Proceedings of the Interdisciplinary STEM Teaching and Learning Conference

Volume 1 Article 1

5-2017

Volume 1, Proceedings of the Interdisciplinary STEM Teaching and Learning Conference

Recommended Citation

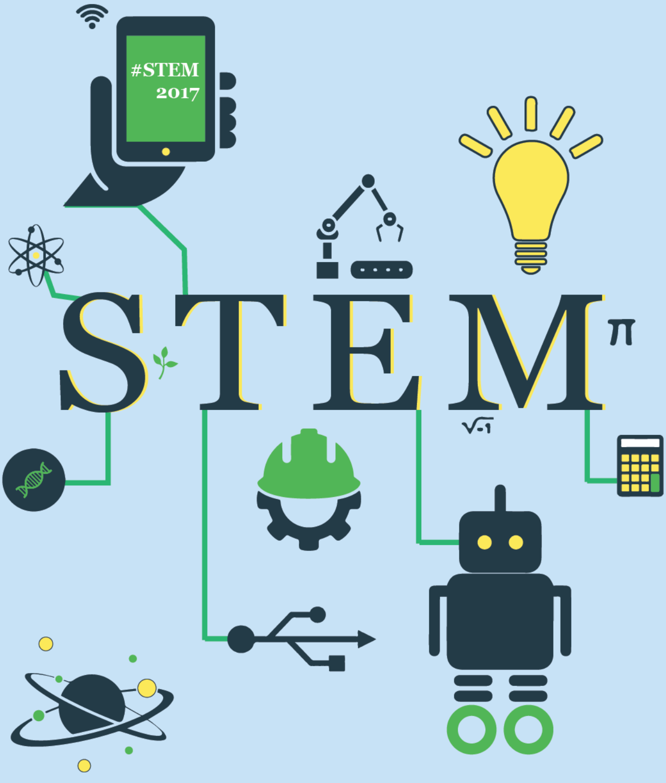
(2017) "Volume 1, Proceedings of the Interdisciplinary STEM Teaching and Learning Conference," *Proceedings of the Interdisciplinary STEM Teaching and Learning Conference*: Vol. 1 , Article 1.
DOI: 10.20429/stem.2017.010101
Available at: https://digitalcommons.georgiasouthern.edu/stem_proceedings/vol1/iss1/1

Volume 1, Proceedings of the Interdisciplinary STEM Teaching and Learning Conference

Abstract

Full version of volume 1 of the *Proceedings of the Interdisciplinary STEM Teaching and Learning Conference.*

SCIENCE TECHNOLOGY ENGINEERING & MATH



Conference Proceedings

Editor's Note

It was with great pleasure that I was able to organize and put together the inaugural volume of the Proceedings of the Interdisciplinary STEM Teaching and Learning Conference. The opportunity to read the different studies and converse with authors from all over the region was rewarding and makes me proud of the good work being done in interdisciplinary STEM education.

The first volume of the Proceedings of the Interdisciplinary STEM Teaching and Learning Conference includes topics from special education, curricular integration, using primary resources, methods for using new technologies, and cellular testing. I was truly impressed with the scope of the work presented at the conference and articulated in these papers.

I want to acknowledge the Institute for Interdisciplinary STEM at Georgia Southern University and our fellows and affiliates who graciously and quickly assisted with the review process. Thank you to Lisa Stueve for leading this year's conference and Marsha Pate, Kania Greer, and Robert Mayes for all their support along the way.

Cheers to this inaugural volume!

Best,
Lisa Millsaps

DOI: 10.20429/stem.2017.010101

Proceedings of the Interdisciplinary STEM Teaching and Learning Conference

Volume 1, 2017

TABLE OF CONTENTS

Importance of STEM Extracurricular Activities for Students with Disabilities

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Abstract: Students with disabilities are underrepresented in science, technology, engineering and mathematics (STEM) careers (National Science Foundation, 2015). The underrepresentation is a problem because the nation's competitiveness depends on diverse individuals with STEM knowledge, skills, and abilities to drive innovation that will need to new products and economic growth (Business-higher Education Forum/A Policy Brief, 2014; National Academies of Sciences, Engineering, and Medicine, 2016; National Science Board, 2016). The author discusses the importance of engaging students with disabilities in informal Science, Technology, Engineering, and Mathematics activities.

Keywords: extracurricular, clubs, STEM, disabilities, social skills, soft skills, informal, self-efficacy, self-determination

The Importance of Extracurricular Activities for Students with Disabilities

All students, including students with disabilities (SWD) who participated in after-school programs that offer a variety of experiences develop skills and self-confidence (Kleinert, Miracle and Sheppard-Jones, 2007). These social and emotional skills are difficult to achieve in the typical classroom setting (Snellman, Silva, Frederick & Putnam, 2015). Kleinert and colleagues (2007) pointed out the Individuals with Disabilities Education Act (IDEA) requires schools to provide access to extracurricular activities and recommended participation in after-school programs is included in students' Individual Education Programs (IEPs). After-school clubs can integrate needed work place (soft skills, i.e. collaboration) and social skills interventions with students who share similar interests in a natural, informal, learning environment. Students with disabilities develop social competence by experiencing friendships and gaining valuable teamwork skills. These experiences are needed for many post high school jobs, especially in the STEM areas.

Extracurricular activities have been associated with improved academic performance and psychosocial development (Durlak, Weissberg, & Pacan, 2010). Students who participate in after-school activities have been positively linked to higher grades, test scores, school value, school engagement, and educational aspirations (Fredricks & Eccles, 2008). Additionally, participants have positive

DOI: 10.20429/stem.2017.010101

psychological benefits such as higher self-esteem, psychological resiliency, and lower rates of depression (Fredricks & Eccles, 2008). Moreover, some studies show a link to after-school club participation and lower dropout rates, delinquency, and substance abuse levels (e.g., Eccles & Barber, 1999; Mahoney, 2000; Mahoney & Cairns, 1997).

Science, Technology, Engineering, and Mathematics Education

In many countries, including the U. S., an economy based on the understanding of STEM is replacing traditional manufacturing (Kaku, 2011). Unfortunately, the U.S. is ranked 25th in science on the latest Program of International Student Assessment (Organization for Economic Cooperation and Development; OECD, 2016). Across the world there is clear evidence of a significant need for students who have an understanding of STEM and the diverse range of associated careers (National Science Board, 2016).

Science, technology, engineering and mathematics education plays a critical role in shaping culture and economic development through innovation (Cooper & Heaverlo, 2013). To be successful during STEM learning experiences, students must move beyond low-level cognitive tasks and gain a foundational understanding of the content (Marino, Gotch, Israel, Vasquez, Basham, & Becht, 2014). A meaningful STEM program encourages students to develop solutions that incorporate a variety of disciplines (Basham, Israel, & Maynard, 2010). Educators can create engaging learning environments where students are encouraged to identify and solve problems (Marino, Israel, Beecher, & Basham, 2014). Students' benefit when they work collaboratively to develop solutions across subject areas (Schroeder, Scott, Tolson, Huang, & Lee, 2007). Examples of STEM activities include robotics competitions (i.e. For Inspiration and Recognition of Science and Technology [FIRST], Best, Vex), STEM clubs (i.e. Science, Engineering, Communication, Mathematics, and Enrichment [SECME], science, engineering, coding), design challenges (i.e. solar car, astronaut), and STEM competitions (i.e. Science Olympiad, Math Olympics, Odyssey of the Mind).

Due to barriers to access STEM programs, SWD have been historically excluded from postsecondary STEM education (Burgstahler, 1994; Burgstahler & Chang, 2009; Moon, Todd, Morton, & Ivey, 2012). In fact, according to the U.S. Census data (2013), people with disabilities constitute 6% of the nation's general workforce, but only 2% of its STEM professionals. The reason for the exclusion is barriers that include reading levels of SWD, lack of inquiry and procedural skills, as well as lack of executive functioning skills. Therefore, it is imperative researchers and educators develop programs for SWD to overcome these barriers for SWD to participate in postsecondary STEM education.

Informal Science, Technology, Engineering, & Mathematics Learning

Denson, Haily, Stallworth, & Householder (2015) reported a need for reform in Science, Technology, Engineering, and Mathematics (STEM) education to attract a more diverse workforce. Watson and Froyd (2007) stated a diverse population in STEM careers impacted the level of creativity, innovation, and quality of STEM products and services. However, many STEM learning environments are formal and fail to introduce underrepresented students to STEM professions (Denson, Austin, & Hailey, 2013). Furthermore, researchers have recognized the importance of informal learning environments that will be instrumental to the reform of STEM education (National Research Council [NRC], 2015).

Chubin, May, and Babco (2005) postulated an effective informal learning environment in STEM must (a) promote awareness of engineering, (b) provide academic enrichment, (c) have trained and competent instructors, and (d) be supported by the educational system of the student participants. Informal learning environments are categorized into (a) everyday experiences, (b) designed settings, and (c) programmed settings (Kotys-Schwartz, Besterfield-Sacre, & Shuman (2011). As noted previously, informal learning environments typically take place outside of the traditional classroom environment and have been an integral part of education for years (NRC, 2015). Informal learning environments associated with school are often called extracurricular activities.

While science education often focuses on curriculum and teacher professional development, learning in non-school settings is often overlooked (Bell, Lewenstein, Shouse, & Feder, 2009). Every year millions of Americans explore informal learning institutions (i.e. science centers and museums) to pursue their interests (Bell et al., 2009). Informal science learning and community-based organizations include libraries, schools, think tanks, institutions of higher education, government agencies, private companies, and philanthropic foundations. Informal environments include a family discussion at home, visits to museums, nature centers, or other designed settings and every day activities like gardening. Informal learning environments include participation in

DOI: 10.20429/stem.2017.010101

clubs and recreational activities like hiking and fishing. Science enthusiasts who organize themselves into community-based organizations stimulate the science specific interests of students (Bell et al., 2009). As a result of the need for reform in STEM education, the Committee on Successful Out of School STEM Learning was established by the Board of Science Education to examine the potential of non-school settings for science learning (NRC, 2015).

The committee found evidence that individuals of all ages learn science across many venues. Furthermore, out of school programs have been shown to (a) contribute to student's interest in and understanding of STEM, (b) connect youth to adults to serve as mentors and role models, and (c) reduce the achievement gap by socioeconomic status (NRC, 2015). While the research is not robust enough to determine which programs work best for different types of students, the field of informal science learning research looks promising. The committee recommended programs that produce positive outcomes for learners are engaging, responsive, and make student connections (NRC, 2015).

Extracurricular Activities

There is a variation in activities offered in schools due to an increase in specialization and/or interest in specific types of extracurricular activities. Examples of school activities include sports, music, clubs, and/or religious activities (Adachi-Mejia, Gibson Chambers, Li, & Sargent, 2014). Extracurricular activities with a focus in STEM have become more popular due to an increase in young people's exposure and play an important role in influencing the trajectory of STEM learning for adolescents (Adams, Gupta, & Cotumaccio, 2014; Bell, Lwenstein, Shouse, & Feder, 2009).

Structured extracurricular activities as explained by Balyer and Gunduz (2012) included excursions, competitions, physical education, scouting, music, folklore, education/journal preparation, shows, theatre, fashion shows, exhibitions, chess, tennis, basketball, fair and creative drama. These activities are delivered inside or outside of school as a strategic tool to diminish negative behaviors. Extracurricular activities have a positive impact on student development and contribute to formal learning programs (Fredericks & Eccles 2006). Researchers revealed extracurricular activities have impacts on grades, exam results, and responsibility toward school, culture, socialization, motivation, positive attitudes toward school and educational eagerness (Darling, Caldwell, & Smith, 2008; Llyeras, 2008; Luthar, Shoum, & Brown, 2006; Fujita, 2006).

Additionally, researchers showed students developed and learned skills they enjoyed (Fredericks & Eccles, 2006; Shulruf, Tumen, & Tolley, 2008).

Extracurricular Activities and the Law

In 2013, the United States Department of Education, Office for Civil Rights issued guidance on school districts' legal obligation to provide SWD equal access to extracurricular athletic activities. According to Section 504 of the Rehabilitation Act, SWD have an equal opportunity to participate in extracurricular activities. However, in 2010 the U. S. Government Accountability Office (GAO) found many SWD were not given an equal opportunity to participate in extracurricular athletics (Galanter, 2013). Specifically, the authors of the GAO report (2010) stated, "Under the implementing regulations for both IDEA and Section 504, schools are required to provide students with disabilities equal opportunity for participation in extracurricular activities, which often include athletics" (p.2). The guidance is often interpreted to include extracurricular activities such as STEM clubs and hobbies (*Independent School District No. 12, Centennial v. Minnesota Department of Education, 2010*). Furthermore, IDEA (2004) Section 300.107(b) provides a non-exhaustive list of examples of extracurricular and nonacademic activities that expressly includes athletics, clubs, and activities offered by groups sponsored by the school district.

Self-Efficacy and Self-Determination in STEM.

In order to be successful in STEM careers, SWD must develop self-efficacy and self-determination skills. In 1997, Bandura wrote self-efficacy is the "belief in one's capabilities to organize and execute the course of action required to produce given attainment" (p.2). There are four factors to a students' sense of self-efficacy; mastery experiences, vicarious experiences, social persuasion, and self-management (Bandura, 1994). Additionally, positive prior experiences that result in positive outcomes increase confidence and willingness to persist when faced with challenges (Bandura, 1997; Schunk & Pajeres, 2009). Resilience, perseverance, and stress to perform a daunting task are reduced when a student sees a similar peer succeed through vicarious experiences (Bandura, 1997; Jenson, Petri, Day, Truman, & Duffy, 2011; Schunk & Pajares, 2009). Because self-efficacy beliefs are malleable, they can be changed through social persuasion (McNatt & Judge, 2008). Teachers, parents, and peers can boost confidence resulting in a student who is more likely to put forth and sustain greater effort

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DOI: 10.20429/stem.2017.010101

(Jenson et al., 2011). Within the field of STEM, SWD reported an increase in self-confidence when seeing other SWD succeed (Jenson et al., 2011). Organizers of after-school STEM activities can promote an increase in self-confidence by actively recruiting SWD to participate in their programs.

Not only is self-efficacy a problem for SWD, many SWD who wish to pursue postsecondary education in STEM need support in self-advocacy and self-determination skills (Grigal & Hart, 2010). Self-determination skills are needed to effectively advocate for needed accommodations (Izzo, Murray, Priest, & McArrell, 2011). Additionally, Test and colleagues (2009) found in a systematic review of the literature that self-determination skills in high schools were a predictor of post school education and independent living skills. Students with disabilities need to develop self-determination and self-advocacy skills to meet the demands of STEM degrees and careers (Izzo et al., 2011). Another skill needed by SWD to persist in STEM careers is soft skills.

Students with Disabilities Need Soft Skills to Succeed.

Special educators often deliver social skills instructions to change the behavior of students in self-contained environments (Miller, Lane, & Wehby, 2005). The skills are taught to students with disabilities by breaking the task down into steps then incorporating discussion, modeling, roleplaying, reinforcement, problem solving, and feedback (Elliott & Gresham, 2007). However, many teachers do not feel prepared to promote positive peer interactions (Dee, 2011). Within after-school STEM activities, coaches naturally promote positive interactions through teamwork and collaboration in a supportive environment. Thus, rather than prescriptive direct instruction using different types of curriculum, the goal of most STEM activities are team based competitions. The outcome is not an individual grade or accomplishment of an Individual Education Program goal or objective, but to win a competition or award in a natural environment.

Social skills in the workplace are often called soft skills. Robinson and Stubberud (2014) described soft skills as thinking in a creative way, thinking critically, networking, and working in teams to improve a program. Green and Blaszczynski (2012) described soft skills as personal qualities, habits, attitudes, and social graces that make someone compatible to work with and a good employee. Soft skills include teamwork, communication, leadership, customer service, and problem solving skills. According to De Ridder, Maysman, Oluwagbemi, and Abeel (2014) soft skills are defined as the social behaviors needed to become successful in the workplace. Attributes of soft skills include friendliness, empathy, and optimism (Heckman & Kautz, 2012). In other words, people who have a strong work ethic and work well in a team have soft skills. Soft skills are hard to acquire through reading and it is recommended they are learned through practice or informal learning environments. Informal learning environments like after-school STEM activities give SWD an environment to practice and generalize soft skills needed before transitioning to the workplace. Employers indicate soft skills are an important factor of job performance, if not more important than technical skills (Glenn, 2008). Soft skills are more difficult to teach and measure than technical skills (Loughry, Ohland, & Woehr, 2013). Industries hire individuals with strong soft skills in order to retain a competitive edge (Glenn, 2008). Employment in the United States has shifted and requires more employees to interact with others.

In STEM, successful students are not only problem solvers with high technical skills but are effective at soft skills like collaboration and communication (Brewer & Smith, 2011). Soft skills are so critical that 6 out of the 11 undergraduate student outcomes required by the Accreditation Board for Engineering and Technology (ABET) focus on soft skills (Williams, 2001). Given the importance of soft skills in the STEM workforce, it is surprising the engineering education research community does not give it more attention (Singer & Schweingruber, 2012).

Where do we go from here?

Students with disabilities are attracted to science activities like robotics (Howard & Park, 2014). Additionally, SWD often express unique attributes that are particularly beneficial to STEM careers (Basham & Marino, 2013). White and Mitchell (2013) pointed out these include:

1. Sustained, hypersensitive attention to detail
2. The ability to disassociate themselves from emotional attachment when completing tasks
3. Repetitive, systematic procedural knowledge and skills
4. The ability to conceptualize outcomes and solutions to complex STEM problems

Additionally, SWD depend on hands-on, inquiry-based instruction to access science content (Melber, 2004). Melber and Brown (2008) remind

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DOI: 10.20429/stem.2017.010101

us that personally relevant topics are critical for engaging SWD in science learning. Maroney, Finson, Beaver, & Jenson, (2003) advocated for creating science experiences that make SWD feel emotionally safe and have the freedom to pursue investigations without unnecessary teacher evaluation or interference in the learning process. Falvey (2005) reported educators must believe (a) in student's capacities; (b) highlight student's strengths, gifts, and talents; and (c) SWD are competent in order for successful informal learning to take place.

To be successful in STEM careers, students must possess certain qualities. Some of these qualities include critical thinking, information literacy, reasoning and argumentation, innovative, flexible, takes initiative, appreciate diversity, reflective, communicate, collaborate, responsible and personable (NRC, 2012). Many students with disabilities exhibit strengths in several of these qualities including analytical aptitude as well as being creative with the ability to think outside the box. Students with disabilities exhibit several characteristics that will help them become successful in STEM occupations. Employers are recognizing these strengths by hiring more people with disabilities. Diversityinc.com's list of top 10 companies for hiring people with disabilities include STEM institutions like Ernst & Young, Accenture, Prudential Financial, Microsoft, AT&T, and IBM (2015). In 2016, 27 companies were recognized for exemplary hiring and employment practices for people with disabilities including Lockheed Martin, Boeing, Capital One, Northrup Grumman, and Prudential. Educators need to continue to provide innovative approaches such as extracurricular activities to address the skills deficits in students with disabilities who want to pursue STEM careers. One way to address the barriers to entry into STEM careers is by providing access through recruitment to STEM extracurricular activities to students with disabilities. Furthermore, SWD should be actively recruited to participate in STEM activities through strategies such as reverse inclusion whereby a club is formed for SWD using IDEA funding and students without disabilities would be allowed to participate.

