# Integrating Evolution Across the Biology Curriculum

This IUSE Engaged Student Learning (Exploration tier) proposal is submitted by Armstrong State University (ASU herein; Savannah, GA) to improve evolutionary education across the biology curriculum. We request funding to sustain a two-year implementation. Our proposal outlines novel instruction previously not used at ASU and integrates the use of 3D technologies, computer simulations, and genetic sequencing to cultivate a deeper understanding of core evolutionary concepts. Our combination of instructional methods, overall theme, and use of technology is original and will provide training of in-demand technology to a diverse and underrepresented population.

## Part 1: Introduction and Justification

**<u>Objective</u>:** We propose to develop inquiry-based, outcome-driven activities to teach evolution. We will deploy these activities in upper-level biology electives that do not currently have laboratory sections. Supporting modules and concepts will also be introduced in two required introductory courses with laboratory sections to stimulate student interest and facilitate a continuous thread of learning (Fig. 1). Specific project activities include:

1. Emphasize and reinforce *structure and function* through inquiry-based and outcome-driven instruction of evolution, genotype, phenotype, and natural selection.
2. Devote instructional periods previously used for traditional lecturing to engage students in 3D scanning, 3D printing, computer modeling, computer simulations, genetic sequencing, molecular modeling, and bioinformatics.
3. Build a continuous thread of student involvement and instruction, starting with the required lower-level courses of *Introductory Biology II* and *Genetics* and continuing through upper-level electives without corequisite laboratory components including *Evolution*, *Epigenetics*, *Bioinformatics*, and *Functional Morphology*.
4. Students completing multiple courses in the sequence will have cutting-edge experience with evolutionary concepts. Students completing two or more elective courses in the sequence will be eligible for a semester-long capstone research project.

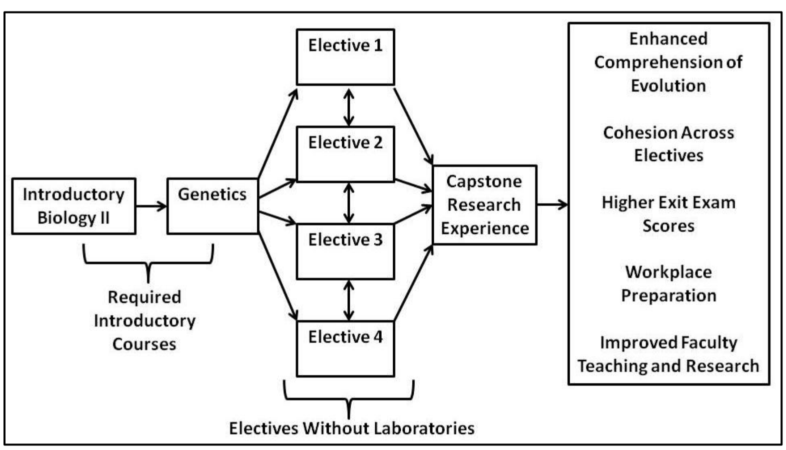


**Figure 1. Overall Project Summary**

**<u>Goals</u>:** ASU is a primarily undergraduate institution whose mission is to be student centered and promote active student and faculty engagement. Our student-first curriculum, with innovative teaching methods and new technology, will improve student understanding of evolution by exposing students to inquiry-based education, stimulating interest in biology, and increasing cohesion between cross disciplinary topics. By emphasizing the emerging interdisciplinary fields of genomics, bioinformatics, computational biology, computer modeling, biomechanics, and bioengineering, students will develop a deeper understanding of evolution and natural selection. Furthermore, the use of computing and other 3D technologies will excite and engage students, increase knowledge retention, develop desirable skills for workplace preparation, and increase engagement and interest in conducting research.

Our proposal seeks to follow general recommendations from The American Association for the Advancement of Science Vision and Change document (AAAS 2011) for improving biology education:

1. Introduce the scientific process to students early and thread the concepts through multiple courses.
2. Increase the emphasis on problem solving via inquiry-based, outcome-driven projects that develop students as active learners and ensure knowledge is applied.
3. Cultivate a deeper understanding of central topics in the field (more depth; less breadth).
4. Employ multiple modes of instruction to improve the connections between lecture topics and hands-on exercises.
5. Emphasize the importance of research and technology to provide meaningful opportunities to students.

**Statement of the Problem:** Many students lack proficiency in scientific inquiry and reasoning, and these deficiencies are stimulating discussion on how to improve science education and assessment (Fu et al. 2009; Pellegrino 2013). In response, the U.S. National Research Council (NRC 2012) defined science competency as the understanding of the intertwined and interdisciplinary aspect of core concepts rather than discrete, individual topics.

According to Pellegrino (2013) and the NRC (2012), students must move beyond the terms of “know” and “understand” when assessing science competency and advance to more rigorous categories of “analyze,” “compare,” “predict,” and “model.” However, Pellegrino (2013) argues that methods needed to improve and assess scientific reasoning are currently lacking.

Evolution is a core concept in the biology curriculum, and all biology students must be exposed to it early on in their program and then have it reinforced through their matriculation (Anderson et al. 2002; Sinatra et al. 2008). According to the AAAS Vision and Change document (AAAS 2011), the top three core concepts biologically literate students must develop are:

1. “***Evolution:*** *The diversity of life evolved over time by processes of mutation, selection, and genetic change.”*
2. “***Structure and function:*** *Basic units of structure define the function of all living things.”*
3. “***Information flow, exchange, and storage:*** *The growth and behavior of organisms are activated through the expression of genetic information in context.”*

Despite the importance of teaching evolution throughout the biology curriculum, Nelson (2008) claims teaching of evolution in institutions of higher learning is currently ineffective. Additional corroborating reports show that students do not thoroughly understand the tenets of natural selection after receiving dedicated lecture instruction (Anderson et al. 2002).

