy-Coupling Mechanism” (you are not responsible for the details in Fig. 7.14 and Fig. 7.15).

Comparisons**Chapter 7:**

Concept 7.5 Fermentation and aerobic respiration enable cells to produce ATP without the use of oxygen (only Figure 7.17)

Concept 7.6 Glycolysis and the citric acid cycle connect to many other metabolic pathways (only Figure 7.18)

Connections**Chapter 8:**

Concept 8.3 Subsection on “Evolution of Alternative Mechanisms of Carbon Fixation in Hot, Arid Climates” (you are not responsible for the term/concept “photorespiration”, for the details on “CAM plants”, or for the subsection on “The Importance of Photosynthesis: A Review”)

EBIO 1210 Tentative General Biology Lecture Schedule (Fall 2015, MWF), MUEN E050
 Sections 001 (10:00-10:50 am) & 002 (11:00-11:50 am); Professors Demmig-Adams & Flaxman
 Required textbook reading is listed below under “Reading”. For the first 8 weeks of EBIO1210 (Demmig-Adams), textbook reading is optional (see D2L for a file entitled “Optional Reading Week 1-8”).

Please note that especially for Weeks 9 – 15, portions of this syllabus may be different from the TTH class. So, **ONLY** use this syllabus if you are in a MWF section!

Dates	Topics
Week 1 (8/24-8/28)	Introduction; course goals & logistics; required materials Intro to <i>MasteringBiology</i> homework site; Tips for success Lipids 1: Fats and their link to energy metabolism and health
Week 2 (8/31-9/4)	Lipids 2: Phospholipids; polarity as the key to solubility of substances; cholesterol & steroid hormones Membranes 1: Membrane structure & function; links to ecology; start with Membranes 2: Movement of substances; principles of active and passive transport
Week 3 (9/9-9/11)	Monday, Sept 7 th Labor Day – NO CLASS Membranes 2 continued Membranes 3: application to nerves & muscles; links to nutrition Proteins: Structure & function; links to health
Week 4 solubility, and (9/14-9/18)	Proteins: hemoglobin and sickle-cell trait / myoglobin; synthesis, signaling by protein and steroid hormones Health connections: cholesterol & heart disease; fats & metabolic programming; aquaporins and health
Week 5 (9/21-9/25)	Monday, Sept 21 st , No Class Evening of Sept 21st – EXAM 1, 7:00 to 9:00 pm, Online via D2L Cell Diversity: Cell features of diverse organisms; links to evolution & health Start with Carbohydrates: Principles; links to energy metabolism; energy flow in ecosystems; links to health and metabolic programming
Week 6 (9/28-10/2)	Carbohydrates continued Photosynthesis: Principles; energy flow in ecosystems Start with Respiration: Principles
Week 7 (10/5-10/9)	Respiration: Energy flow in ecosystems; aerobic cellular respiration Comparison of photosynthesis & respiration, and of aerobic respiration & fermentation in muscles & in microbes; links to industry & health Start with Connections: Plants and the global atmosphere; biofuels; pros and cons of different photosynthetic pathways (C3 and C4)

Week 8 **Connections:** Health connections: nutrition and the regulation of fat storage and (10/12-10/16) immune response; Faculty Course Questionnaires

Week 9 Monday, Oct 19th, **No Class**
(10/19-10/23) **Evening of Oct 19th – EXAM 2, 7:00 to 9:00 pm, Online via D2L**
Cell division & genetic material in cells: Mitosis
Reading: Chapter 9 in *Focus*

Week 10 **Cell division & genetic material in cells:** Meiosis
(10/26-10/30) Reading: Chapter 10 in *Focus*
Genes, heredity, and Mendelian genetics: introduction
Reading: Chapter 11 in *Focus*

Week 11 **Genes, heredity, and Mendelian genetics:** continued
(11/2-11/6) Reading: Chapter 12 in *Focus*

Week 12 **Genes, heredity, and Mendelian genetics:** conclusion
(11/9-11/13) **DNA and its replication**
Reading: Chapter 13 in *Focus*

Week 13 MONDAY: in-class review for Exam #3
(11/16-11/20) **Evening of Nov. 16th – EXAM 2, 7:00 to 9:00 pm, Online via D2L**
Weds. & Fri.: **Gene Expression**
Reading: Chapter 14 in *Focus*

THANKSGIVING BREAK, 11/23 – 11/27

Week 14 **Viruses** (optional reading Chapter 17 in *Focus*)
(11/30-12/4) **Gene Regulation**
Reading: Chapter 15 in *Focus*

Week 15 **Gene Regulation and Development**
(12/7-12/11) Reading: Chapter 16 in *Focus*
If time permits: one lecture period on biotechnology and/or DNA sequencing
Evolution

December 15th (Tuesday), FOURTH EXAM (30 question) + CUMULATIVE FINAL EXAM (30 questions), Online via D2L, 10:30 A.M. – 1:00 P.M.