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https://digitalcommons.georgiasouthern.edu/stem_proceedings/vol1/iss1/1
DOI: 10.20429/stem.2017.010101

Enhancing Interdisciplinary Attitudes and Achievement via Integrated Biology and Chemistry Curriculum

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Abstract: Success in undergraduate biology courses relies upon a firm grounding in chemical principles. We sought to raise students' awareness of the connection between these two disciplines and to improve their understanding of each by carrying out a pilot project that integrated the curricula of Principles of Chemistry II (CHEM1212K) and Principles of Biology I (BIOL1107K) during the Fall 2016 semester. The study involved two course pairs: one section of each course delivered in the traditional non-integrated manner and a second pair of sections that were integrated across the chemistry and biology disciplines in both the scope and sequence of the content delivery. Both integrated and non-integrated sections were taught by the same instructors, who have expertise in both chemistry and biology to ensure a full understanding of both courses' content. Attitudinal surveys administered at the beginning and end of the semester showed that students in the integrated BIOL/CHEM section of our pilot study appreciated the delivery of an integrated curriculum and improved their awareness of the connections between the two disciplines. End-of-course assessments of topic mastery demonstrated improvements in the integrated students' capacity to understand and apply both biology and chemistry topics compared to students in the non-integrated sections.

Keywords: integrated curriculum, interdisciplinary, chemistry, biology, integrative learning

Acknowledgments: This research was supported by a grant from the USG-STEM Education Improvement Plan.

Introduction

The increasing interconnectedness and globalization of 21st century culture combined with the expanding body of knowledge about the natural world poses a challenge for both undergraduate students, who are expected to navigate these trends while mastering an increasing collection of facts and skills, and the faculty and administrators who educate and support them on the path to graduation. Two movements of particular significance in higher education – and with major implications for each of these parties – advocate for change from the traditional "stovepipe" set of discrete courses to those in which curricula are integrated across the college. Such programs aim to make course content more relevant while preparing students to solve complex problems that relate across different areas of study. The first movement draws on a growing collection of evidence showing that undergraduate research experiences enhance lasting learning, and in STEM fields, also enhance student interest in STEM careers (Awong-Taylor, 2016; Laursen, 2010; Lopatto, 2007, 2009; National Science Council, 2003).

In the second movement, an equally compelling argument has also been made that integrative learning across multiple disciplines in the humanities and social sciences, as well as STEM, also enhances lasting learning, perhaps even more so than undergraduate research experiences (Newell, 2010; Pursell, 2009; Ulsh, 2009; Van Hecke, 2002; Wolfson, 1998). For many working in higher education, the goals exemplified by these two movements may seem intuitively appropriate but, in practice, present significant administrative and instructional challenges that inhibit widespread implementation. In addition, limited resources coupled with myriad compelling and competing demands make implementation much more challenging for large public institutions than for highly competitive, well-funded schools.

The project we describe in this paper was carried out at Georgia Gwinnett College, a 4-year public college in the University System of Georgia with an enrollment of over 12,000 students and an open-access (non-competitive) admissions policy. Biology is one of the most popular majors and serves as a gateway for many of our graduates to careers in health and exercise science, government and industry, as well as graduate study in biological, biochemical, or environmental science. A common challenge for incoming Biology majors is the depth of understanding of fundamental chemical principles that is required to truly master the concepts presented in BIOL1107K (Principles of Biology I), a foundational 4-credit lecture/lab course that provides majors with an introduction to cell biology and biochemistry. We therefore targeted integrative learning in biology and chemistry by intentionally pairing this course with CHEM1212K (Principles of Chemistry II), a 4-credit lecture/lab course that constitutes the second semester of the general chemistry curriculum

DOI: 10.20429/stem.2017.010101

and has a general focus on quantitative applications of chemical concepts. Our intent was not just to improve our students' mastery of chemical and biological principles but also to present the courses' content in a way that clarified their interdependence and mutual relevance. As our students are non-competitive for admissions purposes, it was our expectation that they would substantially benefit from atypical instructional approaches designed to enhance learning and develop persistence.

Methods

Course Structure and Population

Four separate course sections for this study were established during the Fall 2016 semester: one section of BIOL1107K into which students freely enrolled, one section of CHEM1212K that was similarly open for normal student enrollment, and one section each of BIOL1107K and CHEM1212K in which we recruited student volunteers to enroll simultaneously, forming a cohort of students enrolled together in the integrated BIOL/CHEM sections. The only requirement for inclusion in the integrated courses was that students meet all course pre-requisites. Students in the non-integrated sections enrolled at random based on individual preference for schedule and/or instructor.

The experimental BIOL/CHEM schedule consisted of three-hour morning lectures in biology (Mondays) and chemistry (Wednesdays) with Monday and Wednesday afternoon blocks reserved for each subject's corresponding labs. To minimize variation in course schedule between the control and experimental groups, each of the non-integrated control sections similarly comprised two weekly blocks of three hours each to cover the respective biology or chemistry lecture and lab sessions. The same instructors led both the integrated and non-integrated class sections to eliminate variation in instructor efficacy and style; an experienced biochemistry instructor (Dr. Huey) taught the biology content for both the integrated and non-integrated BIOL1107K sections while an experienced biophysical chemist (Dr. Guo) taught the chemistry content for the integrated and non-integrated CHEM1212K sections.

Integrated Curriculum

To develop the integrated BIOL/CHEM sections, the instructors collaborated before and during the pilot semester to integrate the independent curricula used by the non-integrated sections (Table 1) into a synchronized plan

(Table 2) for use in the integrated sections. The color scheme used for Table 1 and Table 2 is the same for easier tracking of changes in the integrated curriculum. The intent was to coordinate in curricular space and time as many of the biology and chemistry concepts as possible to highlight the conceptual connections and mutually supporting application of shared biology and chemistry techniques and procedures to more complex, multi-dimensional problems.

Table 1. Regular curriculum for BIOL 1107K and CHEM 1212K. Shared contents are labelled in the same color.

Week	BIOL1107K	CHEM1212K
	Introduction to the Course	Introduction to the Course
1	Chapter 1: Life -- Chemical, Cellular, and Evolutionary Foundations	Chapter 9: Review Electron Configurations, Valence Electrons, Chemical Bonding
		Chapter 9: Lewis Dot Structures of Ionic Materials, Lewis Dot structures of Covalent Compounds
2	Chapter 2: The Molecules of Life – Atoms and Bonding	Chapter 9: Lewis Dot Structures of Covalent Compounds, Formal Charge, Resonance
3	Chapter 2: The Molecules of Life -- Water and Its Properties	Chapter 10: VSEPR and Molecular Shape
		Chapter 10: Predicting Polarity, Bonding Theories, Chapter 15: pH and pOH
	Chapter 2: The Molecules of Life -- Macromolecules	Chapter 11: Types of Intermolecular Forces
4	Chapter 3: Nucleic Acids and the Encoding of Biological Information	Chapter 11: Intermolecular Forces in Liquids and Gases, Phase Diagrams
5	Chapter 4: Translation	Chapter 12: Intermolecular Forces at Work in Liquids
	Chapter 4: Protein Structure	Chapter 13: Introduction to Kinetics, Rates of Reactions, Initial Rate Method
6	Unit 1 Test	Chapter 13: Integrated Rate Laws and Activation Energy
	Chapter 5: Organization of the Cell	Chapter 13: Reaction Mechanisms and Catalysts
7	Chapter 6: Overview of Metabolism	Chapter 14: Equilibrium and Equilibrium Constants
	Chapter 6: Chemical Reactions and Enzymes	Chapter 14: Determining Equilibrium Concentrations
8	Chapter 7: Glycolysis -- Overview	Chapter 14: Le Chatelier's Principle
	Chapter 7: Glycolysis -- Reactions	Chapter 15: Acid/Base Chemistry and Ka/Kb
9	Chapter 7: Citric Acid Cycle	Chapter 15: Determining Concentration in Acid/Base Solutions using Ka or Kb
	Chapter 7: Electron Transport Chain	Chapter 15: Acid/base properties of Salts, Molecular Structure and Acid/Base Strength, Lewis Acid/Bases
10	Chapter 8: Photosynthesis	Chapter 16: Buffer Range and Buffer Capacity. Determining pH in Acid/Base Titrations
	Unit 2 Test	Chapter 16: Determining pH in Acid/Base Titrations
	Chapter 10: Cell Form and Function	Chapter 16: Ksp, and Complex Ion Equilibrium
11	Chapter 10: Cytoskeletal Elements	Chapter 17: Review of Enthalpy, Introduction to Entropy and How to Calculate It
	Chapter 11: Mitosis	Chapter 17: Gibbs Free Energy and How to Calculate It
12	Chapter 11: Meiosis	Chapter 17: Gibbs Free Energy in Nonstandard states and Relating Gibbs Free Energy to Equilibrium
	Chapter 12: DNA Replication	Chapter 18: Balancing Complex Redox Reactions and Galvanic Half Reactions/Cells
13	Chapter 14: Mutation	Chapter 18: Determining Cell Potentials, Relating Cell Potentials to Gibbs Free Energy and Equilibrium Constants

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DOI: 10.20429/stem.2017.010101

Table 2. Integrated curriculum for experimental sections. Shared contents are labelled in the same color.

Week	BIOL1107K	CHEM1212K
1	Introduction to the Course	Introduction to the Course
	Chapter 1: Life -- Chemical, Cellular, and Evolutionary Foundations	Chapter 9: Review Electron Configurations, Valence Electrons, Chemical Bonding
2	Chapter 2: The Molecules of Life – Atoms and Bonding	Chapter 9: Lewis Dot Structures of Ionic Materials, Lewis Dot structures of Covalent Compounds
		Chapter 9: Lewis Dot Structures of Covalent Compounds, Formal Charge, Resonance
3	Chapter 2: The Molecules of Life -- Water and Its Properties	Chapter 10: VSEPR and Molecular Shape
		Chapter 10: Predicting Polarity, Bonding Theories, Chapter 15: pH and pOH
4	Chapter 2: The Molecules of Life -- Macromolecules	Chapter 11: Types of Intermolecular Forces
	Chapter 3: Nucleic Acids and the Encoding of Biological Information	Chapter 11: Intermolecular Forces in Liquids and Gases, Phase Diagrams
5	Chapter 4: Translation	Chapter 12: Intermolecular Forces at Work in Liquids
	Chapter 4: Protein Structure	Chapter 14: Equilibrium and Equilibrium Constants
6	Unit 1 Test	Chapter 14: Determining Equilibrium Concentrations
	Chapter 5: Organization of the Cell	Chapter 14: Le Chatelier's Principle
7	Chapter 10: Cell Form and Function	Chapter 15: Acid/Base Chemistry and Ka/Kb
	Chapter 10: Cytoskeletal Elements	Chapter 15: Determining Concentration in Acid/Base Solutions using Ka or Kb
8	Chapter 11: Mitosis	Chapter 15: Acid/base properties of Salts, Molecular Structure and Acid/Base Strength, Lewis Acid/Bases
	Chapter 11: Meiosis	Chapter 16: Buffer Range and Buffer Capacity. Determining pH in Acid/Base Titrations
9	Chapter 12: DNA Replication	Chapter 16: Determining pH in Acid/Base Titrations
	Chapter 14: Mutation	Chapter 16: Ksp, and Complex Ion Equilibrium
10	Unit 2 Test	Chapter 13: Introduction to Kinetics, Rates of Reactions, Initial Rate Method
11	Chapter 6: Overview of Metabolism	Chapter 13: Integrated Rate Laws and Activation Energy
	Chapter 6: Chemical Reactions and Enzymes	Chapter 13: Reaction Mechanisms and Catalysts
12	Chapter 7: Glycolysis -- Overview	Chapter 17: Review of Enthalpy, Introduction to Entropy and How to Calculate It
	Chapter 7: Glycolysis -- Reactions	Chapter 17: Gibbs Free Energy and How to Calculate It
	Chapter 7: Citric Acid Cycle	Chapter 17: Gibbs Free Energy in Nonstandard states and Relating Gibbs Free Energy to Equilibrium
13	Chapter 7: Electron Transport Chain	Chapter 18: Balancing Complex Redox Reactions and Galvanic Half Reactions/Cells
	Chapter 8: Photosynthesis	Chapter 18: Determining Cell Potentials, Relating Cell Potentials to Gibbs Free Energy and Equilibrium Constants

Survey and Instrument Analysis

Using Institutional Review Board (IRB) approved project documents, we collected both attitude and performance data for all students enrolled in the integrated and non-integrated sections. For the attitude surveys, four-level Likert-scaled attitudinal surveys were used to collect data at the beginning and the end of the semester for all the participants. Demographic surveys were also given to better understand the profiles of students involved. In the twenty-question attitudinal survey, we assessed students' attitudes towards 1) biology, 2) chemistry, 3) integrated curriculum vs. regular curriculum, and 4) forming a biology-chemistry learning community with the same group of students in two courses. In addition, the attitudinal survey examined students' confidence in applying chemistry concepts, biology concepts, and recognizing the connection between chemistry and biology.

Student performance data were collected via pre- and post-assessments of biology, chemistry, and integrated biology-chemistry concepts and problems. Results were reported to the project coordinator (Dr. Pursell), who compiled and analyzed students' performance assessment, attitudinal, and demographic surveys. The project coordinator was not involved in teaching control or experimental sections; conversely, the course instructors were not involved in collecting attitudinal or demographic survey data and did not have access to these data until after the semester had concluded. The results from the surveys are reported under "Attitudinal Survey" in the Results section.

Pre- and Post-Assessment Analysis

Both the control and experimental sections took the same common content assessment at the beginning (pre-assessment) and the end of the semester (post-assessment), and assessments were evaluated by the instructors using a common rubric. Aside from questions focusing on biology and chemistry as two separate subjects, there are integrated assessment questions requiring the application of both biology and chemistry concepts. These integrated assessment questions focus on the shared contents in both courses and students in the control sections should have learned the concepts required to solve these problems. Student performance data on these assessments were both analyzed in aggregate using analysis of variance (ANOVA) and individually correlated with their incoming grade point average (GPA) using correlation analysis. Significance was assumed at $P < 0.05$ for each statistical test. The results for pre- and post-

DOI: 10.20429/stem.2017.010101

assessments are reported under “Effect of Integrated Curriculum on Chemistry” and “Effect of Integrated Curriculum on Biology” in the Results section.

Results

Attitudinal Survey

We examined student attitudes through survey questions to which students responded using a 4-point Likert scale (strongly agree=1, strongly disagree=4). The surveys were done at the beginning and again at the end of the course. Our particular interest was to then determine if individual students changed attitude about surveyed topics, presumably based on their experiences in either the integrated sections vs. the non-integrated sections. Preliminary data indicates several findings worth pursuing in subsequent iterations of the study.

Students in the integrated and non-integrated sections reported enjoying science, biology, and chemistry slightly less at the end of the semester than they did at the beginning of the semester. In terms of persistence, this is a potentially positive finding as students did not significantly change their reported enjoyment level in these topics after completing a rigorous semester, while nation-wide many first-year STEM students' experience in STEM courses is so daunting that they quit STEM and seek majors in non-STEM disciplines (President's Council of Advisors on Science and Technology, 2012; Seymour, 2000; Tobias, 1990). At an open-access institution such as ours, first year STEM students are especially vulnerable to the challenges of a rigorous academic program because they most likely have not experienced such a program in their pre-college academic preparation.

The integrated section had a stronger preference for taking biology and chemistry as integrated courses after completing the semester than they did at the beginning of the semester, indicating their perceived value with the integration. On the other hand, students in the non-integrated sections had a stronger preference for separate courses at the end of the semester.

The integrated section and the non-integrated biology section thought they improved their ability to apply specific biology and chemistry concepts by the end of the semester. Compared to the beginning of the semester, the non-integrated chemistry section reported less ability to apply both biology and chemistry topics, which was not unexpected since many of these students in the non-integrated chemistry section had not or will not take any biology courses during their college career.

Concerning the necessity of applying chemistry concepts in order to apply biology concepts, all three sections agreed with this necessity both at the beginning of the semester and again at the end of the semester. However, concerning the necessity of applying biology concepts in order to apply chemistry concepts, all three sections strengthened in their agreement from the beginning of the semester to the end of the semester that biology concepts are not necessary to applying chemistry concepts. This results implies that students believe chemistry supports biology, but not the other way around. In thinking about this finding, perhaps previous student experience in chemistry in high school and college has been with very traditional chemistry curriculum and instruction, which has been very slow in integrating biological applications of chemical concepts. Conversely, for many years, the biology community has incorporated the concepts of molecules, reactions, and energy, even at the introductory level, when broaching topics such as photosynthesis, respiration, and DNA reproductive processes. As such, students in biology are accustomed to viewing biological topics through the lens of chemical concepts while the converse is not so for students of chemistry viewing chemistry topics through the lens of biological concepts.

All students had virtually no change from beginning to end of semester in either their preference for study groups with classmates or preference for lecture vs. active learning environments. For pre- to post, students maintained a neutral preference (neither favor nor oppose) for study groups and preferred to have lecture rather than active learning. Colleagues at our college teaching introductory STEM courses with active learning techniques have also have noted this student preference for lecture. We surmise this lecture preference of introductory students is twofold: 1) it is what they are accustomed to from high school and 2) they prefer that instructors "tell them exactly what they need to know for the test," which students translate to lecture, rather than having to actively work to figure out for themselves what they need to learn in the course.

Effect of Integrated Curriculum on Chemistry

The Integrated BIOL1107K/CHEM1212K (N=10) and the chemistry control (N=23) sections were investigated to understand the effect of the integrated curriculum on understanding chemistry concepts. Because very few of the chemistry control section students were concurrently taking BIOL1107K

DOI: 10.20429/stem.2017.010101

(N=2), we report the results from the chemistry control population as a whole and do not distinguish among students' prior or current biology experience.

The average percentage scores of CHEM1212K pre- and post-assessments were higher for the control chemistry section compared to the integrated section (Table 3). These students also had higher incoming CHEM 1211K grades and a higher overall GPA, possibly reflecting a firmer prior knowledge base in chemistry and stronger mathematical skills. Conversely, the integrated students demonstrated a higher average percentage score compared to Control CHEM1212K on the questions targeting shared content in both biology and chemistry in the pre- and post-assessments taken by all students; however, the difference was not judged to be significant (P = 0.16, Table 3). To eliminate the effect of insufficient exposure to interdisciplinary problems, both Integrated BIOL1107K/CHEM1212K and Control CHEM1212K sections had multiple interdisciplinary problems embedded in the curriculum throughout the semester. As all the integrated assessment questions focus on the shared contents in both courses, students in both the control and integrated sections had access to the knowledge and resources required to solve these problems.

Table 3. Student profiles of integrated and chemistry control sections.

	Student Population	
	Integrated BIOL1107K/CHEM1212K	**Control CHEM1212K**
	N = 10	**N = 23**
Incoming GPA	3.07 ± 0.60	3.42 ± 0.42
CHEM1211K final grade, grade points earned	3.09 ± 0.83	3.35 ± 0.78
CHEM1212K final grade, grade points earned	2.70 ± 1.06	3.09 ± 0.85
CHEM Pre-Assessment (%)	2.1 ± 3.7	2.7 ± 3.2
CHEM Post-Assessment (%)	54.5 ± 20.9	59.8 ± 20.1
Integrated Assessment Score (%)	38.7 ± 20.9	31.3 ± 18.6

Note: significance was assumed at P < 0.05.