Even more troubling are multiple reports showing no statistical difference in assessment scores on evolutionary concepts between biology majors and non-majors after being taught the topics in their respective settings (Sundberg and Dini 1993; Anderson et al. 2002; Alters and Nelson 2002). Overall, the aggregate of college graduates have a low understanding of evolutionary concepts (Alters and Nelson 2002).

Multiple reasons have been proposed to explain the poor assessment performance on evolutionary topics. In general, traditional 50-minute uninterrupted lectures are very unsuccessful ways to promote learning (Alters and Nelson 2002). Specifically, after completing traditional lecture courses, Gardiner (1998) reports that material retention is as low as 20%.

Coupled with this is the claim by Linhart (1997) that the majority of textbooks incorrectly or inadequately present evolutionary concepts.

Furthermore, it has been suggested that a large underlying reason for low assessment performance on evolutionary topics is the incorrect acceptance of alternative conceptions and preconceived notions by students about evolution and natural selection (Alters and Nelson 2002; Sinatra et al. 2008). Specifically, the misconceptions lead to resistance against instruction, reduced interest, lower comprehension, and diminished critical thinking (Bishop and Anderson 1990; Alters and Nelson 2002; Anderson et al. 2002; Scharmann and Harris 1992; Clough and Driver 1986).

Since the spring 2013 semester, we have given ASU students in *Principles of Biology II* (a traditional lecture course coupled with an independent laboratory for biology majors and pre-health profession tracks) a 25-question pretest/posttest assessment. Of these 25 questions, 11 are specific to evolution, speciation, and natural selection. The assessment has been administered over five academic terms to 889 students. Overall, the students showed an improvement from pretest (36.5% correct response rate) to posttest (64.6% correct response rate) among the 11 questions, but the posttest scores are still below intended performance.

Since 2010, graduating ASU biology majors have been required to complete the Educational Testing Service (ETS) Major Field Test for Biology as their exit exam. This exam is broadly divided into four subscores, including one subscore on population biology, evolution, and ecology. For the years where data are available (2010, 2011, 2012, and 2014), the mean subscore for ASU biology graduates was 48.65 out of a possible 100 points (n = 103). The national average for this same time period (2010-2014) was 52.7 (n = 45,174; ETS 2014). In total, 43% of all students scored below the national average while just 37% of all national student scores are below the ASU average (ETS 2014). These scores demonstrate how nationally college graduates have a poor understanding of evolution, but also indicate ASU biology graduates are performing below their peers.

Furthermore, the AAAS Vision and Change document (AAAS 2011) further identifies the following top three core competencies students must learn about scientific inquiry:

1. "***Ability to apply the process of science:*** *Biology is evidence based and grounded in the formal practices of observation, experimentation, and hypothesis testing."*
2. "***Ability to use quantitative reasoning:*** *Biology relies on applications of quantitative analysis and mathematical reasoning."*
3. "***Ability to use modeling and simulation:*** *Biology focuses on the study of complex systems."*

In the fall semester of 2011, our Department of Biology developed a survey instrument to assess student evaluations of learning in biology classrooms. On the survey are questions relating the use of the scientific method, the use of critical thinking skills, and the development of critical thinking skills. After the first year this instrument was used, the department averages show that only 33% of responding students stated that the use of the scientific method was very helpful in learning course material. While 42% of respondents reported they were able to critically analyze course material, only 30% of students stated they made great gains in their critical thinking skills.

Based on the combination of exit exam scores, pretest to posttest averages, and our student learning gains assessment, our program needs to improve how we teach evolution throughout the curriculum. Furthermore, we need to make the application of the scientific process and the development of critical thinking skills our top priorities in the context of biological topics central to evolution and natural selection. Student performance on exit exams suggests that evolution is not a central tenet in their biology curriculum and we need to create a continuous thread of evolutionary thought throughout their education.

<u>**Proposal Overview**</u>**:** We recognize our need to improve biological literacy and core competencies, especially evolution and natural selection. Research has shown that personal biases and misconceptions are the most limiting factors influencing student comprehension of evolution and natural selection (Alters and Nelson 2002; Anderson et al. 2002; Sinatra et al. 2008). Inquiry-based and outcome-driven learning addresses and corrects student misconceptions, whereas traditional lecturing does not change them (Alters and Nelson 2002; Sinatra et al. 2008; Nelson 2008). Improving student comprehension of evolution should not entail only adding to their existing knowledge; it must focus on them seeing the world in new and different ways (Sinatra et al. 2008).

For the students to see the natural world in different ways, particularly when comprehending evolution, they must integrate scientific and critical thinking with experimental design (Nelson 2008). Students must directly test their misconceptions through outcome-driven projects and critical thinking (Alters and Nelson 2002) and they must establish criteria for comparing these alternative misconceptions (Nelson 2000). Models and simulations are essential for biologists to understand complex concepts, and the implementation of models and simulations needs to be increased in undergraduate courses (Rowland-Godsmith 2009).

We propose to improve how we teach evolutionary concepts via new technology and implementing new teaching methods. This additional infrastructure will reinforce inquiry-based and outcome-driven projects that directly test student generated hypotheses of evolution. We will dedicate traditional lecture time to hands-on exercises focusing on discovery and tangible outcomes through the use of models, simulations, and genetic sequencing. Overall student engagement and the application of the scientific process will increase.