The final exam time on December 15th is when you will take both Exam #4 (30 questions; exam worth a maximum of 100 points) and the cumulative final (30 questions; exam worth a maximum of 100 points). The cumulative final will have *approximately* 7 or 8 questions from each of the four units of material in the class. In other words, the cumulative final will have a representative balance of questions on material from the entire semester.



CU President Bruce
Benson 2014:

Employers increasingly
demand a workforce
capable of critical
thinking and analytical
reasoning, effective
communication, the
ability to apply
knowledge and skills in
real-world settings, and
teamwork.

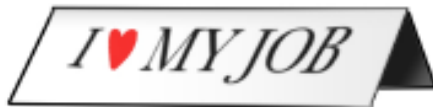


Illustration by
Alex Dubro-
Maeda



EBIO1210: General Learning Goals

- Practice **critical thinking**
- Apply critical thinking skills to science

Illustration by
Alex Dubro-
Maeda

The iClicker logo, featuring the word "iClicker" in white lowercase letters on a blue rectangular background.

EBIO1210: General Learning Goals

- Interact with peers, share information, make evidence-based arguments during in-class *iClicker* discussions



Illustration by
Alex Dutro-
Maeda

- I pledge to work to**
- (1) provide the tools and transparency for your success in this class**
 - (2) uphold standards to protect the long-term value of your degree from CU**

Exam Topics posted in online course content in Desire2Learn (D2L)

The verbs matter: "know", "relate", "deduce", "predict", "apply"

Illustration by Alex Dutro-Maeda



I pledge to work to

- (1) provide the tools and transparency for your success in this class
- (2) uphold standards to protect the long-term value of your degree from CU

**First half of Fall
EBIO1210:
Content-related
Goals**

1. To make connections between the **molecules of life**, their functions within organisms, and the interaction of organisms with the environment

2. To follow **information flow** through biological cells; to identify indispensable **cell features**

3. To follow **energy flow** through biological systems

while making connections to human health & society



Illustration by
Alex Dutro-
Maeda

Strategy for success in this class



“Cramming” doesn’t work



EBIO1210: General Learning Goals

- Practice **critical thinking**
- Apply critical thinking skills to science

(Comment: critical thinking is a skill like playing an instrument or a sport; can't just practice for 20 hours before the concert or game for success; Introduce Alex D-M)

Illustration by
Alex Dutro-
Maeda



Just as with an instrument or a sport, practicing several times a week works – “cramming” doesn’t

Illustration by
Alex Dutro-
Maeda



“iClicker questions are easier”

Illustration by
Alex Dutro-
Maeda

As is the case with a foreign language, understanding is easier than being able to say it yourself.

(First I do it and we do it together)



Understanding is easier than being able to do it yourself

Illustration by Alex Dutro-Maeda

(First I do it and we do it together, then you do it on your own; cook that meal once a week in the weeks leading up to the exam)



Understanding is easier than being able to do it yourself

Illustration by Alex Dutro-Maeda



Understanding is easier than being able to do it yourself

Illustration by Alex Dutro-Maeda



Understanding is easier than being able to do it yourself

Illustration by Alex Dutro-Maeda



Illustration by
Alex Dutro-
Maeda

Strategy for success in this class
as recommended by past students

All "Exam Topics" for Exam 1 are posted in D2L.

- (1) **BEFORE** class: Download lecture files, read "Exam topics" and prepare for answering *iClicker* questions.
- (2) To be able to **COUNT** the 150 min of class time per week as part of your exam prep, peruse the lecture PPT before coming to class.
- (3) Use the *MasteringBiology* **HOMEWORK** to review **LECTURE** PPT.
- (4) Go over material and **SAY OUT LOUD** what the reasons are **WHY** each answer option is correct or incorrect for all *iClicker* and homework questions.



Illustration by Alex Dutro-Maeda

Strategy for success in this class



Build Your Own Safety Net

Confirm the correct answer by excluding all answers that are wrong;

be able to give reasons for why all incorrect answers of *iClicker* and homework questions are wrong;

thereby become immune to confusion and make your preparation solid enough to be able to select the correct answer no matter how the question is worded on the exam.

Beginner / expert

Illustration by Alex Dutro-Maeda

- Come to the exams well-trained / practiced. Cover up the answer options and be able to say “I know what this about; they could be asking about this, that or that; then look at the answer options and decide which it is.
- Need to start working through the material NOW to keep up.