Effect of Integrated Curriculum on Biology

The study design yielded three populations of students among the two sections (integrated and non-integrated) of BIOL1107K: 1) the Integrated BIOL1107K/CHEM1212K cohort (N=10); 2) students enrolled in the non-integrated BIOL1107K section that were simultaneously taking a separate CHEM 1212K section ("Control BIOL1107K+ CHEM1212K" group, N=10); 3) students enrolled in the non-integrated BIOL1107K section that did not take CHEM1212K at all during the Fall 2016 semester ("Control BIOL1107K-CHEM1212K" group N=10, Table 4). Analysis of variance (ANOVA) among the three populations of students revealed no significant difference in the students' GPA prior to the Fall 2016 semester (Table 4). Scores on the BIOL1107K pre- and post-assessments and on the standard BIOL1107K End-of-Course (EOC) Assessment tended to be higher for the Integrated course students compared to the control BIOL1107K groups, but these differences were not judged to be significant ($P > 0.05$ for each parameter). There were also no significant differences among the groups' average improvement in their BIOL1107K pre-assessment scores over the course of the semester (Δ BIOL Assessment), the students' final BIOL1107K grades, or their final CHEM1212K grades earned at the end of the semester, although each of these parameters again tended to be higher for the Integrated group compared to the control BIOL1107K students (Table 4). Students in the Integrated section were better able to correctly answer the biochemistry free-response questions ("Integrated Assessment" Table 4) at the end of the semester compared to BIOL1107K students either concurrently taking a non-integrated CHEM1212K course or not enrolled in CHEM1212K at all during Fall 2016 ($P = 0.008$). The Integrated group also performed significantly better on that component of the BIOL1107K EOC Assessment that dealt specifically with chemical and biochemical topics ("BIOL1107K EOC Assessment Score – Chemistry Questions", Table 4) than did their control counterparts ($P = 0.038$). Previous studies with small sample sizes support the significance of our results. (Pursell, 2017; Ruxton, 2006).

The correlation among each of these variables in the three populations of BIOL1107K students was examined (Figure 1). Incoming GPA in all populations examined was positively and significantly correlated with final course grades for both BIOL1107K (Figure 1a) and CHEM1212K. Similar correlations were observed between students' GPA and scores on the BIOL1107K EOC Assessment (Figure 1b) and student performance on the chemistry-specific questions on the BIOL1107K EOC Assessment (Figure 1d). However, there was no significant correlation between student GPA and improvement on the BIOL1107K EOC post-assessment compared to the pre-assessment administered at the beginning of the semester within the Integrated group (Figure 1c). This

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DOI: 10.20429/stem.2017.010101

observation suggests that students' academic performance prior to enrolling in the BIOL1107K/CHEM1212K integrated course did not pre-determine their ability to improve their overall understanding of biology topics. In contrast, both control groups of BIOL1107K students demonstrated a significant positive correlation between their GPA at the beginning of the semester and the differential between their biology pre- and post-test scores (Figure 1c).

Table 4. Student profiles of integrated and biology control sections.

	Student Population		
	Integrated BIOL1107K/CHEM1212K	**Control BIOL1107K + CHEM1212K**	**Control BIOL1107K - CHEM1212K**
	N = 10	**N = 10**	**N = 10**
Incoming GPA	3.07 ± 0.60	3.02 ± 0.39	2.83 ± 0.64
BIOL1107K final grade, grade points earned	2.70 ± 0.95	2.60 ± 1.07	2.50 ± 1.08
CHEM1212K final grade, grade points earned	2.70 ± 1.06	2.57 ± 0.53	N/A[2]
BIOL Pre-Assessment, %	42.6 ± 19.2	35.3 ± 10.2	28.2 ± 4.9
BIOL Post-Assessment, %	71.1 ± 18.6	66.7 ± 18.1	58.8 ± 19.3
Δ BIOL Assessment, %	32.7 ± 8.99	19.8 ± 12.7	22.0 ± 13.7
CHEM Pre-Assessment	1.3 ± 2.2	N/A[1]	N/A[2]
CHEM Post-Assessment	32.7 ± 12.5	N/A[1]	N/A[2]
Δ CHEM Assessment	30.9 ± 13.5	N/A[1]	N/A[2]
Integrated Assessment Score	12.0 ± 6.5*	6.0 ± 4.7	4.2 ± 4.6
BIOL1107K EOC Assessment Score, %	70.2 ± 16.6	63.4 ± 15.2	56.2 ± 17.0
BIOL1107K EOC Assessment Score – Chemistry Questions, %	71.0 ± 15.2**	60.6 ± 14.9	52.9 ± 15.7

Note: significance was assumed at P < 0.05.

1 These students were concurrently enrolled in a non-integrated section of CHEM1212K during the Fall 2016 semester and did not take the CHEM1212K Pre- or Post-Assessments.

2 These students were not enrolled in CHEM1212K at all during the Fall 2016 semester and did not take the CHEM1212K Pre- or Post-Assess ments.

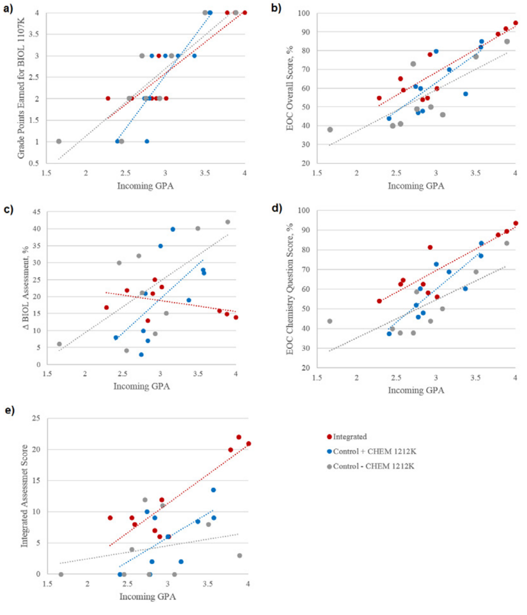
* Significantly different from control groups, P = 0.008

** Significantly different from control groups, P = 0.038

The correlation between GPA and performance on the Integrated

Assessment questions was also determined among the three BIOL1107K student groups. Both Integrated BIOL1107K/CHEM1212K students and students taking non-integrated BIOL1107K and CHEM1212K separately showed a significant positive correlation between these parameters, with the Integrated section showing a significantly higher level of achievement on the Integrated Assessment questions overall (Figure 1e and above). In contrast, the BIOL1107K students who were not concurrently enrolled in CHEM1212K during Fall 2016 showed no correlation between their incoming GPA and their performance on the Integrated Assessment questions.

Figure 1. Correlation analyses of a) BIOL1107K GPA vs. incoming GPA, b) EOC overall score vs. incoming GPA, c) ΔBIOL1107K Assessment score vs. incoming GPA, d) EOC Chemistry questions score vs. incoming GPA, and e) Integrated Assessment score vs. incoming GPA for three populations of BIOL1107K students.



Conclusions

Our study assesses the effect of integrated curriculum on students' attitudes towards learning two courses as an integrated course, their conceptual

DOI: 10.20429/stem.2017.010101

understanding of contents in both disciplines, and the awareness of connection between the two disciplines. Even though the total number of students from the one-semester study is small, there are several noteworthy indications in this initial set of data. Our attitudinal survey shows that the integrated curriculum can improve students' preference in taking the two courses as an integrated course after the completion of the course, which indicates their perceived value of the integration. The attitudinal survey also shows that integrated curriculum is effective in improving students' ability to apply both biology and chemistry topics. This is demonstrated by better performance on integrated assessment questions requiring application of knowledge in both disciplines in the integrated section over biology control section. The difference between integrated and chemistry control sections was not statistically significant, which would require further observation for firm conclusion. In terms of recognizing the connection between the two disciplines, students in all sections acknowledge that chemistry is fundamental for proper application of biology principles, especially the biology topics that have a chemistry aspect. This is illustrated by better performance on components of the BIOL1107K EOC Assessment that dealt specifically with chemical and biochemical topics in the integrated section.

This project is currently continuing for the Spring and Summer 2017 semesters, during which the same course structure has been implemented with respect to schedule and instructors; we will also introduce two integrated laboratory projects targeting the shared content in both courses. It is our hope that the trends we have observed in this pilot study will be confirmed and will be of use in re-designing STEM curricula within our institution.

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Assessing Student Progress and Performance across the Curriculum: A Tool to Evaluate Program Success Quickly

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Abstract: Evaluation of student learning is of paramount importance to the educational community and allows reflection on program successes and weaknesses; however, best practices are hotly debated. This project designed and implemented an assessment system in which an identical, mixed-format assessment was given to all levels of students in the Georgia Gwinnett College biology program at the start of the semester for academic years 2014-15, 2015-16 and Fall of 2016. The assessment contained multiple choice and free-response questions, and evaluated lab reports from core courses in the biology program. This system allows for longitudinal assessment of students, provides quick results for timely action, and can allow analysis of interesting demographic questions. We found student achievement on program goals was lower than previously assessed and student performance on multiple choice questions was higher than free-response questions. There was a modest, but temporary, gain in performance on the ability to effectively communicate science. Additionally, males outperformed their female counterparts and Hispanics underperformed their non-Hispanic peers.

Keywords: program goals, longitudinal comparison, higher education, formative and summative assessment

Acknowledgements: This work was funded by a grant from the University System of Georgia STEM Initiative II Project. We would like to thank all the faculty in the biology discipline at Georgia Gwinnett College who volunteered their services and class time to make this project a success.

DOI: 10.20429/stem.2017.010101

Introduction

Collegiate programs frequently determine a set of goals that reflect the required outcomes of the program. Evaluating student performance on program goals is of vital importance to determine progress through the program and identify targets for future remediation (Boyer 1990). In other words, faculty should know how well their students meet the goals set for them and adjust accordingly. Ideally, students become increasingly proficient in content knowledge and essential skills pertaining to their given field, i.e., seniors should display a higher mastery of outcomes than juniors, who are more capable than sophomores, and so on (Gardner et al. 1983). Graduates should possess the abilities expected of a budding professional and therefore be capable of success in a relevant field or post-graduate program. The ongoing process of improving assessment and evaluation began in earnest in 1918, has since experienced many significant changes in focus, including the Reagan administration report *A Nation At Risk*, and more recently has received new impetus from the Obama administration's "College Scorecard" initiative (Sims 1992). Furthermore, faculty should play a creative and consistent role in the development and implementation of any program assessment so they and their students can benefit (Emil and Cress 2014, Stohlman 2015).

Content knowledge, conceptual understanding and acquisition of essential skills often determine student progress over the duration of an academic program. Metrics used to determine proficiency on goals include longitudinal standardized exams, exit exams, portfolio building, and capstone or senior field experience analysis (Banta et al. 2009, Ruben 2016). Each metric has benefits and costs and proper assessment is often time-consuming. Exit exams are relatively quick and provide data comparable across students and campuses, but they often do not directly address a given institution's progress towards specific goals (Astin 2012). Exit exams also do not provide a baseline of performance or a sequence of progress; perhaps student performance at the end of a program is the same as it was at the beginning, or students make gains but fall short of a preset numerical goal (Tucker 2006). Students may also refrain from putting forth their best effort on exams not linked directly to success in a course. Alternatively, questions relevant to course goals can be embedded in exams given in diverse courses (Astin 2012), but the data then reflect progress in courses, not in programs, and must be aggregated, thus losing specificity. This type of assessment can also introduce bias from professors with expectations for individual students with whom they are familiar (Imrie et al. 2014). Neither exit exams nor exam-embedded questions provide true longitudinal data, which can allow educators to pinpoint areas of weakness in the curriculum. Here, we describe a comprehensive method of program evaluation that provides detailed longitudinal assessment of program goals while minimizing time constraints and mediating potential biases.

The described changes in evaluation methods took place within the biology discipline in the school of Science and Technology at Georgia Gwinnett College (GGC). GGC is a relatively new public, four-year, access institution that has grown rapidly in the last decade (from fewer than 100 students to almost 13,000 since being established in 2005). However, classes remain relatively small; biology classes are usually 24 students. Additionally, the college is highly diverse, 73% non-white, and has many students (36%) who are the first in their family to attend college. Importantly, biology majors at GGC are demographically representative of the entire school.

Biology majors are expected to show proficiency in content and laboratory skills as determined by seven program goals designed by the discipline's faculty (Table 1). Previously, program goals were assessed by measuring course goals using exam-embedded questions given to every student. These multiple-choice questions were on the final exam of every section of every course and graded by the corresponding professor. If an evaluation tool is to serve as formative for the faculty to modify the program, it must reveal a chain of causality; meaning instruction provides (or does not provide) increasing content knowledge for students (Hawthorne 1989). Because the previous method lacked consistent, unbiased, longitudinal assessment of any of the program goals, we were unable to robustly assess content achievement in any program goals.

Table 1. Program Goals for the biology program at Georgia Gwinnett College.

1. Communicate in oral and written form the ability to locate, critique, and utilize scholarly resources.
2. Demonstrate proficiency in basic lab skills and experimental design.
3. Apply basic chemistry and math to the study of the life sciences.
4. Know the structures and functions of cells.
5. Know the structures and functions of biomolecules (nucleic acids, pro teins, lipids, carbohydrates).
6. Explain the sources of genetic variation and determine patterns of inheritance. Describe the role of evolutionary mechanisms in biological diversity.

DOI: 10.20429/stem.2017.010101

For many years, students at all ranks had consistently reached our 'satisfactory rate' of 70% or more for every goal. These high levels of success could either have been due to genuine measurement of knowledge and skills or insufficient rigor on questions. As a result, faculty confidence in assessment was low. Surveys conducted at the discipline level suggested faculty did not agree with the following assertions: (1) our current assessment methods significantly help to inform teaching, (2) accurately reflect our majors' knowledge and skills, or (3) the amount of time and energy we spend on assessment is appropriate. These results broadly match faculty opinion of assessment elsewhere (Emil and Cress 2014).

Therefore a new measurement tool and evaluation method was designed by faculty in the biology program in order to improve our ability to discern areas in need of remediation. The measurement tool consisted of a single comprehensive exam given to randomized subsets of students from all ranks in the core courses required for completion of a biology degree. The exam included open-ended questions (free response) in addition to multiple-choice questions to evaluate application, rather than simple retrieval. The importance of free response questions in the assessment of higher order learning is well established (e.g., Birenbaum and Kikumi Tatsuoka 1987, Becker and Johnston 1999, Nichols and Sugrue 1999, Resnick and Zurawsky 2007, Heyborne et al. 2011). Essay and short answer questions can allow students to cover a wider range of content than a multiple choice or matching question, they more easily assess the integrative and/or applied levels on Bloom's taxonomy as students are typically asked to "apply" or "explain", and allow students to express their reasoning for a given answer, providing important information for formative assessment. The exam was administered to a random selection of courses at the *beginning* of the semester, thus uncoupling student performance with professor evaluation, 'teaching to the test,' or confusing student knowledge with 'cramming' for a final. Identical tests were given to students at all levels (freshmen, sophomores, juniors, and seniors), providing consistency and facilitating an instantaneous, longitudinal comparison of student performance before completion of the program. In addition to the standardized tests, we gathered a sample of lab reports from classes common to all students in the program. Student-written lab reports facilitated assessment of goals 1 and 2 which pertain to scientific communication and experimental design. Tests, as well as lab reports, were scored simultaneously by a panel of biology faculty from diverse sub-disciplines.

Grading was blind; graders had no knowledge of student identity, rank, or course.

We hold this assessment method reduces subjectivity, while providing detailed analysis of student progress through a program in time to affect change. It is efficient and provides faculty full control over program assessment while not being overburdensome. Here, we provide a description of the method with brief examples of the data it provides. Our method is not specific to biology or STEM programs and easily could be applied to other curricula at other institutions.

Methods

Design and Administration of the Assessment Exam

To assess the program, we designed and administered a standardized test to a sample of students at each level of the biology program. The exam consisted of twenty to twenty-five multiple-choice questions and one or two open-ended, short answer questions (free response). At first, questions were created by faculty in the discipline, but recent versions of the exam consisted of vetted questions derived from open-source concept maps (e.g., American Association for the Advancement of Science: http://assessment.aaas.org/topics/ and San Diego State University Division of Undergraduate Studies: http://go.sdsu.edu/dus/ctl/cabs.aspx). Each question was directly linked to a program goal.

The exam was administered to a randomized, representative set of core biology major courses during the first week of the class; if the course had a lab then the test was administered during lab. Half of the common courses were assessed in the fall and half in the spring. Therefore, all courses common to the core were evaluated each academic year. The program goals evaluated are shown in Table 1. A total of 558 biology majors from fall of 2014 through fall of 2016 were evaluated. Students were required to take the exam, but were asked for informed consent to allow use of their responses in publication. Only data from students who gave consent are presented in this paper. Exam questions were optimized over the duration of the project, thus no questions were used on more than one exam during the duration of the study. Tests were given by a designated test administrator (i.e., a faculty member not associated with the course) at the beginning of each semester. Test administrators read from a standardized script which provided reasoning for the exam. At first, students provided an anonymous identification code, but more recently, students provided their

DOI: 10.20429/stem.2017.010101

student ID in order to analyze additional information collected by the Office of Academic Assessment, such as college admission test scores and grade point averages (GPA) and true academic rank. The anonymous identification code or student ID were on both the multiple choice and free response sections of the exam to ensure easy tracking of individual student performance.

Grading Exams

Multiple-choice questions were scored with Scantron ScoreIT software. For each free response question, a panel of full-time faculty graders worked collaboratively to create a rubric before grading (see Stevens and Levi 2013 for information about rubrics). Graders were blind to the identity, current course, and rank of the students being assessed. This was done in an attempt to remove potential biases that can arise when grading the work of students with knowledge of expected performance. Additionally, faculty were given ten control questions used for standardization of the free response to attempt to discern grading bias. For the first two years, faculty who volunteered for grading were awarded a modest stipend for their day's work. More recently, administration and grading of the exam fell to the program goals committee.

Collection of Demographics

At the time of the exam, a separate survey was given to students to assess demographic data such as gender, age, and race. To avoid influencing performance by drawing attention to cultural groups, i.e., stereotype threat (Steele, et al. 2002), this survey was given only after completion of the content sections of the exam. The demographics survey also gathered data about major, career plans, enrollment status (full-time or part-time), and workload.

Determining Rank

Unfortunately, determining level in the program (e.g., freshmen, sophomore, junior, or senior) is difficult since students often do not correctly report their rank, or have deferred taking courses in the program for several semesters resulting in their rank by hours not equivalent to progress in the major courses. Therefore, we determined rank in the program by combining information on each student's self-reported rank, the class in which the test was administered, and which classes they report having passed. Together, these responses provide a more accurate measurement of each student's rank with respect to their degree. When 'rank' is mentioned throughout the paper, it is their rank using the above described 'algorithm'. Our ranks include freshmen, sophomore, junior, and senior

Grading of Lab Reports

Our first program goal addresses students' ability to communicate scientifically and perform scholarship. To assess this goal, we asked professors from core biology courses to submit lab reports assigned during the semester. Lab reports were stripped of class and student identification when graded, but unfortunately, they could not be completely anonymized because the subject matter of the class dictated the subject of the lab report. Thus faculty who have taught the course were potentially able to surmise the course of origin. Demographic data was not taken for students submitting lab reports. Therefore, lab reports were analyzed by comparing classes, which roughly corresponded to rank. To control for professor grading differences, faculty scored lab reports together in the same room, used the same grading rubric and tried to standardize grading using a 'practice' lab report. Additionally, faculty were unknowingly given five of the same lab reports to allow for detection of significant differences in grading. Faculty who volunteered for grading were awarded a modest stipend for their day's work.