<u>**Approach**</u>**:** A continuous thread of inquiry-based and outcome-driven projects will span across six courses in our biology curriculum, beginning in first-year introductory biology and continuing through four upper-level electives. We will draw from the *Disciplinary Core Ideas and Cross-cutting Concepts* from the NRC Framework for K-12 Science Education (NRC 2012) and will use the central theme of *structure and function* throughout our teaching practices as our continuous thread. This will demonstrate the intertwined and interdisciplinary aspects of science. Additionally, by using models, simulations and genetic sequencing of *structure and function*, students can quantitatively analyze data to test individual hypotheses. Also, the repeated analysis of a recurring evolutionary theme will allow students to move beyond the discrete semester mentality and develop integrated knowledge throughout their curriculum.

The continuous thread of *structure and function* will be analyzed from perspectives of evolution, genotype, phenotype, and natural selection. It has been recommended that integrated, active projects teaching evolution should include components on variation, selection, adaptation and heritability (Sundburg 2003). This combination of instruction helps students overcome misconceptions and add to their critical thinking skills and existing knowledge.

The thread can focus on any organism, or group of closely related organisms, but for our initial implementation we will focus exclusively on the evolution of the *structure and function* of hammerhead shark cephalofoils. Future iterations of the project beyond the funded two-year implementation may include additional faculty with different organismal expertise, who can then utilize different organisms to accomplish the same learning objectives.

We chose to use hammerhead cephalofoils as our first example because they are an unusual group of fishes that are characterized by a distinctive lateral expansion of the rostrum (i.e., hammer-shape). The functions of the cephalofoil have long puzzled biologists with hypotheses suggesting this structure enhances locomotion (Driver 1997; Kajiura et al. 2003; Lim et al. 2010), prey capture (Lim et al. 2010), and/or sensory perception (Kajiura et al. 2005; Lim et al. 2010). Among species of hammerhead sharks, there is considerable variation in the shape of this cephalofoil (Lim et al. 2010). This group of fishes represents an ideal system for testing hypotheses about structure, function, and selection. Additionally, there are molecular data for constructing a phylogeny (Martin 1993; Lim et al. 2010)

Furthermore, we have existing technology that has already produced student and faculty research of the functional morphology of cephalofoils with 3D printing. Also, we want to emphasize our coastal and marine location (Savannah, GA) and take advantage of hammerhead species that may be collected from the area. By taking advantage of the local environment and focusing on the *structure and function* of a group of related organisms, we will succeed in cultivating a deeper understanding of core evolutionary concepts.

To promote problem solving and ensure the student projects are outcome-driven, we will use the framework proposed by Nelson (2008) for students to establish criteria for actively compare ideas and develop critical thinking skills about evolutionary topics:

1. Experimental design that allows for direct testing of alternative evolutionary hypotheses and misconceptions. This includes examining existing data, generating new data, and ignoring situations where data is impossible (such as religious ideas). Only research questions where answers can be produced should be posed.
2. Strict analysis of *structure and function* without personal bias regarding complexity. Far too often, misconceptions about "perfection" and adaptation cloud understanding of selection and favorability of particular phenotypes.

Our continuous thread will allow for multiple modes of instruction and the promotion of interrelated topics and disciplines. ASU students will be introduced to this research and inquiry-based project during their introductory biology sequence (*Principles of Biology II*), which will then serve as a foundational experience to build upon and allow the biology program to be more integrated rather than collections of discrete course offerings. After their introductory course, students will continue the thread in the required majors course of *Genetics*, where they will approach the hammerhead sharks and cephalofoils with phylogenetic methods. Our project is then designed for students to take one or more of the following upper-level electives: *Evolution*, *Epigenetics*, *Bioinformatics*, and/or *Functional Morphology.* Students completing one or more of these electives will have an enhanced experience and will have greater working knowledge of evolutionary concepts. If a student successfully completes at least two of these upper-level electives, they will be eligible for a capstone, individualized research experience.

In *Evolution*, the students will analyze the *structure and function* of the cephalofoil from the perspective of natural selection. In the courses of *Epigenetics* and *Bioinformatics*, students will approach the *structure and function* from the perspective of genotype and gene expression. In *Functional Morphology*, students will test different cephalofoil phenotypes by measuring performance.

## Part 2: Continuous Thread Modules

**Module 1: *Principles of Biology II Laboratory (PI Hodgson)*.** This class is the second semester of an introductory series and services approximately 550 students per year. We plan to use one laboratory session to introduce the major theme of the continuous thread. The laboratories are presented as a weekly 3-hour block. We will allocate the first hour for guided inquiry and discussion, the next hour for the hypothesis, experimental design and proposal, and the final hour for the experiment and presentation of results. *The overall objective of this module is to introduce students to cephalofoils and their evolution, the availability of 3D technology, and how the technology can be used to answer specific research questions.* Also, we will excite students and attract them to continue this learning thread through our upper level electives.

**Activity 1: Guided Inquiry.** The one-day laboratory will begin with a facilitated discussion on hammerhead shark biology (number of species, distribution, basic biology) with a particular focus on the cephalofoil. Students will be given a pre-laboratory assignment the previous week to facilitate this flipped classroom discussion. Different prefabricated 3D printed cephalofoil designs will be introduced (Fig. 2), as well as different uses of the cephalofoil. The discussion will also introduce 3D printing, 3D scanning, 3D models, and a flow tank used for measuring hydrodynamics.

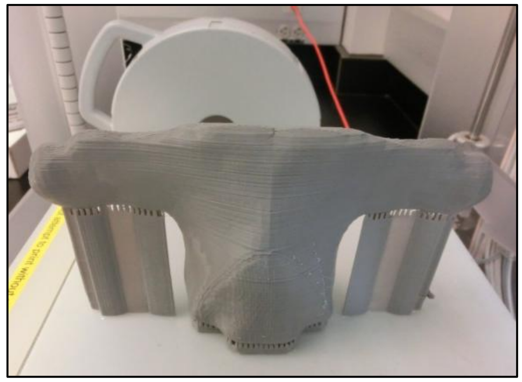

**Figure 2: Model of a Cephalofoil Produced by ASU's 3D Printer**

The example, guided inquiry discussion will compare surface area to volume ratios between a conical rostrum (i.e. non-hammer), the great hammerhead, and the bonnethead; use of previously collected data from the existing technology will be used for emphasis. The instructor will focus on hypothesis, experimental design, data collection, data analysis, and data interpretation when addressing the students. The major questions of the laboratory will ask what is the purpose of the cephalofoil, and what is possible with different cephalofoil shapes? Students will then be taken through an example of the next two steps by the instructor.

