Introducing Mathematics in Non-Science Majors Biology Courses Using MathBench[1]

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Abstract: Teaching of mathematics concepts was implemented in genetics (BiSc2) and environmental science (BiSc3) courses for non-science majors at Penn State York during the Fall 2018 semester using MathBench Biology Modules. Many students at our commuter campus are pulled between the demands of family, jobs, and academics and often do not have the time outside the classroom to brush up on important skills needed to be successful in college. Thus, this project sought to embed high-impact mathematical support activities into instruction during class time to build up this important skill set.

Key Words: mathematics, non-science majors biology, assessments, genetics, simple Mendelian genetics, environmental science, global climate change, web sites on global climate change

Introduction

Beginning in the Fall 2018 semester, and as part of a two-year study to support student learning in general education (non-science major) biology courses, Shaffer and Santiago-Blay have been exploring the effects of supplementing face-to-face teaching with online instruction to strengthen student learning characteristics. Those topics include effective reading of the text book, growth mindset, managing science and math anxiety (Mallow 2016, Shaffer and Smeltzer 2018), as well as resilience for students enrolled in biological science courses offered at The Pennsylvania State University in York (herein referred to as Penn State York). This work builds upon past research completed to improve student success, especially in the first year of college (Moore and Shaffer 2017, Shaffer et al. 2015, Shaffer et al. 2018). In addition to those learning support activities, which address cognitive or attitudinal/behavioral attributes that impact student learning, we decided to incorporate mathematics modules (Aikens and Dolans 2014) to more deliberately support content-based topics as well.

During the fall 2018 semester, JASB taught two undergraduate general education (non-science major) biology courses at Penn State York: Genetics, Ecology, and Evolution (BiSc2) and Environmental Science (BiSc3) at Penn State York. In both courses, JASB used the University of Maryland's

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MathBench Biology Module (Nelson et al. 2009) to encourage improvement and retention of learning.

The courses met for three hours each week for fifteen weeks[3]. During class, students followed the lecture by JASB, taking notes using 200-400-page workbooks designed by JASB that contain detailed learning goals, images, links to videos, as well as many other learning resources, exercises, readings, etc. Informal discussion and supplemental instruction occurred during the lecture as questions arose. The lectures were designed to be lively and interactive with storytelling and multi-media interspersed throughout. Despite the positive classroom learning climate, students still struggled in each course with certain mathematical principles that prevented them from understanding key issues more deeply. To address these issues, embedded instruction was used during class time to help students fill in their learning gaps.

Background and Discussion

Benefits of Embedded Instruction

Embedded instruction is any teaching that occurs within a course that seeks to build up necessary skills or provide ancillary resources that students need to be successful in a course (Dadger et al. 2013, Olson 2010). This happens frequently in K-12 education, especially in support of special education needs (Jimenez and Kamai 2015) and in higher education in the context of case management, student success, and advising (Dadger et al. 2013). In higher education, embedded instruction is more used to make students aware of important campus resources and services, such as mental health counseling, disability services, tutoring, intrusive advising, etc. than for content-related instruction. In terms of learning content, it is commonplace for faculty to add online supplemental resources to their courses that students can use outside of class time to build up important skills that may be lacking. However, it is often the case, that students do not follow up and use the resources, services, or activities that faculty know are critical to their success, both personally and

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[3] Penn State York is a relatively small regional campus of Penn State University located in the city of York, south central Pennsylvania. As of the Spring 2019 semester, the campus enrolls 706 (83.3%) full-time students - defined as taking, at least, 12 credits per semester - and 142 less than full-time students, most of them first or second year students. By age, most students are 23 years young or younger (82.2%). By gender, most (60%) students are males. By race, most (54.8%) identified themselves as Caucasians ("whites"), 7.4% Hispanics, 6% African Americans, and 5.5% Asian Americans, 20.8% are international students, most from China and India. Approximately 18% of Penn State York students are adult learners. Adult learners are characterized by typically being 25 years of age or older, having delayed entering college for at least one year following high school, usually employed full-time, often having a family and dependents to support, may have started college as a traditional student but needed to take time off to address other responsibilities, often looking to enhance their professional lives or may be switching careers, have more experience than traditional students, having already started a career or served in the military (Archer-Clark to Santiago-Blay, February 18-19, 2019, personal communication). Students taking JASB biological sciences courses are a mix of the above listed student types.

academically (Olson 2010). This is acutely the case at a commuter campus where busy students often rush after class to go to a job or attend to other responsibilities, such as family-related needs. This project sought to address this issue by first identifying key math-related bottlenecks (Middendorf and Pace 2004) and then embedding instructional support during class time by using mini-lectures and practice assessments.