Statistical Analysis

Difference between means were tested with Student's t-tests and ANOVA. Significant differences among groups were compared using Tukey-Kramer post hoc tests. Comparison of scores on multiple-choice and free response questions was performed with paired t-tests with individual students as replicates. Sample sizes vary depending on the comparisons being tested and whether or not the particular exam required students to provide the relevant information. Analysis was performed using JMP 13 statistical software from SAS.

Results

Demographics

Race and ethnicity data, which were only measured in the fall of 2014, matched those of the biology department and school as a whole, indicating our sample was representative. 63% of students tested were female, 57% of students

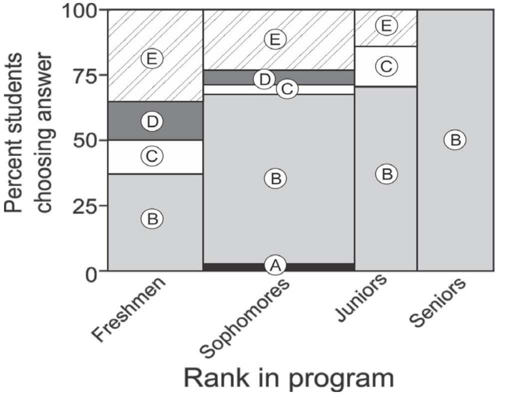
DOI: 10.20429/stem.2017.010101

were traditional college age (18-22 y), and 82% maintained a full-time college schedule (12 credit-hours or more). 82% of students had a job outside of school, with 18% of the total working more than 30 hours a week. A third of students indicated English was not the primary language spoken in their home. 47% of students surveyed intended to enter medical school after completing their bachelor's degree, 29% planned on attending graduate school, and the remaining 24% were split between careers in other health professions, education, or an unlisted field. Career plans did not differ noticeably across ranks.

Item Analysis

Using ScoreIt, individual questions were analyzed to evaluate student performance across ranks in the program and to identify moments in the academic experience where key student misconceptions were addressed. An example of the data available by question is shown in Figure 1; it shows the percentage of students who chose each answer (A-E) for each class rank. More students progressively chose the correct answer B, while E was progressively chosen less frequently. Answer A appears to be a distractor, while answer D is eliminated as a plausible choice by students by their junior year. Using this information, we can analyze each question to determine how students progress through the program at a conceptual level.

Figure 1. Diagram of student choices on an example multiple-choice question across rank. Each multiple-choice question linked to a core concept was analyzed individually using ScoreIt and JMP. The relative proportion of answers was broken down by rank within the program. Column width corresponds to sample size.



In addition, ScoreIt provides point-biserial correlation analysis, which correlates (1) the likelihood each question is answered correctly with (2) the students' overall grades on the exam (Varma 2008). A question with a low point-biserial value is one more likely to be answered correctly by students who did poorly on the exam overall than students who did well overall. Such questions should be evaluated for confusing wording or for not matching the style or content of the rest of the exam.

Overall Scores

Mean scores of all tests combined was 48 +/- 17%, well below the historical goal of 70% set by the program's faculty. There was a significant interaction between student rank within the program and the semester the test was given (Fig. 2), indicating differences in the questions on the exam across semesters. Full factorial ANOVA analysis confirmed both rank and exam are significant determinants of overall score (Table 2). However, most tests showed a significant jump only between incoming freshmen to first-semester sophomores. After the freshman year, there were no differences among the top three ranks, excepting the fall 2016 exam, when seniors scored significantly higher than their lower-ranked peers.

Influence of Sex and Ethnicity

Effects of demographic differences were also assessed and we report a few intriguing findings here. Across exams, males performed significantly better than females (male score = 52 +/- 18, female score = 45 +/- 16, $t = 4.3$, $df = 446$, $p < 0.0001$). Additionally, students self-reporting as non-Hispanic performed significantly better than Hispanics/Latinos (non-Hispanic score = 49 +/- 18, Hispanic/Latino score = 44 +/- 15, $t = 3.3$, $df = 217$, $p = 0.001$). This reduction seems to only apply to students from Hispanic backgrounds in which English is not the primary language spoken in the home and did not hold for other ethnicities with English as a second language (Fig. 3). Indeed, comparison of overall score on the exam suggests that among Hispanic students, the language spoken at home is correlated with content acquisition. This is not the case for other ethnicities.

Figure 2. Mean score on multiple-choice per semester per rank. The dotted line represents the traditional passing score of 70%. Means +/- s.e. shown. Means sharing the same letter do not differ significantly at the 95% confidence level

DOI: 10.20429/stem.2017.010101

based on the Tukey mean comparison method.

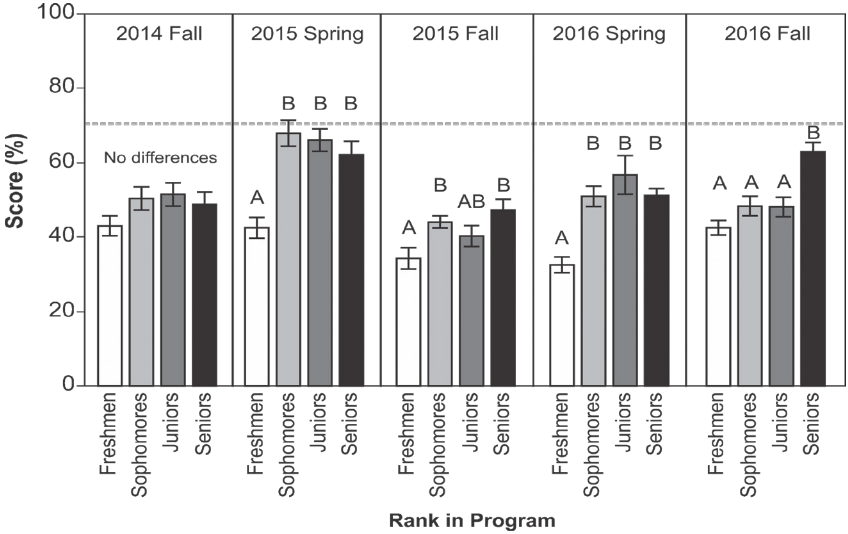
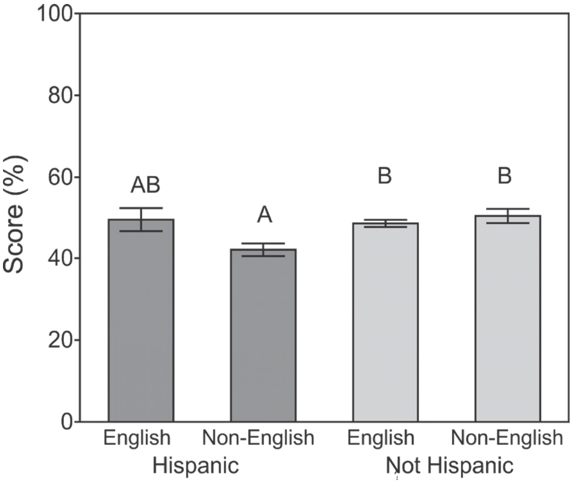


Table 2. Full factorial ANOVA showing significant differences among ranks within program, but also a significant effect of the semester in which the test was given.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F	P
Semester	4	14527.18	3631.80	16.13	**<0.0001**
Rank in program	3	18942.27	6314.09	28.03	**<0.0001**
Semester x Rank	12	8196.08	683.01	3.03	**0.0004**
Error	593	133539.84	2535.58		
Total	612	181696.86			

Figure 3. Mean score of Hispanic and Non-Hispanic students from homes that either speak English as the predominant language versus another language. Means +/- s.e. shown. Means sharing the same letter do not differ significantly at the 95% confidence level based on the Tukey mean comparison method.



Scores across Goals

In addition to being able to determine overall progression through the program and evaluating the effects of specific demographics, using our method, we were also able to assess if any patterns existed for each goal. Figure 4 shows performance varied across goals and differently between exams. The only mildly consistent trend is freshman tend to do worse on the goals compared to all other rank of student. One major exception was goal 7. Students across all ranks in the program consistently scored lower on questions pertaining to evolution, regardless of the exam administered.

Figure 4. Mean score in multiple-choice for each goal per semester per rank in program. Progress on each goal for each exam given (semester). Goal 6 and 7 were not assessed in the spring of 2016. The most common effect is a difference in performance between freshmen and the other ranks. Means +/- s.e. shown. Means within semesters sharing the same letter do not differ significantly at the 95% confidence level based on the Tukey mean comparison method.

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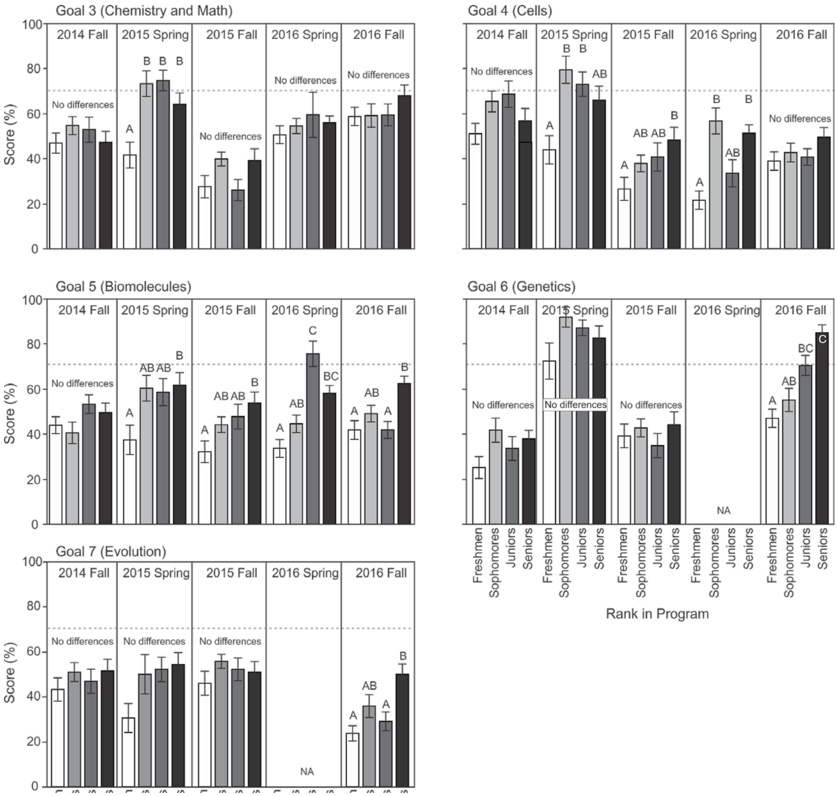
DOI: 10.20429/stem.2017.010101



Overall Scores on Free Response Questions

The free response, short answer questions targeted all of the goals over the course of this project. Because the biology discipline has recently been interested in gaining insight into student's understanding of goal 4, it was assessed most often during this study. The average of all the free response scores, broken down by rank and goal is shown in Figure 5. Similar to the multiple choice section of the exam, freshman often underperformed their higher ranking peers. Again goal 7 showed the lowest gains overall, whereas goals 3 and 5 showed some of the highest gains.

Interestingly, for most goals, students scored significantly higher on the multiple-choice versions of assessment than the free response, excepting goal 3 (Chemistry and Math), which showed the opposite result (Table 3).

Figure 5. Mean score on free response questions for each goal per rank in

program per semester. Means +/- s.e. shown. Means within semesters sharing the same letter do not differ significantly at the 95% confidence level based on the Tukey mean comparison method.

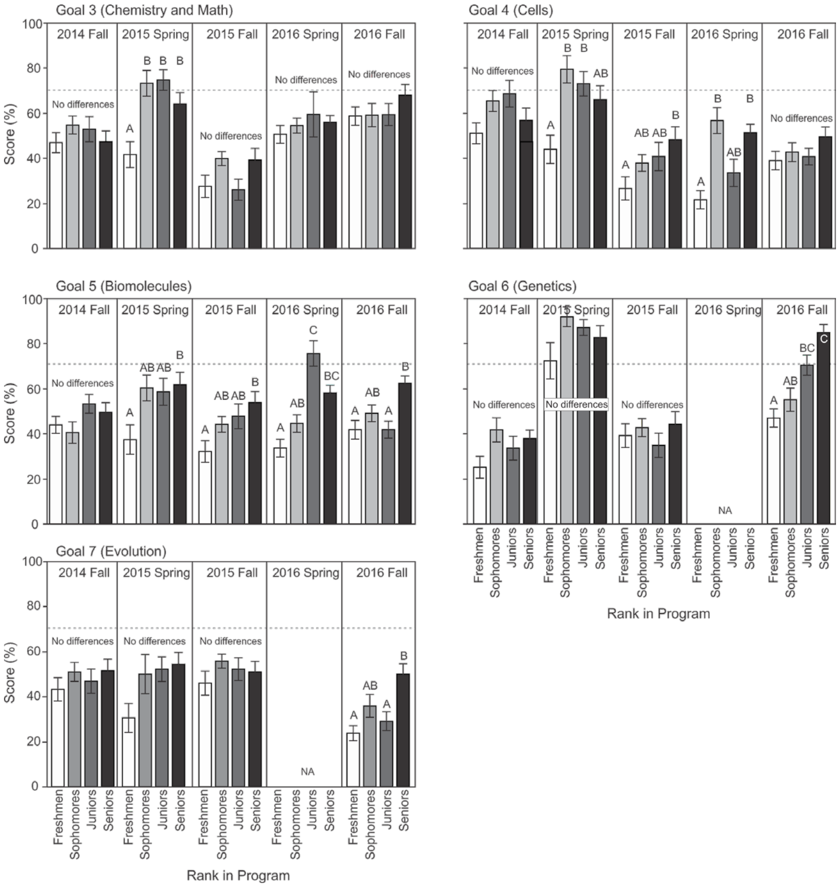


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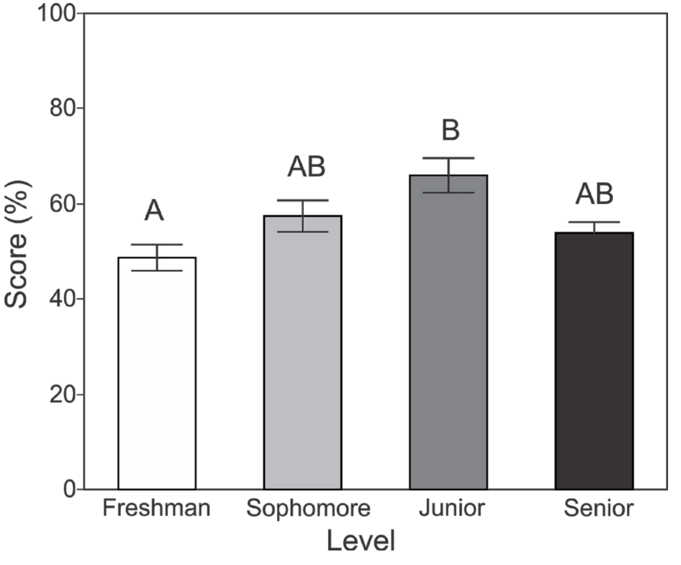
Table 3. Comparison of performance on multiple-choice versus free response questions. Analysis consisted of paired t-tests which control for among-student differences.

Goal	Semester	N	Multiple-Choice (mean %)	Free-response (mean %)	Mean difference	*t*	*p*
Goal 3 (Chemistry and Math)	Fall 2014	69	51.44	60.20	-8.75	-2.33	**0.0228**
	Fall 2015	58	32.75	74.38	-41.62	-10.36	**<0.0001**
Goal 4 (Cells)	Fall 2014	61	63.01	51.68	11.33	3.98	**0.0002**
	Spring 2015	38	71.05	41.56	29.49	7.91	**<0.0001**
	Fall 2016	21	52.38	50.95	1.45	0.578	0.56
Goal 5 (Biomolecules)	Fall 2014	39	49.25	44.82	4.432	2.87	**0.0054**
	Spring 2015	37	56.76	60.95	-4.19	-0.86	0.3921
Goal 6 (Genetics)*							
Goal 7 (Evolution)	Fall 2015	31	53.76	33.07	20.69	5.10	**<0.0001**

Analysis of Lab Reports

Lab reports were collected from each of the core classes that has a corresponding lab and graded by a committee of volunteer faculty in the fall of 2014, and spring of 2015 and 2016. Faculty worked together on a specified day to complete grading of the lab reports using a standard lab report rubric and started grading after first standardizing to one lab report. There was a difference between freshman and junior level courses, though this did not persist into the more senior-level course (biochemistry) (Fig. 6).

Figure 6. Mean score on lab reports across course level. Lab reports were submitted by professors of core courses and did not come with student demographic data. Therefore, lab reports are divided by approximate level of the course. Means +/- s.e. shown. Means marked with different letters are significantly different.



Discussion

Our proposed method is efficient, informative, and effective. Our pilot program shows the assessment tool provides actionable information in the first weeks of a semester with minimum impact on student, professor, or class time and it has already provided novel data, unavailable using our previous method, which suggests areas of targeted remediation. For instance, our data indicate previous assessment methods overestimated performance, as scores differed greatly from the typical 70-80% scores (Fig. 2). Unfortunately, the progressive acquisition of core biology content goals was not found significant in these data, neither in the exam nor our evaluation of lab reports, although there are suggestions of improvement over the duration of the program, particularly after freshman year (Figs. 2, 4-6). These results are somewhat disconcerting, but provide useful information to begin addressing the issues. For instance, the spring of 2014 showed no gains overall in any goal; which could be due to spring

DOI: 10.20429/stem.2017.010101

2014 being the first semester we designed and implemented the assessment. Afterward, deliberate effort was made to validate the questions used for assessment.

By analyzing student choices on individual questions across ranks (as in Figure 1), we provide a longitudinal measurement tool and a potentially powerful way to identify which courses address specific student misconceptions. Or alternatively, these data can reveal times in a student's academic career when a misconception is not appropriately dispelled or potentially created. This is even more impactful as the data become validated historically. Obviously, this requires a reusable measurement tool which is currently still under development in our institution.

Our method allows easy evaluation of each program goal individually, and we did find adequate gains, as well as higher overall scores, for some goals, suggesting satisfactory performance of our program in these areas. Other goals, however, are in need of immediate focus, for example, goal 7, evolution (Figs. 4 & 5). Student understanding of evolution is often lagging, especially in the United States where nearly 40% of Americans profess denial of the theory (Miller et al. 2006). One possible use of these data would be to identify and assess a key misconception or alternative conceptions, such as how natural selection works, a major tenet of evolutionary theory. We can examine the misconception via the granularity of item analysis (Fig. 1) and by designing a module could remediate the issue. Afterward, the same assessment question could be given to all students who took the class in which this module was tested, but at the start of the next semester. Remediation, or lack thereof, would have strong support. Such evidence would provide an argument to disseminate the use of the module, or to ask for funds for additional supplies to further address it. This type of immediate action planning is quite possible using our method.

Performance on lab reports also shows improvement through the ranks, however with important caveats. The lab reports we assessed were provided voluntarily by professors teaching core courses in the curriculum. Therefore, they cannot be associated with individual students and lack demographic data. Instead, we approximate student rank using the course in which the lab report was assigned. Unfortunately, different courses have different requirements for their lab reports and lab reports are based on vastly different experimental styles. Therefore, we cannot guarantee graders are not influenced by their expectations of the course. Remarkably, there is a decline in progress at the senior level

(Fig. 6). Lab reports at the senior level came exclusively from biochemistry courses, which are taught by both biology and chemistry faculty, who often have different visions of the style desired in a lab report. Again, we cannot account for differences in professor requirements, but we suggest there may be discipline-specific differences as well. One hindrance in students' ability to properly communicate science may be related to varying expectations and standards for lab reports or other written projects from different subdisciplines.