**Activity 2: Students Generate Hypothesis and Experimental Design.** Groups of four students will then identify their own hypothesis to test about the cephalofoil and they will design an experiment. Students will be charged with identifying their own question, designing their own experiment, and presenting and justifying their proposal to their peers. A main parameter of the research will be that the students have to use 3D printed models that are already in existence (i.e. their questions about the cephalofoil must be tested with the models). Potential questions that could be suggested by the instructor include: which hammer shape has more drag, which shape is a better receiver, and which traps prey on bottom? The students will be familiar with hypothesis and experimental design from an inquiry-based laboratory experience in the first introductory biology class. Thus, we will reinforce previously learned ideas.

**Activity 3: Experiment and Results.** Students will then perform their experiment, which may include the use of a flow tank and data logging equipment, and present initial results to the group. At the end of laboratory, the students will be asked to write a brief report that clearly describes their hypothesis, experimental design, data collection, results, and interpretation.

**Module 2: *Genetics (Co-PI Schrey)*.** This class is required of all ASU biology and biochemistry majors and it reaches over 100 students per academic year. We plan to use three laboratory sessions to reinforce the major theme and expand the project. *The objective is to demonstrate how DNA sequences can be used to study evolution through phylogenetic analysis.* The laboratories are presented as a 3-hour block. In the first laboratory, we will allocate the first hour for the guided inquiry introduction, the next hour for manuscript breakdown, and the last hour for data analysis and discussion of results. The second laboratory will begin with a breakdown of another manuscript including an exercise in data analysis. The remaining laboratory time will be used for student hypothesis generation, experimental design, proposal, and implementation of the experiment, which will last for an entire laboratory session. At the conclusion of the experiment, students will prepare a presentation on their project and present it to the other students in the laboratory.

**Activity 1: Guided Inquiry.** The laboratory will begin with a facilitated discussion on DNA sequence-based phylogenetic analysis. *The major question of the lab is how did the cephalofoil evolve?* Students read papers by Martin (1993) prior to the first laboratory and Lim et al. (2010) prior to the second laboratory to facilitate a flipped classroom discussion. These papers are DNA sequenced-based investigations of the hammerhead shark. The instructor will focus on hypothesis, experimental design, data collection, data analysis, and data interpretation when addressing the students.

**Activity 2: Students Generate Hypothesis and Experimental Design.** Groups of two or four students will then identify their own hypothesis and they will design an experiment. The main parameter of the research will be that the students must use DNA sequence-based phylogenetic analysis to investigate a broadly defined structure and function phenotype. Students must identify their own question (instructor provides parameters and guidance), design their own experiment, and present and justify their proposal to their peers.

**Activity 3: Experiment and Results.** Students will perform their experiment. At the end of the exercise, students will prepare a presentation that clearly describes their hypothesis, experimental design, data collection, results, and interpretation.

**Module 3: *Evolution (PI Hodgson)*.** This lecture-only class services 30-50 students per year and will evaluate the evolution of the *structure and function* of hammerhead cephalofoils through the inquiry-based and hypothesis-driven perspectives of natural selection. Students will analyze phenotypic performance through a series of computer simulations and literature reviews. The overall analysis of hammerhead cephalofoil phenotype selection will take place through three coordinated activities. The major questions of this module will be: What are the selective pressures that favored the evolution of the cephalofoil? What are limiting factors and opposing constraints influencing cephalofoil shape? How can modeling and simulation technologies be used to answer these questions?

**Activity 1:** The first activity will have the students use dedicated classroom periods to run the evolutionary simulation software *EvoBeaker* (simbio.com/products-college/EvoBeaker) as an inquiry-based, outcome-driven introduction to natural selection. *EvoBeaker* is a generalized overview of central evolutionary concepts that simulates winners and losers, but cannot be modified to simulate hammerhead cephalofoils directly; however, the progression of exercises will familiarize the students with the interplay of genetic mutations and the environment that causes certain phenotypes to be favored and selected. Moreover, they will understand how computer simulations can be used to break down evolutionary processes and test specific hypotheses. They will explore the modification of certain environmental variables and phenotypes to see how different phenotypes will be selected under different pressures. *The overall goal of this coordinated activity is to directly test hypotheses of predator-prey interactions and diversification of foraging strategies under different selective pressures.* Students will use this knowledge and experience to later test hypotheses about the cephalofoils.

**Activity 2:** The second activity will require the students to read, critically analyze, and discuss the cephalofoil manuscripts of Nakaya (1995), Kajiura (2001), Kajiura et al. (2003), and Kajiura et al. (2005) in a flipped classroom setting. Papers will be read prior to attending class to facilitate flipped classroom discussions. Collectively, these papers test alternative hypotheses about the evolution and selection of the cephalofoil morphology. Specifically, Nakaya (1995) and Kajiura et al. (2003) proposed that the cephalofoil evolved analogous to canard wings to improve hydrodynamic lift and maneuverability. Alternatively, Kajiura (2001) hypothesized that the cephafoil evolved into an elongated structure to maximize the pore density of electrosensory organs used in detecting prey. Similarly, Kajiura et al. (2005) proposed that elongated cephalofoils increased the distance between olfactory organs, which provides improved stereo-olfaction used in detecting prey. *The overall objective of this coordinated activity is to give students sufficient background concerning alternative hypotheses about the evolution and selection of the cephalofoil morphology.*

**Activity 3:** After thorough classroom discussion of these papers, the third in-class coordinated activity will involve the students building upon their computer skills learned when using *EvoBeaker* to use the evolution simulation software *Framsticks* (framsticks.com). Unlike *EvoBeaker*, *Framsticks* is user-customizable and students can build a near-endless variety of rudimentary, 3D organisms that simulate movement to test evolutionary hypotheses about phenotypic selection. Based on their literature analysis, students will be charged with developing their own hypotheses about cephalofoil evolution, but more importantly, they will develop simulation methods that can directly be used to test these hypotheses.