Challenges

Finding the time needed to offer the embedded instruction was the first challenge. In science courses, the amount of content to be covered grows every year. At PSY, general education courses may also be the first course that prospective majors will take, and so providing a solid foundation in the content is important. Yet, for non-majors, there may be some challenges when the topics become too technical. This is where embedded instruction can be quite useful. Because the time available to embed additional instruction is limited, identifying the topics that will make the biggest impact is key.

Pace and Middendorf (2004) developed an approach called "Decoding the Disciplines" in which faculty learn to identify key sticking points (bottlenecks) in student learning. Important in this process is understanding and uncovering the tacit knowledge and approaches that faculty experts possess that can remain hidden from novice learners (Pace and Middendorf 2004, Middendorf and Shopkow 2018). Faculty experience in the classroom enables them to quickly identify common and important areas of struggle, but as experts they may not be able to easily remember that novices need to solve problems in those areas. Follow-up conversations with non-experts can expose areas of tacit knowledge that novices need in order to proceed with challenging tasks. In this case, JASB identified and prioritized common areas of student challenge in each course. A conversation with the campus instructional designer, coauthor SCS, helped to uncover some of the tacit approaches used by the expert. MathBench resources then were identified which could act as a bridge by which this necessary learning could occur.

The Courses, Issues, and Instructional Approach

Biological Sciences 2, *Genetics, Ecology, and Evolution* (BiSc2). This course, which has no pre-requisites, emphasizes how living organisms inherit their traits, how organisms have evolved, and how they interact with the environment (Anonymous 2018-2019a). This course is generally taken by non-science majors to fulfill a science requirement to complete a bachelor's degree.

For BiSc2, a common topic that students often struggle with is completing so-called simple Mendelian genetics problems. In particular, students find it difficult to calculate the probabilities of different genotype and phenotype given the frequency of different parental genotypes represented in the gametes. Exams and quizzes ask students to solve Mendelian genetic problems involving crosses both in principle and in practice. To address this common challenge, MathBench's Mice with Fangs: Intro to Punnett Squares located under the Probability and Statistics header was used for embedded skill-building instruction. During the implementation, JASB began lecture with a pre-test to determine base knowledge of the topics. After completing the pre-test, lesson objectives were announced, followed by a micro-lesson using the MathBench resources. Micro-lessons lasted between 3 and 5 minutes after which students were instructed and, we hoped incentivized, that questions related to the micro-lesson would appear on a quiz during the next class period as well as on upcoming exams. Both pre- and post-assessments were meant to identify areas of instructional need, measure growth, and reinforce the learning. Students had access to the Math Bench materials outside of class time along with practice quizzes to reinforce the learning. The assessment instruments, all structured problem-solving exercises, are available in Appendices 1-3.

Biological Sciences 3, *Environmental Science* (BiSc3). This course, which has no perquisites, emphasizes the different types of environments, past and present, uses and abuses of natural resources, disposal of human waste products, prospects for the future, etc. BiSc3 is designed to help students prepare for living in a global society with its complex challenges that impact living systems and their environments. Also, BiSc3 addresses the policy cycle and the citizens who can act with an understanding of ecological principles when exercising community responsibilities to handle the environmental problems of our times, such as water use, solid waste management, global warming, energy use, conservation of irreplaceable natural resources, overpopulation, and the preservation of biodiversity are urgently needed (Anonymous 2018-2019b). An understanding of biological and ecological principles and their application towards environmental challenges should give the student the confidence to be a trustworthy and active citizen, a conscientious steward of nature, and an agent of change for making a healthy, sustainable community and society. Regardless of the students' field of study, as a citizen of both local and global communities, some environmental issues will impact all students' lives.