Free response questions often provide more thorough assessment of student skills and knowledge and can address concepts higher on Bloom's taxonomy (Biranbaum and Tatsuka 1987), although the data on this is mixed (Hogan 1981). However, when used for formative assessment, the choice of question type can also influence future student achievement (Heyborne et al. 2011). We found students typically performed better on multiple-choice questions than free response for the same goal in the same semester. One notable exception to these findings is goal 3 (Chemistry and Math) (Table 3). Perhaps students are more accustomed to word problems in chemistry and math or are more likely to work through a problem rather than guess, when choices are not provided. These results may also relate to the level of Bloom's required for MCQ vs. free response questions.

The inconsistencies of exam questions, demonstrated in Figure 2, do warrant further investigation into the style of questioning. Perhaps these differences are because of the classes students have taken or are due to differences in question difficulty. However, because exams were given during different semesters, the student body itself may have changed. This is especially likely given the rapid growth of GGC. In the future, exams could be cycled to more directly compare progress over time. We are currently investigating using vetted questions from published sources to better standardize our exam.

It is important to note this type of longitudinal approach is not without its critics within the field of assessment and evaluation (Yorke and Zaitseva 2013). Astin (2012) argues measurement tools similar to ours are not informative because there are too many confounding factors to determine causality. Was it, for example, passing a genetics course that shifted aggregate junior's answers on question 7 to C? Is it true that upperclassmen are always a representative sample of the cohort of freshmen they were several years ago? Sometimes factors as basic as retention complicate the data. Additionally, because the multiple choice and free response sections of our assessment are likely considered low-stakes

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DOI: 10.20429/stem.2017.010101

by students, there is concern students do not take the test seriously. Motivating students can increase their performance on low-stakes assessments (Hawthorne et al. 2015). To encourage earnest participation and reduce student anxiety, we gave our assessment the first week of class by a faculty member not directly linked to the class. Additionally, a standardized script was read emphasizing the importance of their participation and how it will benefit their program and thus their education in our program. This was done in an attempt to increase their intrinsic motivation for doing their best on the exam.

One of our ongoing attempts to address some of the above concerns is the use of traceable identifiers for students who take the exam. This will allow us to compare scores with Grade Point Average as well as entry exam scores. Additionally, because the exam will continue to be given each year, students will likely take the assessment more than once in the course of their time at GGC. This allows us to examine a cohort (albeit quite small) for whom we can say with more confidence our program affected. This pool could be expanded by intentionally choosing classes with students already tested.

Despite caveats in longitudinal assessment, the data regarding Hispanic and male students do not rely on those same assumptions about progress and are therefore possible sources of insight into our institution, if not all higher education. Students of Hispanic origin scored lower than non-Hispanic students (Fig. 3). This is most likely due to students using English as a second language (ESL). Many schools provide resources to aid ESL students (Kim et al. 2015) and GGC is no exception. It is informative to know our data identified the difficulties dual language students face and point to further differences based on student origins (see Hambleton et al 2004 for more).

Of note are the consistent trends that self-identified males perform better in aggregate than females. Although similar results have been reported elsewhere, are far from novel (e.g., Hill et al. 2010), GGC may provide an atypical example given that most biology majors are female (62% in 2014-2015, Runck 2015). Despite being the majority, females appear to have lower educational content acquisition. This suggests an avenue for possible programmatic remediation and could relate to the lower rate of employment of females in STEM careers (Beede et al. 2011). Further investigation is required.

Because we were interested in how students were progressing through our biology program, the portfolio or exit exam approach is not an appropriate tool for our purposes. We want to understand which areas of our program are doing well and which may need more attention, thus at GGC we more closely approximate a value-added approach to assessment, with respect to both our stakeholders (students, administration, state education officials) and the concerns of our faculty. This approach is largely due to the nature of our institution and the associated mission. However, this does not preclude the use of salient data for formative assessment of our work as educators. Specifically, the use of traceable identifiers may allow us to measure specific modules for the effect on remediation of key misconceptions. The granularity of the measurement tool we have created allows for a potentially powerful lens to examine the effect of specific changes in course content or emphasis. Overall, we find this method generally easy to use and unique in its ability to provide an abundance of diverse and useful information related to our students' progression through our program.

https://digitalcommons.georgiasouthern.edu/stem_proceedings/vol1/iss1/1
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The Correlation between Extracurricular STEM activities and Student with Disabilities Performance on a Standardized Science Assessment

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Abstract: Students with disabilities perform below their non-disabled peers in science (National Science Foundation, 2015). The purpose of the exploratory research was to determine if informal science learning activities offered in Florida districts make a difference on the performance of students with disabilities (SWD) on the 2015 8th grade Florida science assessment using quasi-experimental research methods. After determining a statistically significant difference does exist on the difference between students with and without disabilities on the 8th Grade Florida Science Assessment, the researcher determined if STEM personnel track the number of students with disabilities who participate in STEM activities. The number and types of STEM activities were collected by district. Lastly, the researcher determined there was a small correlation between SWD performance on the Science assessment and the number of STEM activities offered in each district.

Keywords: extracurricular, STEM, disabilities, correlation, science

Correlation between Extracurricular STEM activities and Student with Disabilities Performance on a Standardized Science Assessment

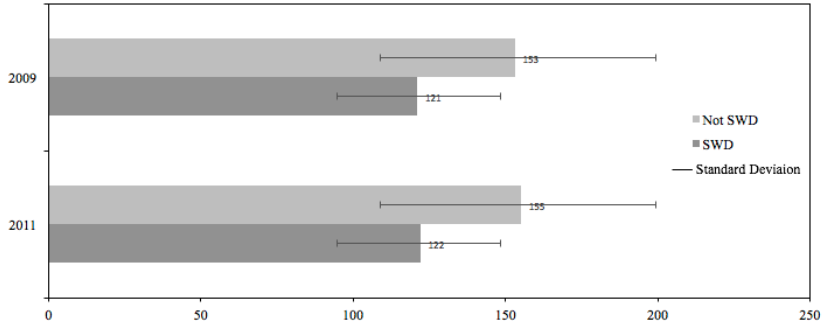
A robust and diverse science, technology, engineering and mathematics (STEM) workforce is critical to our nation's competitiveness because individuals with STEM knowledge, skills, and abilities drive the innovation that will lead to new products, industries, and economic growth (BHED/Act Policy Brief, 2014; National Academies of Sciences, Engineering, and Medicine, 2016; National Science Board, 2016). Even with the clear need for more diverse STEM workers, only 5% of students with disabilities (SWD) enter the STEM workforce (Leddy, 2010). One reason SWD do not enter the STEM workforce is because they struggle in science (Basham & Marino, 2013). Students with disabilities (SWD) have historically and consistently struggled in science (National Center for Education Statistics, 2011). This trend becomes increasingly clear in middle school where the decision is often made to pursue advanced science and engineering courses (Hartung, Porfeli, & Vondracek, 2008).

On the 2011 National Assessment of Educational Progress (NAEP)

DOI: 10.20429/stem.2017.010101

in 8th grade science in all states, a significant difference on the scaled scores of SWD (M = 122, SD = 38) and students without disabilities (M = 155, SD = 32); p = 0.00 was evident. On the 2009 NAEP 8th grade science assessment, there was a significant difference on the scaled scores of students with disabilities (M = 121, SD = 39) and students without disabilities (M=153, SD = 33); p = 0.00 (National Center for Education Statistics [NCES], 2011). See Figure 1 for an overview of 8th grade NAEP science scores where the discrepancy can be easily seen. As a result, educators and policymakers continue to search for programs to close the science achievement gap between SWD and their non-disabled peers.

Figure 1. NAEP Science 8 Grade Scores.



Many general education STEM teachers are unprepared to meet the needs of SWD (Stefanich, 2007). Montgomery and Mirenda (2014) stated teachers of students in inclusive classrooms report they lack the knowledge, skills, and confidence to make instructional adaptations for SWD. Furthermore, the adaptations made were not consistent, systemic, or as frequent as needed (Montgomery & Mirenda, 2014) In 2012, Marino and Hayes stated science teachers lack instructional diversity and have inadequate knowledge of effective pedagogical practices for teaching SWD. As a result, there is a need to research different pedagogical approaches for educating SWD to become scientifically literate citizens. Different pedagogical approaches include teaching science literacy through extracurricular STEM activities.

The purpose of this project is to address the science literacy discrepancy between students with and without disabilities in the 8th grade by determining if STEM activities make an impact on standardized science scores. Should there be a correlation between STEM activities and SWD science scores, then an argument can be made to provide access to more STEM activities to all students, especially SWD. Implications from this research will be discussed.

Purpose and Research Questions

Researchers suggest that participation in out of school science learning experiences has a positive influence on participants' attitudes about science both short term and longitudinally (Antink-Meyer, Bartos, Lederman, & Lederman, 2014; Bhattacharyya, Mead, & Nathaniel, 2011; Bischoff, Castendyk, Gallagher, Schamloffel, & Labroo, 2008; Fields, 2009; Luehmann, 2009). Furthermore, students who participated in extracurricular activities have better academic and social outcomes than students who do not participate (Durlak, Weissberg, & Pachan, 2010). However, SWD are underrepresented in extracurricular activities and struggle with middle school science (Brigman, Webb, & Campbell, 2007; Marino, Gotch, Israel, Vasquez, Basham, & Becht, 2014; U. S. Government Accountability Office, 2013). Therefore, additional research is needed to determine the effect on SWD participation in extracurricular activities and learning outcomes in science (Shields, King, Corbett, & Imms, 2014).

The purpose of the current study was to determine if there were differences between students with and without disabilities on the 2015 8th Grade Florida Science Assessment, the types of STEM activities offered in Florida school districts, and the percentage and type of SWD who participate in STEM activities in each district. Furthermore, the researcher examined the relationship between the number of STEM activities in a district and SWD achievement on the 2015 8th Grade Florida Science Assessment. The findings from this investigation should assist researchers, administrators and teachers in understanding the relationship between extracurricular activities and SWD performance in science. Findings should add to the general knowledge and understanding of extracurricular activities and their impact on SWD.
The research design for this study was guided by the following questions:

- RQ1: Is there a statistically significant difference between the perfor mance of students with and without disabilities on the 2015 8th Grade Florida Science assessment?
  - o Hypothesis – There will be a statistically significant difference
- RQ2: What percentage of SWD do school personnel report as partici pating in after-school STEM activities?

DOI: 10.20429/stem.2017.010101
58

  - o Hypothesis – Most school personnel do not report SWD par ticipation
- RQ3: What federal category of SWD (e.g., specific learning disability) do school personnel report as having the highest level of participation during after-school STEM activities?
  - o Hypothesis – SLD will be the highest reported category.
- RQ4: What is the relationship between the number of STEM activities in a district and SWD achievement on the 2015 8th Grade Florida Statewide Science Assessment?
  - o There will be a small correlation between the number of STEM activities and SWD performance on the science assessment.

The researcher used an exploratory, quasi-experimental single survey design for this study. The researcher created the survey with input from the state STEM director. The survey was then distributed to the STEM or science director in each of the 67 Florida districts. The district directors were instructed to forward the survey to STEM personnel in their districts. The participants in the survey are described in Table 1. These participants were selected, as they would have the most knowledge about the number and types of STEM activities offered in their schools.

Table 1. Position stated by study participants.

Position	Response	Percentage
STEM Teacher	124	47%
Non-STEM Teacher (e.g., special educator, gifted)	46	17%
District STEM Administrator	24	9%
Instructional Coach	7	3%
Specialists	7	3%
School STEM Administrator	5	2%
Other (did not state position)	50	19%
Total	263	

As a part of the survey, school personnel were asked to name the types of STEM activities offered in each district. Table 2 lists the top activities offered in Florida public school districts.

Table 2. Types of Activities Offered in the Respondent's School or District.

Answer	Responses	Percentage of Respondents
Science Fair	188	79
FIRST Robotics	78	33
Common STEM Planning time	48	20
Thematic STEM assignments	57	24
Modeling and Simulation Club	24	10
SECME	80	33
Science Olympiad	69	29
Other	96	40
Total	230	

Summary of the Results

Research Question 1.

The first research question asked the following: Is there a statistically significant difference between the performance of students with and without disabilities on the 2015 8th Grade Florida Science Assessment? Hypothesis 1 stated there would be a statistically significant difference between students with and without disabilities on the 8th Grade Science Assessment. The null hypothesis was rejected based on the independent samples t test analysis, there was a statistically significant difference between the variables.

Table 3. *T*-test for Independent Means

	Levene's Test		*t*-test for Equality of Means						
								95% CI	
	F	Sig.	*t*	*df*	Sig.	MD	SED	L	U
V	.061	.805	20.665	32	.000	17.61	.852	15.925	19.296

Note. EV = equal variances assumed, Sig. = significance, MD = mean differences, SED = standard error difference, CI = confidence interval of the difference, L = lower, U = upper

The question was answered with student performance data accessed from the FLDOE website using an independent samples t test (Table 3). The researcher tested assumptions for normality, homogeneity of variance, and independence on each variable prior to running the analysis. Because the

DOI: 10.20429/stem.2017.010101

assumption of normality was not met in the first analysis on all 2015 8th Grade students, the researcher examined a boxplot and performed a Grubb's test. Consequently, the researcher determined outliers were causing the abnormal distribution. As a result, the researcher removed the outliers, which were more than two standard deviations from the mean. The resulting analysis revealed the assumption of normality was met when outliers were removed on the results of the Florida Science Assessment for all 8th grade students. The assumption of normality was met for SWD and an analysis of the districts with outlying science scores was performed.

The assumption of homogeneity was met as indicated by an insignificant Levene's test. Because there was no random assignment, the assumption of independence was not met. Violation of the independence assumption created potential for an increased probability of a Type I or Type II error. Based on G*power version 3.1.9.2 (Faul, Erdfelder, Buchner, & Lang, 2009) analysis, the suggested sample size was 26 districts for each group for an independent samples t test using two different samples. The resulting analysis determined the mean scores between SWD and all 8th grade Students on the 8th Grade Florida Science Assessment was statistically significant with a large effect size. The results provided evidence that SWD score lower than students without disabilities on the 2015 8th Grade Florida Science Assessment.

Research Question 2.

The second research question asked the following: What percentage of students with disabilities do school personnel report as participating in after-school STEM activities? Hypothesis 2 stated school personnel will report a small percentage of SWD participating in after-school STEM activities. The null hypothesis was rejected based on the descriptive statistics used to analyze the responses from 230 school STEM personnel who answered the question. Of the 230 respondents, 173 or 75% reported their district does not track the number of SWD in their STEM clubs and 47 or 20% stated 0-20% of SWD participate in STEM activities. See Table 4 for more information on the categories of SWD reported.

Table 4. The Percentage of SWD School Personnel Report as Participating in STEM Activities.

Answer	Response	Percentage
We do not track the number of SWD	173	75
0-20%	47	20
21-40%	5	2
41-60%	4	2
Greater than 60%	1	0
Total	230	

Research Question 3.

The third research question asked the following: What disability category do school personnel report as having the highest level of participation during after-school STEM activities? Hypothesis 3 stated the disability category having the highest level of participation during after-school STEM activities was students with learning disabilities. Students with learning disabilities are defined as students who exhibit "one or more of the basic psychological processes involved in understanding or in using language, spoken or written, which disorder may manifest itself in the imperfect ability to listen, think, speak, read, write, spell or do mathematical calculations" (IDEA, 2004; 20 U.S.C. §1401 [30]). The null hypothesis was rejected based on the descriptive statistics used to analyze the responses from the 75 respondents who answered the survey question. Of the 75 responses, 42 or 56% selected LD. It should be noted that only 75 of the 230 respondents answered this question on the survey. Implications of the low response rate are discussed in the results.

Research Question 4.

The last research question asked the following: What is the relationship between the number of STEM activities in a district and students with disabilities' achievement on the 8th Grade Florida Statewide Science Assessment? Hypothesis 4 stated there will be a small correlation between the number of STEM activities offered and SWD achievement on the 2015 8th Grade Science assessment. The null hypothesis of a zero correlation, however, was not rejected based on the analysis of a Pearson Correlation Coefficient because the observed

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DOI: 10.20429/stem.2017.010101

power was .189, which indicates a Type I error may be possible. Thus the researcher could not reject the null hypothesis that the correlation is zero at the .05 level of significance. There was a small positive correlation (Table 5) between the number of STEM activities districts offered and SWD 2015 8th Grade Florida Science Assessment scores. The number of STEM activities offered in a district explained 8% of the variation in the 2015 8th Grade Florida Science Assessment scores. Specifically, the number of STEM activities offered in a district explained 8% of the variance in the test scores. Alternatively, the number of STEM activities in the students' school district did not explain 92% of the variance in scores of SWD.

Table 5. Pearson's Correlation Coefficient.

		Activities	SWD mean score
activities	Pearson's Correlation	1	.235
	Sig. (2-tailed)		.189
	N	33	33
SWD Mean Score	Pearson's Correlation	.235	1
	Sig. (2-tailed)	.189	
	N	33	33

Research question 4 was answered by the researcher with student performance data accessed from the Florida Department of Education (FLDOE) website and the results of an electronic questionnaire distributed to school STEM personnel. Assumptions for variables, outliers, linearity, and normality were tested by the researcher on each variable prior to running the analysis. Assumptions for variables were met. Assumptions of normality was met for STEM activities but not the 8th Grade Science Florida Assessment mean scores of SWD based on the Shapiro-Wilk's test. Even though the assumption of normality was violated for the mean science scores, a Pearson's Correlation Coefficient was calculated because the test is somewhat robust to deviations from normality (Laerd Statistics, 2016). The Pearson Correlation Coefficient (r = 0.235) is interpreted as a small effect size (Cohen, 1988).

Discussion of the Results

Interpretation of the Findings

Analysis of RQ1 added to the research that there is a statistically significant difference between students with and without disabilities on the 8th grade Florida Science Assessment. The results align with what is found in the literature with the history of performance on standardized science assessments between students with and without disabilities in both Florida and the nation. The current study adds to the field of research that SWD continue to struggle in science in the state of Florida. Furthermore, outliers were present in the data from smaller school districts, indicating students from smaller districts perform worse than their peers from larger districts on the Florida Science assessment.

Analysis of RQ2, resulted in data that explains the paucity of information on the number of SWD who participate in STEM activities. Until school and district personnel track the number of SWD who participate in STEM activities, researchers will not be able to determine if STEM activities benefit them, specifically when correlated with student outcomes on standardized assessments. School and district personnel should track the number of SWD who participate in STEM activities. Without the data, research on the effectiveness of such activities will not be robust.

For research question 3, the researcher determined the type of SWD represented in STEM activities. According to the U.S. Department of Education (2014), 35% of all children and youth receiving special education services were categorized as having SLD in 2012-2013. Given most students served under the Individuals with Disabilities Education Act (IDEA) have learning disabilities, students with LD as expected represented the disability category having the highest level of participation in afterschool STEM activities. Additionally, researchers at NCES (2016) reported 66.2% of students with LD spent 80% or more of their time in inclusion classrooms in the fall of 2011, the latest figures reported. Students with LD were more likely to spend most of their time in inclusion classrooms than any other disability category. Specifically, more than 80% of students with LD receive their science instruction in the general education setting (Aud et al., 2012). As a result, the fact that district and school personnel in this study reported students with LD represent the most SWD who participate in STEM activities lends strength to the robustness of the survey as it follows the national trend for students with disabilities and inclusion.