Within *Framsticks*, the students will design prototype stick-model sharks where they can modify specific phenotypes such as hydrodynamic lift, electrosensory organ density, and olfactory organ distance to test hypotheses about foraging success rates. The students can choose to build a series of models, and specify ranges of environmental parameters, that test a single cephalofoil hypothesis or more complex models that test a combination of hypotheses. *The overall goal of this coordinated activity is to give students the inquiry-based opportunity to design experimental methods that generate data from modeling and simulation to quantitatively analyze structure and function with final outcomes.* Furthermore, students will use this activity to understand misconceptions and make conclusions about complexity and “perfection” that hinder comprehension. Students must present their findings through a variety of means, which is further elaborated upon in the Broader Impacts section.

**Module 4: *Epigenetics (Co-PI Schrey)*.** This class is an upper-level and lecture-only elective that reaches 40-60 students per academic year and investigates non-genetic (DNA) inheritance. Students will work in groups to develop a research question to investigate epigenetics using the hammerhead shark cephalofoil as a test model. The major questions of this module will be: What epigenetic mechanisms can affect organismal phenotype? What molecular techniques are used to study epigenetic mechanisms? What is the impact of non-genetic inheritance on evolution?

**Activity 1:** Students will develop a hypothesis about epigenetic mechanisms that may affect this phenotype. This effort will follow several introductory lectures that will introduce epigenetics and molecular epigenetic mechanisms. Students will be required to use primary literature to justify their hypothesis.

**Activity 2:** Students will identify a molecular method to test their hypothesis. The first task will be for students to independently search the literature to identify available techniques. Students will then select a molecular technique to test their hypothesis. They will be asked to justify their choice. Students will generate a full research design, including materials and methods. These reports will be presented to the entire class.

**Activity 3:** Students will breakdown articles addressing non-genetic inheritance and evolution. A series of papers will be the basis of this effort. Papers will include Pal and Miklos (1999), Bonduriansky and Day (2009), Day and Bonduriansky (2011), Klironomos et al. (2013), and Jablonka (2013). They will be read prior to class for a flipped classroom discussion. Students must present their findings through a variety of means, which is further elaborated upon in the Broader Impacts section.

**<u>Module 5: *Bioinformatics (Co-PI Schrey)*</u>.** This class is an upper-level and lecture-only elective that reaches 40-60 students per academic year. We plan to incorporate student-directed investigation to evaluate evolution through the use of advanced biotechnology and bioinformatics. The course is presented two sections: biotechnology and bioinformatics. In the biotechnology half, students will develop and design a next-generation sequencing-based experiment. This will be facilitated by the Department of Biology's Ion Torrent PGM equipment (Fig. 3). In the bioinformatics half, students will work on analysis of next-gen data sets and use online databases. *The main goal is for students to work with next-generation sequencing technology and data analysis.*

**Figure 3: ASU's Ion Torrent PGM**

**Activity:** The proposal will allow students to work in groups to develop a research question using current technology. Students will be free to pursue a topic that interests them, but will be requested to specifically incorporate an evolutionary biology perspective. Student groups will develop a hypothesis, experimental design, detailed protocols, and plan for data analysis. The instructor will present an example that uses the hammerhead sharks. The instructor will encourage students to tailor their projects along two major lines. First, develop idealized projects directly following their interests but with little concern for feasibility. Second, develop a project in line with materials feasible to actually pursue the project in class. The proposals under the second option will then have the opportunity to actually be performed as demonstrations on next-generation sequencing. This will not be limited to the group who developed the proposal, but conducted for the entire class. All student groups will then use the data collected for a multi-stage bioinformatics module. Students must present their findings through a variety of means, which is further elaborated upon in the Broader Impacts section.

**<u>Module 6: *Functional Morphology (Co-PI Francis)*</u>.** This course is a lecture-only and upper-level biology elective that examines the relationship between animal *structure and function*. It services 40 students per academic year. By asking specific how, what, and why questions, students can address how variation in design (structure) contributes to variation in performance (function). Together, *structure and function* are considered to understand an animal's biological role in the environment. Students examine the major functional systems of selected invertebrates and vertebrates, including: structural elements, mechanics of support and movement, scaling and allometry, respiration, feeding, locomotion, sensory mechanisms, and reproduction. This approach allows students to compare design and performance solutions by different animals and consider the larger role of evolution.

Twenty percent of the course will be dedicated to examining how *structure and function* of the hammerhead shark cephalofoil contributes to locomotion through inquiry-based and hypothesis driven tests of phenotype. Students will review the available literature on the role of cephalofoils in locomotion. Afterwards, students will examine the performance differences of diverse cephalofoil shapes by completing three activities.