The issue in BiSc3 that students often struggle with is understanding global climate change and representing that knowledge through graphics. The mathematical challenge in this case is helping students to understand graphical representations of data to more deeply and accurately understand this complex issue (see Appendix 4 for the assessment). The supplemental teaching instruments used during lecture were MathBench's *Iconic Graphs of Climate Change*, *Keeling Nails Carbon Dioxide*, and *Michael Mann builds a hockey team*, located under the *Climate Change* header. Again, a mini-lecture was given during class with pre- and post-activity assessments. The assessment instruments – all a combination of multiple-choice, short answer, and graphing - were given right before instruction; a modified version of the same instrument was given the week after instruction, during the exam in the form of a few multiple-choice questions, and during the last week of the course.

In both courses, MathBench was considered a good approach to supplement students' learning and enhance the likelihood of fulfilling the learning objectives because of the: 1) brevity and simplicity of the text materials to be read, 2) copious illustrations, and 3) in-class/online interactivity.

Conclusions and Future Directions

In the case of both courses, students reported satisfaction with the MathBench activities and embedded model of instruction. The faculty member experienced satisfaction in several ways: 1) developing a deeper understanding of the issues that non-science majors face when learning more technical topics, 2) having an approach (embedded instruction) that resulted in a positive impact without having to give up a lot of class time, and 3) becoming familiar with the MathBench resource that could have broad usefulness across many STEM fields. Because of the positive outcomes of this project for both students and faculty, a follow-up project is currently underway with Institutional Research Board (IRB) approval to address other learning issues that students face using an embedded learning model which will be reported on herein in a future issue.

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Appendices

Appendices 1-3 Assessments Instruments for *Genetics, Ecology, and Evolution* (Biological Sciences 2, BiSc2)

Appendix 1. Pre-Test (given right before lecture)

Your name __________________ Course Name _______________

Simple Mendelian Inheritance

Say you cross Aa x aa. Assuming simple Mendelian inheritance,

1. What is the probability that you will get Aa?

2. What is the probability that you will get aa?

Say you cross AaBb x AaBb. Assuming simple Mendelian inheritance,

3. What is the probability you will get AaBb?

4. What is the probability you will get aaBb?

5. What is the probability you will get AABB?

Appendix 2. Post-Lecture (given the following week)

Your name __________________ Course Name _______________

Simple Mendelian Inheritance

Say you cross Bb x bb. Assuming simple Mendelian inheritance,

1. What is the probability that you will get Bb?

2. What is the probability that you will get bb?

Say you cross AaBb x AaBb. Assuming simple Mendelian inheritance,

3. What is the probability you will get aabb?

4. What is the probability you will get Aabb?

5. What is the probability you will get aAbB?

Appendix 3. Post-Test (last week of the course)

Your name ________________ Course Name ______________

Simple Mendelian Inheritance

Say you cross Cc x cC. Assuming simple Mendelian inheritance,

1. What is the probability that you will get cC?

2. What is the probability that you will get CC?

Say you cross AaBb x AaBb. Assuming simple Mendelian inheritance,

3. What is the probability you will get AABB?

4. What is the probability you will get aabb?

5. What is the probability you will get cCbB? ← Note, this is not a typo.

Appendix 4. Pre-Test and Post-Test for Environmental Science

Your name ________________ Course Name ______________

1. What causes Earth's climate to change? Circle the best answer.

a. Planetary motions of Earth
b. Activities of the Sun
c. Human activities
d. Only options a and b, above
e. All the above

2. Draw a graph showing the concentration of carbon dioxide on the lower atmosphere since 1958 (Keeling curve) and label its axes.

3. Describe what is the Greenhouse Effect?

4. Draw a graph showing the relationship between estimated concentration of carbon dioxide in the lower atmosphere and global temperature (Mann et al. curve) and label its axes.

5. Humans are contributing ___________ to global climate in modern times? Circle the best answer.

a. nothing
b. minimally
c. significantly
d. totally
e. unknown, it is too hard to tell