DOI: 10.20429/stem.2017.010101

However, only 75 of the 489 respondents (15%) who began the survey answered the question. The lack of response on this question impacted the validity of the survey. Consequently, the results are not robust and should be interpreted with caution. Further analysis needs to be conducted to determine why so many respondents skipped this question.

For RQ4, the researcher found the number of STEM activities in a district and the outcomes of SWD on the 8th Grade 2015 Florida Science assessment did have a small correlation (r = 0.235) between the two variables. It is concerning that power was not met and thus rejecting the null hypothesis of no correlation at the .05 significance level cannot be accomplished. The observed power was .189, which indicated a Type I error may be possible, but was not likely. Thus the null hypothesis that the correlation is zero could not be rejected at the .05 level of significance. In other words, failure to reject the null hypothesis, because there is no correlation between the performance of SWD on the 8th Grade Florida Science Assessment and the number of STEM activities offered in a district implies further analysis and research is needed. A possibility exists of a correlation between the two variables, despite the evidence from a single sample (Gall, Gall, & Borg, 2012). Even if the researcher had set a higher significance level, the null hypothesis could not be rejected due to the high p value. Because the researcher selected a .05 level, there is a 1 in 5 chances occur that the researcher will reject the null hypothesis when, in fact, the statistical evidence does not justify its rejection (Gall et al., 2007). If the rejection of the null hypothesis is unwarranted, it is called a Type I error (Cowles & Davis, 1982). Because none of the samples were randomly drawn or assigned, the use of tests of statistical significance is questionable. Furthermore, inferences cannot be made as a result of the current quasi experimental, exploratory research. As a result, replications of the current study should be completed to attain additional information and assurance that the observed results are real. Cohen (1990) suggested future replication of the variables in the same and different settings will provide a more informed judgment of the research.

Limitations

As with any study, limitations arise that affect the outcomes of the research. The study was limited to student performance data from the districts for the year 2015. Additionally, the data was self-reported to the state by school personnel. Some of the data used in this study were collected using a researcher created survey instrument. Findings are based on the assumptions that the participants responded honestly and interpreted the instrument as intended. Additionally, results could be biased by the personality traits of school personnel who responded to the questionnaire compared to the traits of personnel who deleted the questionnaire without answering or forwarding it. Lastly, the results could be biased by the personalities of respondents who did not complete or skipped questions on the questionnaire.

After-school programs in each district and even each school varies and there is no district or state measurement of the number or types of after-school programs offered. As a result, the researcher utilized an electronic survey to ask school personnel about the types of STEM activities offered in their school district. Even after receiving feedback from experts in the field and piloting a survey on STEM activities, the answers varied widely depending on the title of the respondent and whether he or she represented a school or district. As a result, these differences may have been a factor in this study with regards to the number of activities offered in a district as well as the reliability of consistency in responses from the survey. Having a reliability of consistency in responses of less than 80% is another limitation as the reliability of the survey was weak. More research should be conducted on the psychometrics of the survey and the variability of participant responses. Lastly, researcher bias is presumable due to the fact that the researcher holds prior beliefs regarding the influence of STEM activities on SWD due to her experience as a FIRST robotics coach. The study was limited to interpretations made by the author; other plausible explanations may exist.

Recommendations

Additional research is needed on STEM activities and their impact on SWD performance on standardized science assessments because of the discrepancy in student scores. However, there is a dearth in the scientific research on the impacts of STEM activities and SWD. As a result of the outcomes of the current study, the researcher suggests STEM activities may be beneficial to students with disabilities performance in science. Based on the findings, the researcher recommends district personnel track the number and disability category of SWD who participate in extracurricular STEM activities. These data are needed to conduct more robust research in the area of informal STEM learning and SWD.

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DOI: 10.20429/stem.2017.010101

It is recommended the current research be replicated in other states. The size and resources of the different school districts should be considered. It is also recommended more targeted research be conducted within a single district to determine if a correlation exists between different schools in a district. A single district study could possibly control for more variables like teacher preparation, teacher quality, student demographics, etc.

Implications

For Practice

Given the current climate of science education, SWD will continue to fall even further behind if educators do not identify activities that help SWD become successful in science. If activities cannot be offered during the school day, science educators have the potential to offer exciting, competition based extracurricular STEM activities that take place after school. Researchers have studied the effects of extracurricular activities on students with promising results (Mahoney, Levine, & Hinga, 2010; Vandell, Reisner & Pierce, 2007). However, very few studies have focused on the effects of extracurricular activities on SWD (Fisher, 2016). Given this paucity in research, a need exists to identify if STEM activities make a difference on the outcomes of SWD on standardized science assessments.

For Research

The relationship between STEM programs and SWD are rarely researched. To address persistent issues and assist in providing helpful skills and tools to educators working with SWD, it is recommended that current interventions and best practices focus on including more SWD in STEM activities. Oftentimes researchers analyze interventions for SWD; however, as addressed in research question two, many school personnel do not track or report the number of SWD who participate in STEM activities. Therefore, it is difficult to effectively research SWD and STEM activities as an intervention. The researcher recommended, for large national studies, that scientists collect data on SWD who participate in STEM activities. Once this data is gathered, researchers will be able to look more closely at trends and issues of SWD and informal science learning. Finally, previous researchers discuss the positive attributes associated with participating in extracurricular activities (Durlak et al., 2010; Fredricks & Eccles, 2008). To include SWD in research on extracurricular activities, unique data collection methods must be used to ensure SWD needs are represented in the literature.

Conclusion

Students with disabilities perform below their non-disabled peers in science (National Center for Educational Statistics [NCES], 2011; National Educational Longitudinal Study [NELS], 1998; National Science Foundation [NSF], 2013). The achievement gap is a problem because the nation's competitiveness depends on individuals with science, technology, engineering, and mathematics (STEM) knowledge, skills, and abilities to drive innovation that will lead to new products and economic growth (Business-Higher Education Forum [BHEF]/Act Policy Brief, 2014; National Academies of Sciences, Engineering, and Medicine, 2016; National Science Board, 2015). If Florida is to continue to grow and prosper, all students, including students with disabilities must be prepared for the economy they will inherit. The purpose of the current study was to determine if informal science learning activities offered in Florida school districts make a difference on students with disabilities (SWD) performance on the 8th Grade Florida science assessment.

The researcher found many extracurricular STEM activities are being offered in the state of Florida. Furthermore, many districts do not track or know the number of types of students with disabilities who do participate in the activities offered. The researcher attempted to correlate the number of STEM activities offered in each district to the results of the 8th Grade Science assessment of students with disabilities in each district. The results were there was a small correlation of those scores and the number of STEM activities offered. Because this was an exploratory study, more research is needed to address the limitations of the study to see if extracurricular STEM activities can impact science scores of students with disabilities.

DOI: 10.20429/stem.2017.010101

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DOI: 10.20429/stem.2017.010101

Using Primary Sources in STEM Education: An Example

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Abstract: Primary sources are original artifacts from the past that can used to understand an event or time period. They are customarily only thought of in the realm of historical thinking. That is unfortunate because they can also be considered in terms of scientific, economic, cultural, and mathematical thinking. While primary sources are increasingly taking more prominent roles in the social studies and history classrooms, they are still very rare in other disciplines. This paper describes how primary sources gathered from the Library of Congress were situated in a larger STEM lesson focusing on the challenges faced by WWI veteran amputees. Lesson reflection found that with sufficient scaffolding and other support, primary sources make an excellent resource for STEM teachers. Further, STEM and primary sources make natural partners in teaching and learning because they both have an interdisciplinary nature and tend be applied to real world situations.

Acknowledgments: This manuscript was made possible by the author's participation in the Library of Congress Summer Teacher Institute: Science, Technology, and Engineering Focus. Washington, D.C. June 20-24, 2016.

Introduction

American schooling is increasingly moving from the sage on the stage to the guide on the side. This paradigm shift includes allowing students to construct knowledge and make assessments. In this exploratory single exposure study with pre-service teachers, an interdisciplinary lesson was conducted that combined primary sources and a hands-on lesson

Literature Review

Primary Sources

Primary sources are original artifacts based on direct observation that can used to understand an event or time period in terms of historical, scientific, economic, cultural, and mathematical thinking. They can include such artifacts as photos, diaries and journals, musical recordings, and first-hand newspaper accounts (Examples of Primary Sources, n.d.). However, they can also include electronic communication (such as emails and text messages), fingerprints, furniture, and residue containing DNA. The cognitive act of thinking historically via primary source analysis is quite sophisticated as described by VanSledright (2004). Such thinking includes judging primary source perspective which requires assessing the author's social, cultural (and possibly STEM) position. Judging primary source reliability involves comparing it to other accounts of the period. Secondary sources are based on the analysis and interpretation of primary sources and thus one or more steps removed from an event or time period. This literature review is an example of a secondary source.

The classification of a source as primary or secondary is not always clear-cut. That can be seen in the 2013 National Council for the Social Studies document *The College, Career, and Civic Life (C3) Framework for Social Studies State Standards* that states that

> [F]ormer British Prime Minister Winston Churchill's history of World War II is both a primary source, because he was directly involved in some of the events he describes, and a secondary work, because he uses historical sources of many different types to tell the story of developments in which he was not directly involved. (p. 84)

The classification also depends on intent. As an example, textbooks can be viewed as a primary source in a study of how they portrayed women scientists during the Industrial Revolution.

Primary sources engage the learner in a few unique and powerful ways. First, they "engage students both emotionally and personally because the sources represent authentic voices and images" (Stripling, 2009, p. 2). As an example, in one primary source case study titled "Growing-Up before they had to: Children of the Civil War" (n.d.), students analyze primary sources and then answer the following question in paragraph form:

> Through the eyes of the children, what aspects of living through the Civil War would have been most difficult? You must cite evidence to support your answer. Please indicate whether you were satisfied with the evidence and list any additional questions that have been left unanswered through your investigation. (para. 3)

That lesson is a very different cognitive act compared to reading about the American Civil War from a textbook for two reasons: first, it is naturally compelling to children because the sources are from their peers and second, the analysis and interpretation of primary sources is being completed by them

DOI: 10.20429/stem.2017.010101

(which has been done for them in using the textbook).

The use of primary sources address a complaint John Dewey made about schooling in *The Child and the Curriculum* (1943). He stated that "the various studies, arithmetic, geography, language, botany, etc… embody the cumulative outcome of the efforts, the strivings, and the successes of the human race generation after generation" (p. 12). The way in which science subject matter is often presented to students as "cumulated outcome", they are denied access to the efforts and strivings of scientists. Primary sources are an excellent tool to get to the efforts and strivings of scientists. As an example, the Library of Congress website allows students to view and analyze the actual hand written "Notebook by Alexander Graham Bell, from 1875 to 1876" (1875). Students can see over the course of those pages the work that eventually revolutionized society via the telegraph and telephone. Using the primary source, students can replicate his experiments themselves, and see Bell as not some distant famous figure from the past but a fellow thinker and tinkerer.

Unfortunately for educators, primary sources often cannot be found at one clearinghouse or website. The fact that they can be fragile and cumbersome and in such places as cemeteries, courthouses, and historical societies makes the work time consuming. Even for secondary social studies teachers, the actual use primary sources seems limited (Hicks, Doolittle, & Lee, 2004). The Library of Congress is making efforts to change that; they now have such primary source sets as "The Inventive Wright Brothers" (n.d) and "Understanding the Cosmos: Changing Models of the Solar System and the Universe" (n.d.), which includes drawings and illustrations by Ptolemy, Copernicus, Descartes, and Galileo. Both sets include primary sources, teachers guides, and recommended analysis tools.

Educational Standards

Educational standards are frequently cited in teachers' lesson plans as evidence of rigor and alignment with the curriculum. A major change regarding standards has come in the state-led Common Core State Standards Initiative (CCSSI) that created standards in mathematics and English language arts. The CCSSI states that "[E]ducational standards are the learning goals for what students should know and be able to do at each grade level. Education standards, like Common Core are not a curriculum" (http://www.corestandards.org). While standards are correctly not a curriculum, they still provide some guidance in reaching learning goals. As an example, a search of the Georgia Social Studies

Georgia Performance Standards for middle school found nine instances that primary sources are mentioned. Clearly, the state standards communicates the appropriateness of using primary sources here.

A search of A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas that served as a founding document for the Next Generation Science Standards (that in analogous to the CCSSI for science standards) for the phrase "primary source" only turned up one instance. It states that by 12th grade students should be able to "[U]se primary or secondary scientific evidence and models to support or refute an explanatory account of a phenomenon" (p. 84). At the state level, the Georgia Science Performance Standards for middle school science found zero instances that primary sources are mentioned. In sum, whereas standards clearly communicate the appropriateness of primary sources in the social studies arena, they are nearly invisible in the science arena.

STEM

There exists a lack of consensus about what STEM education should look like in K-12 education. That can be illustrated in disagreements whether there should be an interdisciplinary or a multidisciplinary focus (Lederman & Niess, 1997). Some have even taken to referring to STEM as a "metadiscipline" (Morrison, & Bartlett, 2009). The literature finds that regardless the disciplines are like treated separately like silos and that often the "E" in stem is often neglected and sometimes misrepresented (Kelly, 2010).

Looking at the work of most STEM professionals blurs the lines between those disciplines. This is seen in Petroski's book *Invention by Design: How Engineers Get from Thought to Thing (1996)*. He states that the "idea that unifies all of engineering is the concept of failure" (p. 89). But failure isn't just in terms of structure that is likely raised in the classroom; Petroski reminds the reader that it can take economic, aesthetic, or environmental forms also.

It appears from the literature that there is a harmony between primary sources and STEM in terms of teaching and learning in that both have an interdisciplinary nature and they both tend be applied to real world situations. What does it look like when they are paired in an actual lesson? That is described below.

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DOI: 10.20429/stem.2017.010101

Teaching Questions

The two primary teaching questions asked prior to instruction were:

a) How would pre-service elementary education students respond to the primary source aspect of the lesson?

b) How would pre-service elementary education students respond to the hands-on aspect of the lesson?

The teaching questions were answered based on researcher observations and analysis of student worksheets (see Appendix A and B).

Methods

Participants

This 150-minute lesson was taught to a class of twenty-one elementary education students in an elementary science methods and materials course in the semester prior to student teaching.

Procedure

A Google document was created by the instructor prior to class that included twenty five numbered primary sources, all found digitally on the Library of Congress website and focused on some aspect of WWI veteran amputees. The class engaged in a brief discussion about primary sources and then accessed the document using their personal laptops. To increase engagement and accountability, each student was assigned her own primary source to analyze using the Analyzing Photographs & Prints document (see copy in Appendix A). It was adapted from a Library of Congress Teaching with Primary Sources instrument. After approximately twenty minutes of analysis, students shared their work in collaborative groups.

At that point, the discussion pivoted to the engineering design process. This was needed to guide subsequent construction of the prosthetic arms by the collaborative groups. Kelly (2010) found that the optimization step is often neglected in the engineering design process. In this step constraints and criteria are evaluated to guide subsequent prototype construction (and importantly, it replaces trial-and-error). To put this process and step into context for the class, we discussed the criteria and constraints present for Charles Lindbergh in designing *The Spirit of St Louis*, based on Kelly's (2010) identification of the same. Finally, student collaborative groups were then challenged to create a prosthetic arm that could be used to pick up an empty plastic cup and place it on a table (criteria) using only the materials provided (constraints). The materials list is provided in the student guide for the activity (Engineering Design Process: Build Your Own Prosthetic Arm- see Appendix B). The lesson ended with groups presenting their work to their peers.

Discussion

The first teaching question was “how would students respond to the primary source aspect of the lesson?” Based on researcher observations, the students were very engaged with the lesson. Several were disturbed at the lack of respect paid to the veterans in terms of language used such as “pathetic wrecks of war”. Half of the students remarked in the Analyzing Photographs & Prints document on the industry and resolve of the veterans to adapt to, and be successful in, civilian life. In the semester prior, the students completed a social studies methods course. It was surprising then that students could recall no prior exposure to primary sources. Considering that fact, providing the Analyzing Photographs & Prints document proved invaluable to the success of this part of the lesson.

The second teaching question was “how would students respond to the hands-on aspect of the lesson?” One element that proved decisive in the success of the prosthetic arms was showing the class a LEGO prosthetic hand created by the instructor (based on “Biomechanical Hand”, p. 12). Most of the groups created prosthetic arms the included variations of the hand. Of the seven groups, five were able to create prosthetic arms that accomplished the goal of picking up an empty cup and placing it on the table. Considering this activity was completed on the very last meeting of the semester when student effort and interest usually flags, it was impressive the quality of the arms. All the prosthetic arms have been stored for use in the next semester and it is recommended that other instructors do the same. Subsequent classes may benefit by viewing and building on previous work (a reminder of Isaac Newton’s famous reminder of the nature of science in stating, “If I have seen further it is by standing on the sholders [sic] of Giants”).

Conclusion

Teachers often incorporate primary sources into history and socials studies with the intention of making the subject “come alive” (Fredette, 2013). However, primary sources can just as easily make other subjects come alive also.

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DOI: 10.20429/stem.2017.010101

Although there are a number of challenges in incorporating primary sources (as described in the literature review) they are well worth the effort. More than ever, students need to see the interdisciplinary nature of the world. The reality is the today's Millennials will change jobs about four times in their first decade out of college according to recent LinkedIn study by Berger (2016). With new jobs may come new disciplines, and thus interdisciplinary skills come into play. Interdisciplinary lessons, like the one described in this paper, should contribute to those interdisciplinary skills.

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Appendix A

Analyzing Photographs & Prints: Prosthetic Arms and WWI

Primary sources are great resources to be used in the classroom, but not just in the context of social studies. Today's lesson will involve primary sources in a STEM lesson around prosthetic arms. This document is adapted from the Library of Congress Teaching with Primary Sources instrument to analyze photos. Analyze each photo using the Observe-Reflect-Question method and record your thinking on the lines provided. For more tips on using primary sources, go to http://www.loc.gov.teachers

Photo # ___________

Observe: Describe what you see. • What do you notice first? • What people and objects are shown? • How are they arranged? • What is the physical setting? • What, if any, words do you see? • What other details can you see?

____

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Reflect: Why do you think this image was made? • What's happening in the image? • When do you think it was made? • Who do you think was the audience for this image? • What tools were used to create this? • If someone made this today, what would be different? • What would be the same?

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Question: What do you wonder about...who? • what? • when? • where? • why? • how?

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DOI: 10.20429/stem.2017.010101

What other questions would you like to investigate related to your photo? How can you find out?

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Appendix B

Engineering Design Process: Build Your Own Prosthetic Arm

Challenge: You are a member of a team of three or four students, all working together to design and build a prosthetic arm out of the following materials which are provided to you. The arm must be at least 18 inches in length and be able to pick up an empty upright Styrofoam cup containing a golf ball and release it upright onto a table without spilling the ball. Your team must agree on a design for the arm and identify what materials will be used. Your team should draw a sketch of their agreed upon design prior to construction. Part of the teamwork process is sharing ideas and determining which design your team will go with. Trial and error are part of the design process. There is no "right" answer to the problem - your team's creativity will likely generate an arm that is unique from the others designed in your class.

Resources/Materials: long strips of cardboard, binder clips (different sizes), brads, clothespins, craft sticks, fishing line, coat hangers, paper clips (diff. sizes), pencils, rubber bands (different sizes), tape (clear and masking), twine, LEGOS, Tinker Toys, scissors, drinking straws.