**Activity 1: Collecting 3D Data of Shark Cephalofoils.** *The objectives of this activity are to give students hands-on experience working with sharks; allow them to observe and manipulate different cephalofoil phenotypes; discover and propose questions about the structure and function of cephalofoils; as well as collect and analyze 3D data.* To generate 3D models for performance testing, a 3D scanner (Fig. 4; NextEngine 3D) will be used to image the heads of various species of hammerhead sharks (Family Sphyrnidae). Heads of locally collected sharks (e.g., bonnethead shark, *Sphyrna tiburo*), preserved specimens in museum collections (e.g., Georgia and Florida museums of natural history), and existing plaster models (e.g., taxidermy mounts) will be scanned. Additional computed tomography (CT) scans are available from Digital Morphology (http://www.digimorph.org) of the heads of the winghead (*Eusphera blochii*), great hammerhead (*Sphyrna mokarran*), and smalleye hammerhead (*Sphyrna tudes*) sharks. As control for cephalofoil shape, one or more conical-shaped shark heads will also be scanned or obtained from the Digital Morphology website. Students will learn how to obtain, process, and manipulate these 3D data. For CT scans, image slices will be imported into *OsiriX* software and stacked to produce a 3D surface model to be exported in a standard 3D format. Surface models of head shape (from 3D or CT scans) will be processed using *MeshLab* (http://meshlab.sourceforge.net) to remove scanner noise and artifacts.

**Figure 4: ASU's 3D Scanner**

**Activity 2: Producing Physical Models of Shark Cephalofoils.** *The objective of this activity is to learn how to work with 3D printing technology to generate useable materials to answer questions about cephalofoil structure and function*. This activity will also provide students with valuable, employable skills as 3D printing technology develops and expands. From the scans described above, 3D models of sharks will be printed at a smaller, standardized scale. The models generated in the first activity will be imported into 3D printer software to orient, scale to a standard size, and configure the shark heads for printing (Fig. 5). The resulting physical models of shark heads will be used to test hypotheses about the role of the hammerhead shark cephalofoil in locomotion. These techniques have already successfully rendered 3D models of shark heads at ASU for teaching and research; ASU currently possesses a first-generation, entry-level 3D printer (Fig. 2).

**Activity 3: Testing Cephalofoil Locomotor Performance.** *The objectives of this activity are to test hypotheses (i.e., Nakaya 1995; Kajiura et al. 2003) about the locomotor performance of different cephalofoil phenotypes and allow students to answer questions about cephalofoil structure and function.* To visualize and quantify water flow around a cephalofoil requires placing the 3D printed models into a flow tank (flume) with suspended particles. A laser sheet generated by a green laser (GX3 200 mW) fitted with a lens is generated to provide a planar view of the particles and their movement. The movement of these particles is captured by a high-speed video camera (Casio EX-ZR200). The video is then analyzed using the *Image Processing Toolbox of MATLAB* supplemented with the open source plugin *PIVlab* to generate flow patterns, including the travel patterns of particles and their velocities. The data generated by the software will be used to characterize the hydrodynamics of the cephalofoil and the consequences of different cephalofoil shapes. Data on flow patterns, including the travel patterns of particles and their velocities, will be used to characterize the hydrodynamics of the cephalofoil and the consequences of different cephalofoil shapes. Students must present their findings through a variety of means, which is further elaborated upon in the Broader Impacts section.

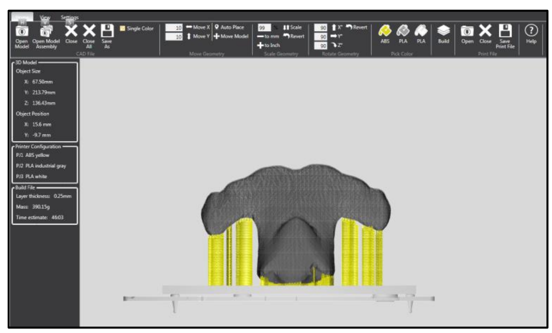

**Figure 5: Cephalofoil Prepared for 3D Printing**

<u>**Capstone Research Experience:**</u> Students who have satisfactorily completed two or more of the upper-level module-based courses (*Evolution*, *Epigenetics*, *Bioinformatics*, and/or

*Functional Morphology*) will be eligible to enroll in a capstone research experience. The ASU Department of Biology will create a two-credit, bi-weekly (six contact hours per week) studio-model course that specializes in individual and collaborative student research projects. This can first occur as a flexible special topics course and then as a designated new course number created after funding. ASU does not currently have the equivalent of an undergraduate thesis project in biology, but this experience will be the near-equivalent for students enrolled and will require students to complete an original research project with a final written manuscript. Students will be taught further how to independently use the various technologies and techniques used in the previous six modules to test their own independent research hypotheses. Moreover, they will be instructed how to quantitatively analyze their own original data used towards evaluating their research hypotheses. Students must present their findings through a variety of means, which is further elaborated upon in the Broader Impacts section.

## Part 3: Management, Evaluation, and Dissemination

**Management Plan:** ASU has previously been awarded NSF-STEP and NSF-TUES support that can be used as examples for the implementation and assessment of this proposal. Additionally, these previously awarded projects demonstrate that ASU students are receiving new models of instruction and faculty have experience, and understand the importance of, implementing wide-scale transformative changes.

This project will follow a strict timeline and budget over two years. We would like to purchase a new 3D printer, flow tank, computer software, and consumables before the fall semester starts 8/17/2015. We request a starting date of 3/01/2015 to allow extra planning time. Our existing 3D printer is a first-generation, entry-level printer that is not capable of the necessary throughput and reliability to sustain this project. The new acquisitions will support all courses except the *Capstone Research* during year 1. After the first year of implementation to provide time for prerequisites to be met, ASU will offer the capstone research experience in fall 2016. The implementation schedule of courses will follow Table 1 below.