Meet your wonderful TAs who are here to help you succeed: TAs, please state your name and whether you are a graduate or undergraduate TA

SUPPORT (whole semester):

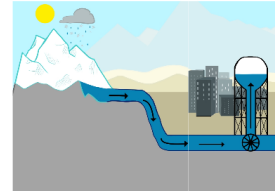
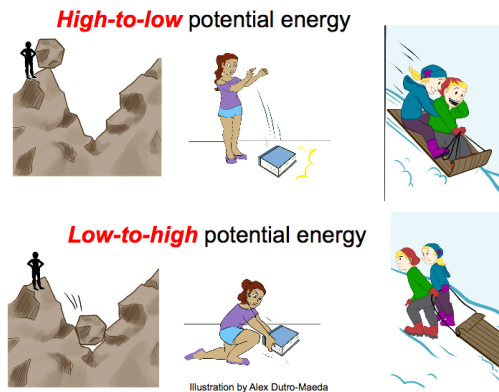
Mr. Derek Sweeney (for help with all logistics questions)
& many Graduate & Undergraduate Teaching Assistants (for help with logistics questions, questions on missed lecture, and general tutoring)

- Visit Help Room / Tutoring Center in Ramaley N197 this week for help with getting set up for use of D2L, *MasteringBiology*, *iClickers*
- Help Room / Tutoring Center will be staffed by TAs most of the week all semester

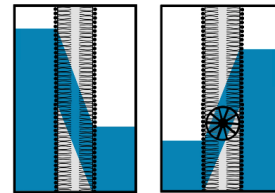
Appendix B

Example Images

ET: Explain the connection between potential energy and the movement of substances across membranes.



Downhill flow occurs without energy input

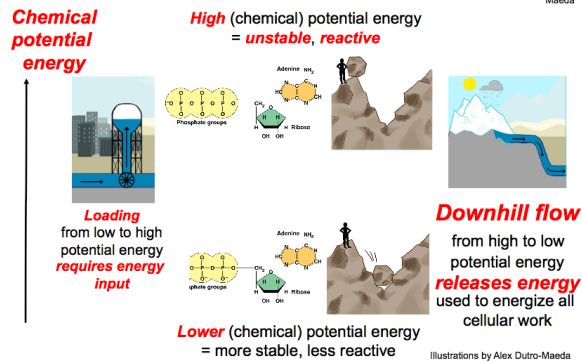


Transport uphill requires an energy-driven pump

Illustration by Alex Dutro-Maeda

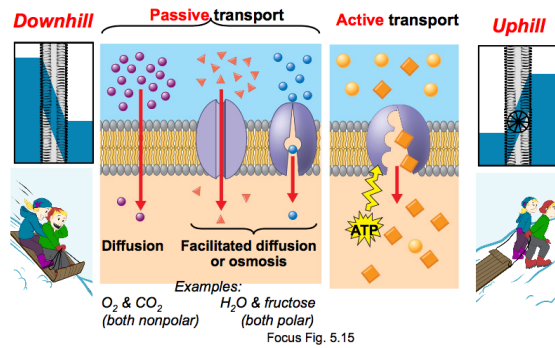
ET: Relate the structure of ATP to its function in fueling the 3 major kinds of cellular work

Illustration by Alex Dutro-Maeda



ET: Predict when ATP energy is needed to fuel transport across membranes.

Overview of the two possibilities



Appendix C

Example Questions From Past Exams

Sample Questions from Exam 2, Fall 2015

Proton transport by the photosynthetic electron transport chain occurs by _____ transport and proton transport by the mitochondrial electron transport chain occurs by _____ transport.

- *A) active; active
- B) active; passive
- C) passive; active
- D) passive; passive

Water has the same role in the model of the hydroelectric dam as the _____ in photosynthetic ATP formation by ATP synthase and as the _____ in mitochondrial ATP formation by ATP synthase.

- A) protons (H^+); electrons
- *B) protons (H^+); protons (H^+)
- C) electrons; protons (H^+)
- D) sunlight; sugars

The dam in the model of the hydroelectric dam is the same as the _____ in chloroplasts and the _____ in mitochondria.

- *A) thylakoid membrane; inner mitochondrial membrane
- B) outer chloroplast membrane; outer mitochondrial membrane
- C) stroma; mitochondrial matrix
- D) inner thylakoid space; mitochondrial intermembrane space
- E) matrix; stroma

Which molecule has the formula $C_{12}H_{24}O_{12}$?

- A) sucrose
- *B) none
- C) fructose
- D) amylose
- E) galactose

The formula for ribose is $C_5H_{10}O_5$. What is the formula of a trisaccharide made from three ribose monomers?

- A) $C_{15}H_{34}O_{17}$
- B) $C_{15}H_{32}O_{16}$
- C) $C_{15}H_{30}O_{15}$
- D) $C_{15}H_{28}O_{14}$
- *E) $C_{15}H_{26}O_{13}$

Predict how much oxygen is produced in photosynthesis compared to how much oxygen is consumed in respiration by a green leaf over a typical 24-hour day outdoors:

- A) green leaves do not consume any oxygen
- B) similar amounts of oxygen are produced and consumed
- *C) more oxygen is produced than consumed
- D) more oxygen is consumed than produced

Why do plants make sugars instead of storing ATP?