Relevant Standards. Next Generation Science Standards (Ages 11-14)

Engineering Design Students who demonstrate understanding can: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions (standard MS-ETS1-1)

Design process criteria definition:

Design process constraints definition:

Motion and Stability: Forces and Interactions Students who demonstrate understanding can: Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object (standard 3-PS2-1)

Prosthetic Arm Sketches

Pre-Build Individual: Pre-Build Group:

Actual final structure:

Post-Activity Exercise Questions

1. Did you use all the materials provided to you? Why, or why not? Which item was most critical to your robot arm design?

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2. How did working as a team help in the design process?

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DOI: 10.20429/stem.2017.010101

3. Were there any drawbacks to designing as a team?

4. What did you learn from the designs developed by other teams?

The Progesterone Receptor - To Be or Not to Be: The Anti-inflammatory Effects of Progesterone in RAW 264.7 Cells

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Abstract: It has been widely established that, in addition to its role in reproduction, progesterone (P4) also has potent anti-inflammatory effects. While the precise mechanisms have never been clearly elucidated in RAW 246.7 cells, it seems logical to assume that this response is – at least in part - a consequence of activation of and signaling through the progesterone receptor (P4-R). However, it has recently been shown that in a rat model, this anti-inflammatory effect is – in fact - independent of the progesterone receptor. In this project, the aim was to characterize this response by assaying nitric oxide production from lipopolysaccharide-challenged RAW 264.7 cells and ascertain the involvement of the P4-R. To determine the contribution of the receptor, RAW cells were incubated in the presence and absence of RU-486 – a potent P4-R antagonist. Our results indicate that the anti-inflammatory response of progesterone was in fact through the activation of the P4-R as cells incubated in RU-486 show an approximate 60% reversal of the inhibitory effect of P4 as compared to cells incubated in the absence of the antagonist. However, because we did not observe a complete reversal, suggests that perhaps other receptors come into play which will be addressed in future studies.

Acknowledgements: The authors would like to thank Dr. David Hurley and Natalie Norton – College of Veterinary Medicine, University of Georgia for their experience, assistance and expertise in the establishment of protocols and analysis of data; The School of Science and Technology, Georgia Gwinnett College for provision of facilities and equipment; and the University System of Georgia STEM Initiative for partial funding of this project.

Introduction

Progesterone (P4) has long been known as a steroid hormone associated with reproduction – more specifically in female reproductive physiology as it is commonly referred to as the 'hormone of pregnancy' (King TL, 2010). Its

DOI: 10.20429/stem.2017.010101

presence is only observed in appreciable amounts during the luteal phase as its source is the corpus luteum, and its primary role during this time period is in endometrial remodeling as well as endometrial angiogenesis in preparation for the arrival of an early embryo (Patel B, 2014). While this effect is critical for the maintenance of pregnancy, just as important is the inhibitory role that P4 has – along with estrogen and inhibin – on the pituitary gonadotropins follicle stimulating hormone (FSH) and luteinizing hormone (LH), respectively (Lesoon LA, 1992). Secondary to these effects, P4 also plays a role as a mediator in many inhibitory pathways such as: 1) modulation of maternal immune response and suppression of key inflammatory mediators given that the luteal progesterone at the decidua level appears to play a major role in the maternal defense strategy, 2) reduction of uterine contractility as adequate progesterone concentrations in the myometrium plays an inhibitory role on prostaglandin and oxytocin's stimulatory activity, and 3) improvement of utero-placental circulation and luteal phase support given that it has been shown that progesterone may promote the invasion of extravillous trophoblasts to the decidua by inhibiting apoptosis of extravillous trophoblasts (Di Renzo GC, 2016). Additionally, P4 is not without its effects in the male in that it serves as precursor to testosterone, has a similar inhibitory effect on the gonadotropins– albeit a weak effect – and is a precursor to capacitation (Oettel M, 2004).

Given the steroid hormone chemistry of P4, it has widely been known to signal through an intracellular receptor which is nuclear in origin – NR3C3, that serves as a transcription factor driving the expression of many genes associated with reproduction (Werner R, 2014). More recently however, a membrane-bound receptor has also been identified which is a G protein-coupled receptor, and has been isolated in many isoforms, namely mPR , mPR , mPR , mPR , and mPR (Wolfson ML, 2016). The advent of signal transduction mechanisms through these receptors have been shown to be primarily anti-inflammatory in nature. However, in the study by Wolfson et al., it was reported that the inhibition of at least one inflammatory mediator (nitric oxide – NO), was through a progesterone independent mechanism. These authors went on to suggest the possible involvement of the glucocorticoid receptors in this immunomodulatory role. Regardless of the receptor involved or cell signaling pathways initiated, the anti-inflammatory properties of progesterone are an exciting avenue for scientific discovery and warrants exploration.

The Immune response is an immunological response that originates via activation by antigens, including the response to pathogenic microorganisms, allergens, as well as autoimmunity to self-antigens, and graft ejections. It can be further subdivided into the adaptive immune response involving T cells, B lymphocytes, and the innate immune response involving the monocyte/macrophage system, neutrophils, eosinophils, basophils as well as other tissues of the lymphatic system. The monocyte/macrophage system is of particular interest based on the many inflammatory mediators activated macrophages produce, namely nitric oxide (NO) and tumor necrosis factor-alpha (TNF) because of their integral role in the initiation of the inflammatory response. Nitric oxide is a gas under standard conditions, is one of several oxides of nitrogen, and is classified as a free radical. In mammals it is a potent vasodilator with short half-life, and an important cell signaling molecule that is involved in many physiological and pathological processes (Hou, 1999). It has been reported that localized NO synthesis in reproductive tissue plays an important role in regulating certain reproductive functions such as endometrial, cervical and myometrial activity (Telfer, 1995), embryo implantation (Battaglia, 2003) as well as embryo development (Chwalisz, 1999). While it is apparent from these studies that NO plays key roles in early pregnancy and even parturition, its concentration must be tightly regulated as it has also been reported that aberrant NO levels have been associated with embryo cytotoxicity (Barroso, 1999), early embryo loss (Haddad, 1995), as well as preterm labor (Cella, 2010). Given that progesterone has been shown to have an anti-inflammatory effect, it seems logical to assume that it also plays a major role in the regulation of appropriate NO concentration during pregnancy. Indeed, the protective role of progesterone has been shown by modulating the innate immune response in an animal model of early pregnancy loss induced by inflammation (Aisemberg, 2013; Wolfson, 2013). In fact it was demonstrated that the Intraperitoneal administration of lipopolysaccharide (LPS), a component of the cell walls of Gram-negative bacteria, to pregnant mice, induces infiltration of the decidua with granulocytes and large granular lymphocytes (LGL), increased uterine and decidual production of nitric oxide (NO) and these changes leads to a 100% of embryonic resorption and fetal expulsion (Ogando, 2003).

On the other hands, TNFα, is a cell signaling protein (cytokine) involved in systemic inflammation and is one of the cytokines that make up the acute phase reaction. It is produced primarily by activated macrophages, although it is also produced by many other cell types such as CD4+ lymphocytes,

DOI: 10.20429/stem.2017.010101

natural killer cells, neutrophils, mast cells, eosinophils, as well as neurons (Carswell EA, 1975). The primary role of TNF is in the regulation of immune cells. Being an endogenous pyrogen, TNF is able to induce fever, apoptotic cell death, cachexia, inflammation and to inhibit tumorigenesis and viral replication and respond to sepsis via IL1 & IL6 producing cells. Dysregulation of TNF production has been implicated in a variety of human diseases including Alzheimer's disease (Swardfager W, 2010), cancer (Locksley RM, 2001), and major depression (Dowlati Y, 2010) to name a few. From a reproductive standpoint, TNF has been identified in the ovary, oviduct, uterus, and placenta (Terranova PF, 1995), and it is expressed in embryonic tissues (Kohchi C, 1994) practically at all stages of development. TNFα levels have also been shown to be significantly elevated in the amniotic fluid of women with uterine infections, and its increased production correlates with the incidence of preterm labor (Romero R, 1989). These observations have implicated TNFα as a cytokine involved in triggering immunological pregnancy loss (Clark DA, 1999; R, 2001), i.e. death of embryos owing to failure of defense mechanisms preventing rejection of the semiallogeneic fetoplacental unit.

Materials and Methods

Cell Culture

RAW 264.7 cells were maintained in MEM culture medium (Fisher Scientific) containing 10% Fetal Calf Serum (FCS, Atlanta Biologicals), 1000 IU Penicillin/Streptomycin (Sigma Chemicals), 2 mM glutamine (Sigma) at 37oC, 5% CO2. Prior to stimulation assay, RAW cells were cultured to 80% confluence and harvested by gentle agitation utilizing a 10 mm cell scraper (Fisher). Scraped cells were then pooled in 1X PBS, and washed twice with centrifugation, 1,800 rpm, 5 min. In between the 2nd and 3rd wash cycle, cell viability assays were performed to determine living vs. dead cells. With each cell harvest, an aliquot of RAW cells were returned to culture flasks to maintain the cell line; after 15 passages, cells were discarded as it has been demonstrated that there is a reduction in receptor expression beyond this time.

Cell Stimulation

Cells were prepared for stimulation assays by combining live cells at a density of 75 x 103 live cells/ml in Minimal Essential Media (MEM, Fisher) supplemented with 10% FCS in polystyrene tubes. To appropriate tubes, lipopolysaccharide (Sigma) was added to final concentrations of 200, 20 or 2 ng LPS/ml to each tube. One milliliter of each cell suspension was then seeded in triplicate to 24-well Falcon tissue culture plates (Fisher) and incubated at 37oC, 5% CO_2. Each well contained a final concentration of 75 x 103 cells in MEM/FCS, and the appropriate dilutions of LPS in a final volume of 1 ml. Control wells contained MEM/FCS alone. Cells were maintained for 48 hrs., afterwhich growth media was harvested and maintained at -20oC until such time as NO assays were performed.

To determine the effects of the progesterone receptor on NO and TNF production, RAW cells were handled and stimulated with LPS as above with the exception that in appropriate wells, cells were incubated simultaneously in 10 M RU-486 – a selective P4 receptor antagonist. Upon the completion of the 48 hr. incubation period, cell supernatant was handled and NO assays performed as previously described.

Nitric Oxide Assay.

This protocol was adopted with modifications from that of Griess (Griess, 1879). Briefly, 100 l aliquots of samples from the cell stimulation assays above were loaded in triplicate into appropriate wells of a 96-well Corning Costar ELISA plate (Fisher), followed by 10 l of nitrate reductase solution to each well. Plates were then incubated at 37oC, 5% CO_2 for one hour. After incubation, 80 ml Griess reagent was added to each well and nitrites (NO_2-) read at 540 nm on a plate reader (BioTek). An 8-point sodium nitrate standard was also established to determine the nitrate concentration of the unknowns.

Tumor Necrosis Factor ELISA (Mouse TNF ELISA Ready-Set-Go, Affymetrix, eBioscience, San Diego, CA).

Initially wells from 96-well Corning Costar (Nunc) plates were coated with capture antibody (anti-mouse TNF ,) in coating buffer and incubating overnight at 4oC. Plates were then washed 3 times with 250 l/well wash buffer consisting of 1x phosphate buffered saline (PBS) containing 0.05% Tween-20. Wells were then subsequently blocked with 200 l/well 1x ELISA ELISPOT buffer at room temperature for 1 hour and all wells washed as previously described. TNF standards consisting of eight serial dilutions of mouse TNF were then prepared and 100 l/well of standards were added to corresponding wells. Additionally, 100 l of media from stimulated cells were added to appropriate

DOI: 10.20429/stem.2017.010101

wells with two additional wells containing ELISA/ELISPOT buffer which served as plate blanks. Plate was sealed and incubated for 2 hrs. at RT, afterwhich wells were washed as previously described. The detection antibody (Anti-mouse TNF -Biotin) in buffer was added at 100 l/well. Plate was sealed and incubated at RT, for an additional 1 hr. and wells washed as previously described. 100 l/well of Avidin-Horseradish Peroxidase (HRP) in buffer was then added to corresponding wells, and plate was sealed and allowed to incubate for 1 hr at RT, and wells were washed as previously described. TMB solution was then added at 100 l/well and incubated at RT, 15 min. afterwhich 50 l of stop solution (1M H2PO4) as added and plates were read at 450 nm on a plate reader (BioTek)

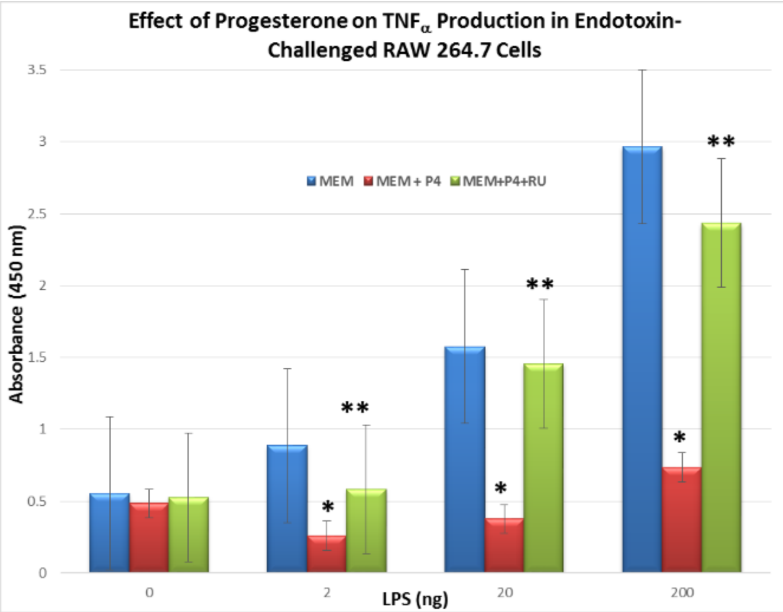
Results

Nitric Oxide Production as a Result of Endotoxin Challenge

Initially, after endotoxin challenge, there was a significant increase ($p < 0.05$) in NO production at all concentrations as compared to controls (Fig. 1, Table 1). Specifically, there was an approximate 40% increase in NO release from RAW cells with each 10-fold increase in endotoxin concentration (2 ng/ml, 20 ng/ml, 200 ng/well). Upon addition of a saturating concentration of progesterone (10 M), there was a significant decrease ($p < 0.05$) in NO production by 12, 46 and 62% at 2, 20 and 200 ng/ml, respectively. To determine if this effect was due to activation of the progesterone receptor specifically, the P4-R antagonist RU-486 was co-incubated in wells containing stimulated cells along with progesterone. In these wells, there was a rebound in NO production – which is to say a reversal of the inhibitory effect – in cells incubated with 10 M RU-486 by 7, 27 and 58%; while there was a significant difference ($p < 0.05$) in the cells stimulated with 20 and 200 ng/well LPS, cells stimulated with 2 ng/ml endotoxin did not surpass this level of statistical scrutiny.

Figure 1. Effect of Progesterone (P4) on Nitric Oxide (NO) Production. RAW cells were treated with a 10-fold increase in LPS to stimulate a significant ($p < 0.05$) concentration-dependent production of NO (blue bars). Treatment of cells in conjunction with 10 M P4 elicited a significant inhibition of NO production (red bars). Treatment of cells with 10 M RU-486 – a potent antagonist of P4

exhibited a partial reversal of this inhibitory effect (green bars). * denotes a significant difference to LPS stimulated cells at that concentration, and ** denotes a significant difference from LPS stimulated cells and LPS + P4 stimulated cells.



Tumor Necrosis Factor-Alpha Production as a Result of Endotoxin Challenge
Stimulation of RAW 264.7 cells with 2, 20 and 200 ng LPS resulted in a significant ($p < 0.05$) concentration-dependent increase in TNF production as compared to controls (Fig. 2, Table 1). Specifically an approximate 35% increase in TNF upon stimulation with 2 ng/ml LPS as compared to controls, followed by a 70% increase in TNF production with two successive 2-fold increases of LPS concentrations. Upon co-incubation with 10 M P4, there was a significant ($p < 0.05$) decrease in TNF production by approximately 70% at all concentrations of LPS. After inclusion of 10 M RU-486 along with the saturating concentration of P4, a similar reversal of the inhibitory effect of P4 alone was seen as was observed in the NO assays. While no significant difference was seen at the low concentration of LPS (2 ng/ml), there was significance at the two higher concentrations (20, 200 ng/ml).

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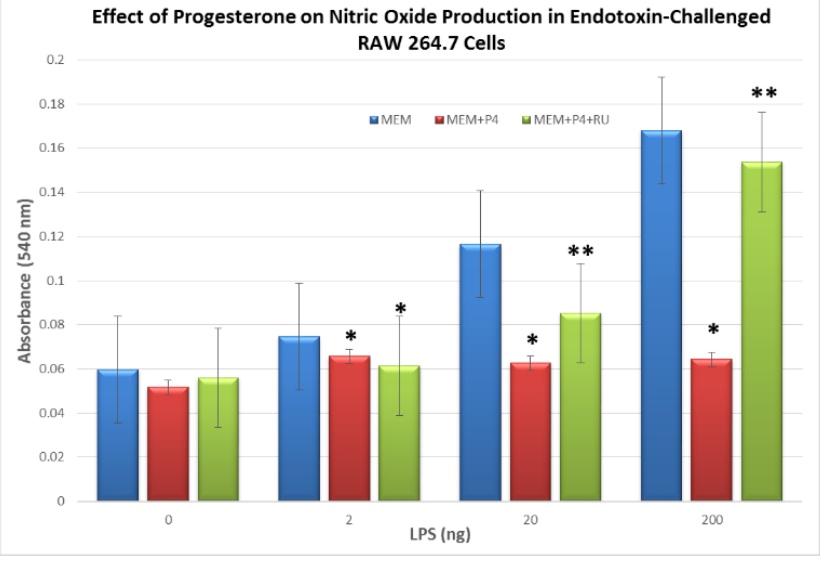
DOI: 10.20429/stem.2017.010101

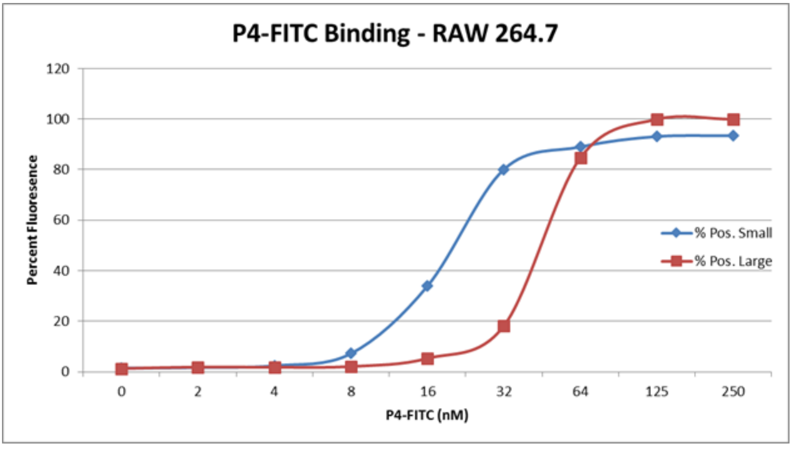
Figure 2. Effect of Progesterone (P4) on Tumor Necrosis Factor-Alpha Production. RAW cells were treated with a 10-fold increase in LPS to stimulate a significant ($p < 0.05$) concentration-dependent production of TNF (blue bars). Treatment of cells in conjunction with 10 M P4 elicited a significant inhibition of NO production (red bars). Treatment of cells with 10 M RU-486 – a potent antagonist of P4 exhibited a partial reversal of this inhibitory effect (green bars). * denotes a significant difference to LPS stimulated cells at that concentration, and ** denotes a significant difference from LPS stimulated cells and LPS + P4 stimulated cells.