<table>
<tr><th></th><th>Task/Course</th><th>Fall 2015</th><th>Spring 2016</th><th>Fall 2016</th><th>Spring 2017</th></tr>
<tr><td rowspan="7">Table 1. Schedule for implementation of modules. Note: the first cycle will utilize hammerhead shark cephalofoils. After the funded implementation expires in spring 2017, the modules may be changed to use other organisms or groups of closely related organisms with the existing infrastructure.</td><td>Principles of Biology II</td><td>√</td><td>√</td><td>√</td><td>√</td></tr>
<tr><td>Genetics</td><td>√</td><td>√</td><td>√</td><td>√</td></tr>
<tr><td>Evolution</td><td></td><td>√</td><td></td><td>√</td></tr>
<tr><td>Epigenetics</td><td></td><td>√</td><td></td><td>√</td></tr>
<tr><td>Bioinformatics</td><td>√</td><td></td><td>√</td><td></td></tr>
<tr><td>Functional Morphology</td><td>√</td><td></td><td>√</td><td></td></tr>
<tr><td>Capstone Research</td><td></td><td></td><td>√</td><td>√</td></tr>
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Roles in this project will be delegated. PI Hodgson will ensure completion on time and maintain the budget. Also, Hodgson will maintain and update computer resources and simulation software. Co-PI Francis will be responsible for maintenance of the 3D printer, 3D scanner, and flow tank. Co-PI Schrey will operate and oversee upkeep of the gene sequencer. Senior Personnel Draud (ASU Department Biology Head) will assist overall logistics and ensure the necessary courses are scheduled. Consultant Nivens (ASU Associate Provost of Student Engagement and Success) will design and implement the assessment plan.

**Sustainability Plan:** Grant funds will be used to purchase computer software, a 3D printer with higher throughput and reliability than our existing printer, a flow tank and data logging technology, and consumables to support the implementation of the project. After the two-year implementation, the ASU Department of Biology will sustain the longevity of this project by purchasing consumables and providing funds for equipment maintenance. After analyzing the *structure and function* of the hammerhead cephalofoil during implementation, future iterations of this continuous thread may use other organisms and utilize other ASU faculty expertise. This pattern can be repeated indefinitely.

**Expected Outcomes**: We expect student comprehension of evolution to improve after implementing this project. Studies have shown structured active learning promotes student comprehension of natural selection from pretest to posttest at a normalized gain of 25% greater than traditional lecture pedagogy (Sundberg 2003; Nelson 2008).

Our project transforms lecture-only courses into facilitated discussions and directed inquiry. This gives students experience with outcome-driven research. Repeated exposure to applying the scientific process is the best way to learn science, improve critical thinking skills, and developing scientific inquiry (AAAS 2011; Sadler and McKinney 2010). Usually, this repetition is accomplished during dedicated independent research projects, oftentimes over the summer months (AAAS 2011). However, research experiences, even if in classroom settings, increased material retention for up to nine months longer after instruction and activities concluded when compared to traditional lecture settings (Lopatto 2007; Hunter et. al 2007; AAAS 2011). Sundberg (2003) further demonstrated that student understanding of evolution was maximized when lecture and hands-on exercises were integrated into a single course rather than taught in separate lecture and laboratory sections. Moreover, in lecture classes that implemented integrated topic threads and dedicated research exercises, student gains were slightly higher than students conducting independent summer research (Trosset el al. 2008).

**Broader Impacts.** The improvement of the evolution curriculum at ASU will provide equity for underrepresented groups by giving them access to new technology and research opportunities. ASU is a primarily undergraduate institution with 5459 bachelor degree seeking students (ASU data from 2013). Of these undergraduates, 604 are declared biology majors. As of fall 2013, undergraduate enrollment at ASU was 38% underrepresented minorities, 68.8% female, and 32% first-generation. Also, 29.2% of the undergraduate student body is over the age of 24 and the mean student age 24.38 years. ASU is a military-friendly institution and is official partners with the *Yellow Ribbon Program* and *Got Your 6 Campaign* for active and veteran military personnel. According to published reports, underrepresented groups have higher STEM retention and success when taught through active learning and inquiry-based scientific processes (CRLT 2009). Our hands-on use of technology will increase retention and success.

According to the AAAS Vision and Change document (AAAS 2011), the field of biology is rapidly changing through advancements in understanding evolution, genomics, proteomics, and systems biology. Advancements in these areas are tightly coupled with the need for models, simulations, computation, and quantitative data analysis. Our proposal will provide access to the use of these technologies for ASU biology majors. Furthermore, this project will serve students in their preparation for post-baccalaureate education and workplace employment by giving them training using emerging, desirable, and cutting-edge technologies.

This project will benefit both teaching faculty and students. Teaching methods and assessments will be disseminated to other institutions through social media, presentations at professional conferences, and publications in peer-reviewed journals. Within ASU, we invite other faculty, including biology and other departments, to participate in our continuous thread using simulations, models, and genetic sequencing. Doing so will build collaborative partnerships and bridge interdisciplinary boundaries, which will only serve to further enhance student experiences and opportunities.

After the successful completion of each upper-level elective and capstone research experience, ASU students will be required to present their results to their classroom peers as an oral presentation and/or written manuscript in the standard scientific format. They must have a well referenced introduction, appropriately detailed and documented materials and methods, results presented graphically and with an appropriate analysis of the data, and a discussion evaluating the different hypotheses. Students will also be required to present their findings to a larger audience, including research conferences and social media. Doing so will enhance their ability to communicate with others and understand the relationship between science and society. ASU has its own university-wide Student Scholars Symposium every spring semester and can accommodate a large number of student presentations. The ASU Department of Biology will also facilitate faculty-student presentations at regional and national professional society meetings (examples include the Society for Integrative and Comparative Biology and the American Society of Ichthyologists and Herpetologists). Additionally, students will be required to disseminate their projects to their peers through the use of blogs, Wikis, Twitter, Facebook, Instagram, YouTube, and/or other social media platforms. ASU faculty will submit student authored and coauthored manuscripts of original research to peer-reviewed journals.