- A) Cellular work in plants is powered directly by sugars, not by ATP.
- *B) ATP is too unstable to be stored.
- C) Sugars make plants more palatable (tasty) to consumers.
- D) Sunlight can only be converted to sugars, not to ATP.
- E) Plants are unable to make ATP in the chloroplast.

Which energy-rich state is not found in either cellular respiration of animals or in plant photosynthesis?

- *A) a sodium (Na^+) gradient
- B) energized electrons
- C) NADH
- D) ATP
- E) a proton (H^+) gradient

At the beginning of photosynthetic electron transport, electrons are removed from _____ and, at the end of the mitochondrial electron transport chain, the electrons become part of newly formed _____ molecules.

- *A) H_2O ; H_2O
- B) O_2 ; H_2O
- C) H_2O ; NADH
- D) C-H bonds; H_2O
- E) NADH; O_2

Predict where the O_2 -binding capacity of hemoglobin will be lowest.

- A) in the lungs
- B) in the bloodstream on the way from the lungs to the muscles
- C) around brain cells while in a state of deep sleep
- *D) around muscle cells during intense physical activity

What do fast-twitch and slow-twitch muscle fibers have in common?

- *A) they both produce ATP
- B) they produce ATP at the same speed
- C) they produce the same amount of ATP from a glucose molecule
- D) they both use oxygen
- E) they both use fermentation

Fast-twitch muscle fibers have the advantage of _____ and the disadvantage of _____.

- A) extracting a lot of energy from glucose; not being able to act over extended periods
- B) using fat as a long-lasting energy source; not being able to use oxygen
- *C) acting quickly; not extracting a lot of energy from glucose
- D) acting over extended periods; not being able to use fat as an energy source
- E) making a lot of ATP; not being able to operate without oxygen

Compare energy transformations in mitochondria with energy transformations in other membranes of the cell: Build-up of the proton gradient in mitochondria is energized by _____; build-up of the sodium (Na^+) gradient across the outer cell membrane of a nerve cell is energized by _____.

- *A) electron flow; ATP
- B) ATP; ATP
- C) electron flow; electron flow
- D) ATP; electron flow
- E) electron flow; NADH

Compare the proton gradient in chloroplasts or mitochondria with the potassium (K^+) gradient across the outer cell membrane of a nerve cell: When considering to which form of energy the gradient is converted, potassium flowing along its concentration gradient during an action potential is most like protons flowing through the

- A) mitochondrial ATP synthase.
- B) chloroplast ATP synthase.
- *C) uncoupling protein.
- D) photosynthetic electron transport chain.
- E) mitochondrial electron transport chain.

Which is true?

- A) Photosynthesis produces ATP and respiration consumes ATP.
- *B) Electrons are removed from water in photosynthesis and accepted by oxygen in cellular respiration.
- C) ATP energizes H^+ transport from low to high concentration in both chloroplasts and mitochondria.
- D) NADPH feeds electrons into the photosynthetic electron transport chain, and NADH feeds electrons into the mitochondrial electron transport chain.

Picture a cow eating grass. Most of the sun's energy absorbed by the grass and then consumed by the cow is eventually converted to what form?

- A) fat in the cow
- B) ATP in the cow
- C) glycogen in the cow
- *D) heat in the environment
- E) CO_2 in the environment

A plant cell can reuse the _____ released in cellular respiration to make another round of sugar in photosynthesis, but cannot recycle the _____ released after using ATP for cellular work.

- *A) carbon dioxide; energy
- B) energy; carbon dioxide
- C) energy; heat
- D) sugar; ADP
- E) carbon dioxide; ADP

Which took place in the absence of molecular oxygen (O₂) or ozone (O₃)?

- A) evolution of organisms from the ocean to the terrestrial (land) habitat
- B) evolution of multi-cellular organisms
- *C) evolution of organisms using only fermentation to generate ATP
- D) evolution of ATP formation in mitochondria
- E) evolution of plants and animals

Appendix D

Three Types of Instruction

Three types of instruction			
Aspect	Type A	Type B	Type C
Materials	Ramps, Springs, Sinking Objects		
Goal setting	By Teacher: "can you find out whether X makes a difference in how far the ball rolls?"		
Physical manipulation of materials by child	Yes	Yes	Yes
Design of each experiment	Teacher	Student	Student
Probe question s	Yes	Yes	No
Explanation s	Yes	No	No
Summary	Yes	No	No
Execution of experiment s	No	Yes	Yes
Observation of outcomes	No	Yes	Yes

Key features of each of three types of instruction used. Each column represents a type of instruction; each row refers to a critical feature of each type of instruction.

Source: Klahr (2013).