Discussion

These data clearly indicate that stimulation of RAW 264.7 cells with varying concentrations of lipopolysaccharide (LPS) initiate an inflammatory response insofar as the production of nitric oxide (NO) and tumor necrosis factor-alpha (TNF) are concerned. These results are to be expected however as RAW cells are an immortalized murine macrophage leukemic cell line established from an ascites of a tumor induced in a male mouse (*Mus musculus*) by intraperitoneal injection of Abselon Leukaemia Virus (A-MuLV) (Raschke WC, 1978). RAW cells were chosen as the experimental model in the present study as they propagate quickly, cell culture needs are minimal - but more importantly - upon stimulation with an inflammatory insult results in a myriad of immunologic responses. In the present study, we were able to show that RAW 264.7 cells express the progesterone receptor, and that progesterone binds with high affinity and saturation at 125 nm (Fig. 3).

Figure 3. P4-FITC Binding Assay. RAW 264.7 cells were treated with 2-fold serial dilutions of FITC-P4 in Ros media and incubated, 1 hr. 100 l of cell-P4-FITC solution was then added to 300 l FACS buffer and incubated an additional hr. Cell suspension was then washed 3x followed by analysis on an Accuri C6 Plus flow cytometer (Becton-Dickinson).



Further, stimulation of RAW cells with LPS initiates an inflammatory response by the production of NO and TNF in a concentration dependent manner. Additionally, we were able to show that upon co-incubation with progesterone this response was ameliorated as shown by the reduction in both inflammatory mediators. That being said, because we have demonstrated this response, it should not be assumed that this response is due to the effects of progesterone acting solely through its receptor. In fact, in a rather elegant study by Wolfson and colleagues (Wolfson ML, 2016), it was shown that in a rat model, stimulation with endotoxin resulted in a significant increase in NO production, and that this

DOI: 10.20429/stem.2017.010101

effect was inhibited by treatment with progesterone as seen in the current study. However, it was also reported in this study that this response was independent of progesterone receptor activation as co-treatment with a progesterone receptor antagonist had no apparent effect on this inhibitory effect (Wolfson ML, 2016). These authors went further to suggest that perhaps this response was an effect of glucocorticoid receptors activation as incubation of cells with a glucocorticoid receptor antagonist restored similar NO levels as was seen in cells stimulated with LPS alone. In the present study, we show that in fact the progesterone receptor activation is involved by a partial reversal of progesterone's inhibitory activity of both NO and TNF (Fig's. 1, 2; Table 1).

Table 1. Production of nitric oxide and tumor necrosis factor from LPS-challenged RAW 264.7 cells, and subsequent P4-dependent inhibition. Nitric oxide assays revealed a concentration-dependent increase in NO production followed by a 12, 46 and 62% inhibition following P4 incubation. Tumor necrosis factor assays revealed a similar concentration-dependent increase in cytokine production followed by a 71, 76 and 75% inhibition of TNF following P4 incubation. With the exception of the low dose of LPS in the NO assays, RU-486 revealed a partial reversal of this inhibitory effect.

NO Production in LPS-Challenged RAW 264.7 Cells				
LPS (ng)	NO (pg)	NO Gain	P4 Inhibition	Antagonism RU-486
2	17.3	20.09%	12.05%	NA
20	28.25	48.78%	46.21%	26.56%
200	47.54	64.48%	61.71%	58.13%
TNFα Production in LPS-Challenged RAW 264.7 Cells				
LPS (ng)	TNFα (pg)	TNFα Gain	P4 Inhibition	Antagonism RU-486
2	51.11	37.52%	70.71%	55.56%
20	178.89	64.86%	76.09%	74.12%
200	642.11	81.32%	75.26%	69.84%

pecifically, regarding the production of these two inflammatory mediators, a 58.13% and 69.84% increase in NO and TNF was observed, respectively from cells stimulated with 200 ng LPS (high dose). With this in mind, the question arises as to why the contrasting effects in this study as compared to that reported by Wolfson et al. To this point, the answer may lie in the fact that the study by Wolfson was conducted through the in vivo infusion of LPS to pregnant and non-pregnant mice with or without progesterone and two differing antagonist – RU-486 and Lonaprisan – a P4 antagonist with higher affinity for the P4-R than RU-486. Peripheral blood monocytes (PBMC) were then collected, cultured for 24 hrs afterwhich cell supernatants assayed for nitrates and nitrites as described. Additionally, PBMC from these mice were also assayed for inducible nitric oxide synthase (iNOS) mRNA as an indicator of NO production. In the present study, our group directly stimulated RAW 264.7 cells (a macrophage cell line) with a range of LPS concentrations as well as fixed concentrations of both progesterone and RU-486. Given this, it is difficult to compare the two studies due to the fact that in the report by Wolfson et al., LPS (1 g/g), progesterone (67 g/g – pregnant mice and 4 g/g – non-pregnant mice), RU-486 (10 g/g) and Lonaprisan (1 g/g) were administered via intraperitoneal injection while in the present study, RAW cells were stimulated with LPS (2, 20 and 200 ng/ml), and further treated with progesterone (10 M) and RU-486 (10 M) at fixed concentrations. Irrespective of these discrepancies, it seems clear that 1) progesterone plays a centralized role in the maintenance of pregnancy and regulation of NO and TNF concentrations in reproductive tissues and, based on these results, that 2) it is an important inhibitory mediator in the inflammatory response insofar as NO and TNF production are concerned, and 3) the action of which are at least in part, through activation of the progesterone receptor.

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DOI: 10.20429/stem.2017.010101

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DOI: 10.20429/stem.2017.010101

Learn to Program in Python - by Teaching It!

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Abstract: The US Bureau of Labor Statistics predicts over 8 million job openings in IT and computing, including 1 million cybersecurity postings, over the current five-year period. This paper presents lessons learned in preparing middle-school students in rural Georgia for future careers in computer science/IT by teaching computer programming in the free, open-source programming language Python using Turtle graphics, and discusses exercises and activities with low-cost drones, bots, and 3D printers to get students interested and keep them engaged in coding. Described herein is one pair of instructors' (one middle-school, one university) multi-year, multi-stage approach to providing engineering and technology courses, including: how to code Turtle graphics in Python; how to engage children by using short, interactive, visual programs for every age level; building cross-curricular bridges toward technology careers using 3D printing, robotics, and low-cost drones; and, how to build more advanced programming skills in Python.

Introduction

The initial inspiration for an Engineering and Technology course at a rural middle school, which now includes computer programming, originated from the desire to provide a unique approach to teaching problem solving skills to my students. My personal observation at that time, after a decade of teaching, was that my students were overly focused on getting a correct answer and not on the process of finding solutions. With an interest in computers and a minimal background in computer programming, I proposed to my school's administration, and eventually got approved, to teach robotics during my planning period. Within a school year I had acquired, on a very limited budget, some LEGO Mindstorm Robotics kits and started preparing engineering and programming challenges for my "lego kids", as they were called by my colleagues.

The primary goal of the robotics program was for students to shift from an answer-driven attitude of learning to embracing multiple approaches and possible solutions for any given problem or challenge. At first, my students were slow to embrace the paradigm shift to problem solving and were often frustrated when it came to solving multifaceted problems with as many possible solutions.

I expected this change to be challenging for my students but did not expect it to also be a challenge to the parents who vocally expressed concern about their child's progress in the class and what they could do to better prepare them for the challenges. It took time, but by the end of the class my students were asking good questions, seeking multiple solutions, modifying their approach when necessary, and collaborating with each other.

The robotics program lasted for several years and was, in many ways, a successful attempt at robotics, programming, and changing the way my students approached problem solving. The robotics program showed my students were highly motivated, problem solvers, when challenged and would be interested in a multi-grade connections course in engineering and technology. It also proved to be the foundation of a larger engineering and technology program, thanks to the ability to demonstrate significant student demand through high participation rates in both robotics classes and after-school programs.

Background

Much, if not the majority, of the literature on middle-grades computing curriculum concerns the use of visual applications, like Scratch, Alice, or even Flash (described below), to teach introductory programming, and many school systems start their programming courses as special electives or after-school programs. Webb and Rosson (2013), in one typical example, used the drag-and-drop, block-based programming environment Scratch to teach an outreach enrichment program for middle-school girls. The researchers used scaffolded activities, stepping from building a story, to solving a maze, to storing data in a list, to working with sensors and motors.

Before Scratch, previous researchers had even employed visual tools like Macromedia (now Adobe) Flash, the once-popular Web animation and programming tool, to teach computing concepts in middle school using animations and simple 2D games. One such team developed an after-school program focused on game programming in Flash (Werner, Campe and Denner 2005), and found that IT fluency overall improved for middle-school girls who created Flash games.

LEGO robotics have also been popular tools in teaching introductory programming concepts and in stimulating STEAM interest and motivation in middle-schoolers (Kaloti-Hallak, Armoni, and Ben-Ari 2015). Like Scratch, the LEGO programming software allows easy drag-and-drop blocks to form the logic

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DOI: 10.20429/stem.2017.010101

of a program, but the effects can be seen in real life by running the "code" on a LEGO Mindstorms robot. In our program, we had access to a limited number of LEGO robots, and we wanted to take advantage of both the variety of activities and the inherently interesting "hook" of getting students to program the bots to perform tasks in the live classroom environment. However, robots alone could not fill a full nine-week course at the scale we had the opportunity to teach programming, let alone a full semester or eventually a year of coding.

Other researchers have used different visual software, like the AgentSheets platform used in Scalable Game Design (Bennett, Koh, and Repenning 2011) that allowed students to build visual games like Frogger relatively easily. Others used virtual 3D software like Curiosity Grid (Hulsey, Pence and Hodges 2014) in a one-week summer coding camp environment for girls, to motivate greater STEAM interest in middle-school females. Still others have developed entire CS Principles curricula using game-based systems like ENGAGE (Buffum et al. 2014).

But, similar to Scratch and other visual programming tools, software packages like these were built specifically for teaching, not for programming. This introduces two significant obstacles in developing coding fluency and problem-solving ability in programming in general. First, the software limits the extent of the programming students can do; by building teaching-based tools, some essential low-level programming constructs are unfortunately left out, forcing students to feel like they're not doing "real" programming. Second, there is often a learning curve in figuring out how to use an already-limited tool, taking time away that could have been spent learning how to solve problems by programming in a text-based language.

More recently, partly in response to these issues, there has been a trend toward using text-based programming languages, most notably, Python. Armony, Meerbaum-Salant, and Ben-Ari (2014) studied middle school students who had studied Scratch versus those who had no programming experience at all, and found that, while the Scratch users could pick up concepts faster in a text-based programming course in high school, there was *no significant difference* in overall achievement at the end of the high-school class. This seemed to indicate that there was an initial benefit to learning the concepts taught in Scratch, but that the benefit faded over time and had less lasting impact on "real" programming ability in text-based languages by the end of a second course.

Tabet et al. (2016) designed a middle-school curriculum that started out in Alice, a 3D drag-and-drop environment used to create animated scenes, for learning basic programming concepts, but quickly progressed to Python to convey more advanced problem-solving skills in a text-based language. The authors were attempting to achieve a better "mediated transfer" of concepts between the visual Alice tool and the text-based Python language, and found some positive impact on performance for students who learned Alice in seventh grade followed by Python in eighth grade. However, this was in a middle school that provided two full years of programming instruction with support from four university faculty.

Implementation

I knew I would have to be resourceful, as is the case for teachers in many smaller community schools, to begin an engineering program in rural north Georgia. The robotics program was successful, but it was not a cost-effective platform for teaching a multi-grade connections course in a school system that currently did not have a budget for engineering and technology. While reading through the Georgia Performance Standards (GPS) for Engineering and Technology and preparing the course curriculum, I began actively looking for places to integrate computer programming as a cost-effective means to teach the engineering and technology subject-matter content. In the first iteration of a "real" technology course at my school, I found myself teaching up to twenty-six students per class, six classes per day, in nine-week rotations, for a total of twenty-four different classes in one school year. Even with the drastic price drop for engineering and technology resources (such as Arduino, Raspberry Pi, and 3D printers), I knew I would have to use coding to teach the GPS standards, as well as career-relevant skills, and keep the cost of the class per student as low as possible. My school had some refurbished computers that were not being used, and an almost closet-sized classroom that I could use as a makeshift engineering room and computer lab. I was eager to get started, so overlooking some obvious challenges was easy from the start, but they would have to be addressed as the school year, and the development of the program, progressed.

I chose to use a "real" text-based programming language, Python, from the start, with very visual programs based on Turtle graphics to give students immediate, graphics-based feedback as they developed basic through advanced programming skills. My primary resource for teaching computer programming was a coding book by my co-author for this paper, titled T*each Your Kids to*

DOI: 10.20429/stem.2017.010101

Code. I divided the book into two parts so it could be spread out over two years (sixth and seventh grade). This afforded me time during the short quarter (nine weeks) to teach engineering and computer programming content without having to sacrifice time in either area. I would also have just enough time to properly introduce coding to a student body that had zero programming experience.

The first five chapters of *Teach Your Kids to Code* were what I taught to my sixth graders, introducing the concepts of basic coding, loops, conditions and variables with colorful, visual apps in Turtle graphics. The coding unit lasted four weeks and amazingly my sixth grade students used the Python programming language to write around 40 different programs in that time. The seventh grade students used the second half of the coding book to get more involved in functions, timing, animations and game programming. This was the continuation from the introductory chapters and included more advanced programming concepts.

Because the material is brand new to the student body, the course is being phased in over a three-year period, and we're in the second year. Next year the eighth grade students will be learning Java, which is a more abstract but even more widely used programming language and a more functional skill set for someone interested in computer programming for AP Computer Science and college classes. Furthermore, I decided to enhance the programming curriculum through creative use of LEGO robots, programmable quad-copter Parrot Mini Drones, and 3D printers, both to engage students in more physical, kinesthetic activities while coding, and to interest students in broader STEAM applications and technologies across the curriculum beyond mere programming.

One major challenge that needed my attention was the classroom space. My classroom was way too small for teaching a course that included the need for computer equipment, engineering equipment, storage, materials and peripherals. An ideal environment for an engineering course, that included computer programming like my course, realistically required each student to have his or her own computer and sufficient space to interact with engineering equipment, such as drones, 3D printers, and electronic devices safely. I could not change the size of the room, so arranging the space as creatively and efficiently as possible was my only option. That meant only having twelve computers and six tables for twenty-six students. Initially I had two to three students writing one program at a time on one computer. This led immediately to disruptive behavior and a lack of inclusive learning, as the student holding the book was not learning at the same pace, if at all, as the student writing the code. This challenge needed to be resolved quickly and, for me, the solution was to use the school's computer labs whenever possible. Fortunately for my situation, my school has a separate computer lab for each grade that I could usually schedule several times per week when needed. This may not be an option for every school, while others may have computer labs in almost every classroom, but my recommendation is to get the computer-to-student ratio as near to 1:1 as possible. I rotated, three times a day, between the different computer labs using a mobile cart to hold the coding books, but having one computer per student while programming reduced disruptions (almost completely) and greatly increased student interest and confidence in coding. The students were more excited each day we visited the computer lab, took more ownership of their programming, and were better able to correct errors and write programs in Python.

There are plenty of off-the-shelf kits for engineering and coding that are affordable and easy to integrate into the classroom. One option is a Parrot Mini drone that allows the user to fly manually, or by using block programming through an application called Tickle (as of now only available through the iTunes store) or Tynker, available for both Android and iOS devices. These drones are affordable ($59-75 or so on Amazon), so several can be purchased for group projects, and they are extremely durable. My students were able to use what they had learned about programming to code flight plans directly into Tickle then watch as their drone took off, flew around the gym, performed tricks, then landed safely.

Another two options that are an excellent mix of engineering and programming are Arduino and Raspberry Pi. Both of these electronic sets are extremely affordable, easy to set up, modify, and program. The Internet has plenty of great projects for both and most provide step-by-step instructions and downloadable programs to run. The options on the market right now are limitless, but not all STEAM products are created equal, so be sure to research what you plan to buy before spending significant money. Consider getting one or two devices as a mini-pilot, especially if you have a few highly motivated and capable students that could attempt a few labs and projects, then make a presentation to the class (or to your administration, asking for funding for full classroom sets).

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DOI: 10.20429/stem.2017.010101
104

Getting started in STEAM
• Look for free resources, and start with what you have. You can easily begin coding if your school has an existing computer lab. If not, use one computer in your room as a lab station, and rotate students on and off.
• Keep costs low by purchasing affordable kits in small quantities, and let groups of students create projects together as teams.
• Get parents involved by hosting STEAM nights that include student-led presentations and computer programming.
• Demonstrate to your administration the effectiveness of STEAM teaching by inviting them to program with the students, observe student created projects, and attend a STEAM night.
• Use student achievement and student/parent interest to justify a larger budget for STEAM related resources and even an Engineering and Technology course.

Conclusions

The results of the Engineering and Technology class have been evidenced in several areas since I began teaching the course last year. I have seen a definite increase in student interest, both male and female, for engineering, technology, and computer programming-related topics. My students have shown a marked increase in the desire to pursue an engineering or programming related career, and they often inquire about what courses our local high school offers in engineering, technology, and computer programming. My students have also demonstrated greater ability and interest in peer collaboration, shared problem solving, and they are far more comfortable learning without having a clear, definable answer to challenges.

I have also learned over the last year that an engineering program is essential if we, as educators, want to best prepare our students for the workplace they will be entering—a workplace in desperate need of persons knowledgeable of and comfortable with engineering, technology, and computer programing. I also learned that, as part of that program, computer programming in some degree must be included. Many of the electronic components and products we used in the course to learn engineering, including 3D printers, drones, robotics, and Arduinos, were all modifiable using computer programming. My students were quick in insisting we find ways to modify, reprogram, or "hack" everything in the classroom. I agreed, and we quickly set about, over several weeks, teaching ourselves the same standards I had planned for in my "official" lesson plans.

Last, but not least, I have learned that teaching engineering, technology, and computer programming can be frightening if you have little to no experience, but it can be done, and is honestly easier than I first imagined. One thing to remember is that you do not have to know everything about every programming language, hardware platform, type of technology, or electronic device. I discovered that most students are very eager to learn independently and then share what they have learned with their peers. Allowing them to do this worked so well that I took every Friday off from teaching so they could work on independent technology projects. I used the Georgia Educational Technology Fair categories (*http://www.gatechfair.org/categories*) as a blueprint for their projects, grading rubrics, and instructions. At the end of the course they took great pride in presenting to the class their projects and what they had learned.

As for coding, starting with a programming language that is easier to read and write, such as Python, will help grow your confidence and will definitely be easier for students new to programming to learn. Writing the program for yourself prior to teaching is important for targeting potential pitfalls, identifying common errors, and areas where students will be able to be creative and add their own code. But, once the students jump in, letting them explore and try new things, and being able to respond to questions with, "I'm not sure, let's try and see what happens!", has been easier, and more fulfilling and instructive to me, personally, than any other experience in my teaching career.

As educators, by nature, we are resourceful and inquisitive. Teaching and learning computer programming in many ways requires the same skill set. Going online and searching for solutions to programming errors or problems is very helpful. Being inquisitive and challenging yourself to write good programs will only encourage your students to exhibit the same behavior. Add to that an honest dose of being willing to try, fail, and figure out mistakes to build something new, and you can teach yourself to code, while teaching it to your students.

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DOI: 10.20429/stem.2017.010101

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DOI: 10.20429/stem.2017.010101