**Assessment (Consultant Nivens).** The goal of this grant is to establish an effective, engaging and technologically advanced program of instruction in the evolution curriculum. The core of the curriculum is inquiry-based activities and experiments that are woven through a number of courses and a capstone experience. Throughout the program, scientific process, problem solving, multiple modes of instruction and new technology are employed as tools to promote a deeper understanding of essential topics. Formative and summative evaluation efforts will target each of these implementation activities, with data gathered from all primary grant participants – lower level students (LS), students in elective courses (ES), capstone research students (CS) and faculty (FAC). These data are used to determine whether the project is delivering the activities, outputs, and outcomes. These assessments will also include identifying successes and challenges in implementation and student mastery. Table 2 specifies annual benchmarks and evaluation strategies for grant objectives in Year 1. Evaluation in Year 2 will follow a similar format, with modifications based on Year 1 experiences.

In the first 2 months of the grant period, the PIs will work with the evaluator to develop the initial content of program formative assessment vehicles such as surveys, interview questions, pre and post-tests and other measures. CS progress will be assessed through the Survey of Undergraduate Research Experiences (SURE) using preflection, SURE III and follow-up administrations, locally developed UR assessment surveys, poster sessions held on campus as well as student meeting travel and attendance. CS progress will also be monitored by counting the number of papers co-authored by students.

Formative assessment will be used to evaluate ongoing project activities and to provide information to the investigators to assist them in determining progress, identifying challenges and improving the project at key milestones. The emphasis of the formative assessment will be on providing feedback on best practices for implementation (via teaching observations, faculty interviews), feedback from faculty training (surveys of participants), student skills assessment data (quizzes, focus group interviews, pre and post tests, exit exams and other rubric-based assessments) and Student Assessment of their Learning Gains (from SALG surveys). They will be given to students at the beginning of the semester, after each set of activities in the course and at the end of each course. CS will receive additional assessments during their research experience. Summative assessment will be used to determine and document to what extent students have increased their ability to perform problem solving tasks, have retained information throughout this academic pathway and have developed a deeper understanding of evolution. Summative assessment will take place at the end of each grant year and will include other administrative data. Data on faculty perceptions, student interest, student performance and student retention will be presented and discussed with the PI/Co-PIs at summative annual meetings and presented in NSF reports. Barriers to implementation will be identified and strategies designed to address the challenges. Subsequent meetings will include an evaluation of the effectiveness of the designed strategies accompanied by further refinement as necessary.

**Table 2.** Evaluation design chart that delineates the main evaluation questions, expected outcomes, methods, and schedule for the project evaluation. (TWE= to what extent)

| **Major TWE Questions** | **Outcomes of Interest** | **Data Source** | **Proposed Method** | **Schedule** | **Milestone** |
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| 1. TWE have students increased their specific science process skills? | • Increased success rate in the 2 introductory courses<br>• Increased interest in CS<br>• Increased performance in other biology courses requiring process skills | •PI and Co-PIs<br>•LS, ES, CS<br>•Other BIOL FAC | • Faculty and student interviews<br>• Student grades on quizzes, pre/post tests, Rubric data<br>• SALG surveys<br>• Student grades/DFW rates Student retention rate<br>• DFW rates in subsequent courses<br>• Student GPA data | • Start and end of semester<br>• After the set of activities<br>• End of each grant year | •Students completing experiencing more process skills activities will perform better in current and subsequent courses and will express an increased interest in capstone |
| 2. TWE has student content knowledge of evolution core topics increased? | • Increased registration in elective courses in evolution<br>• Increased participation in CS<br>• Quantitative measures show content knowledge increases | •PI and Co-PIs<br>•LS, ES, CS<br>•Other BIOL FAC | • SALG surveys<br>• Grades in courses<br>• Pre and post tests<br>• Exit exams<br>• Grading rubrics<br>• Faculty and Student focus groups | Prior to grant period (institutional data and student performance prior to redesigns)<br><br>Start and end of semester<br><br>After the set of activities | • Student scores are increased over prior scores<br>• More interest in elective courses in evolution<br>• Students will be better prepared at the lower level for advanced course work<br>• Will have fewer mis-conceptions about evolution |

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| 3. TWE have student become active learners? | • Increased participation in CS<br>• Quantitative measures show content knowledge increases | •LS, ES, CS | • Classroom observation<br>• Focus groups<br>• SALG surveys<br>• Grades in courses<br>• Pre and post tests<br>•Exit exams | During individual courses<br>Start and end of semester<br><br>After the set of activities<br>End of each grant year | • Students will be better prepared at the lower level for advanced course work<br>• Student elective course and CS participation and completion will increase |
| 4. TWE has new technology improved student learning of evolution concepts? | • Students will be better prepared at the lower level for advanced course work<br>• Quantitative measures show content knowledge increases<br>• Students express understanding of the technology and its applications | •LS, ES, CS<br>•PI, Co-PIs | • Student involvement and success in CS projects<br>• SALG surveys<br>• Focus groups | Start and end of semester<br><br>After the set of activities<br>End of each grant year<br><br>End of each student capstone experience | • Student elective course and CS participation and completion will increase<br>• Student scores are increased over prior scores<br>• SALG surveys indicate student knowledge of technology in |
| 5. TWE have faculty embraced and engaged in pedagogical change? | • Faculty and students will present and publish curricula<br>• Faculty in all biology areas will participate in workshops and engage in more active and outcome based learning | •LS, ES, CS<br>•FAC<br>•PI, Co-PIs | • Number of publications and presen-tations<br>• Faculty surveys on training workshops<br>• Teaching observations | • End of years 1 and 2<br>• End of the faculty training workshop | • Active and outcome based educational models will be the cultural norm in the Department of Biology |