# An Integrated STEM Introduction To Increase Interdisciplinary Thinking And Research Preparation

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## Abstract

An integrative introduction to the sciences and an introduction to scientific writing can provide a strong foundation for broadly trained STEM majors to explore the interconnectedness of STEM disciplines and prepare them for scientific research. These goals have been accomplished through a sequence of two first-year courses, STEM 101: Integrative STEM Freshman Seminar and STEM 105: Inquiry Seminar. In STEM 101, students define the STEM disciplines, see the interconnectedness of the disciplines, learn scientific ethics, and develop team-building skills as they complete a group project that explores the nature and process of science. In STEM 105, students learn about and then engage in a variety of forms of scientific communication as they develop and present an independent research proposal.

## Introduction

Modern higher education in science values interdisciplinary learning environments (Brewer, 2011; National Research Council, 2003), which prepare students to see the importance of other disciplines and provide deeper frameworks for building arguments and solutions (Gouvea, 2013). An integrative approach that involves multiple strategies, including the development of a support network, integration of peer and professional mentoring, development of study skills, and opportunities for research, has been shown to be critical in helping students persist in STEM (Brownwell, 2009; Toven-Lindsey, 2015; Wilson, 2012).

Students from groups traditionally underrepresented in STEM careers including first-generation college students and students from rural backgrounds, underrepresented minorities, or low socioeconomic status backgrounds are likely to lose motivation toward a demanding career without support or an introduction to the variety of careers in STEM that are available (Packard, 2015). The first year of a student's college career is especially critical for these students (Padgett, 2012). Early introductions to research and expansion of interdisciplinary thinking leads to a stronger sense of self-efficacy and belonging as a scientist, which can lead to increases in STEM degrees and careers (Lent, 1987; Nugent, 2015; Shaw, 2010). Courses and cohort experiences that emphasize these strategies have the potential to impact student success and broaden participation in STEM careers.

A two-semester series of freshman-level courses was designed at a mid-sized, midwestern, public liberal arts and sciences university to prepare students to engage in interdisciplinary research in STEM fields. STEM 101: Integrative Freshman Seminar introduces study skills, scientific ethics, and the interdependence of STEM courses. STEM 105: Integrative Inquiry Seminar focuses on scientific communication and culminates with written and oral research proposals. The framework of these courses began as a series of workshops for summer undergraduate research students in STEM disciplines. An interdisciplinary group of two to three faculty members team-teach these courses by attending all class sessions and co-leading the course discussions. While time-intensive, this approach allows students to see areas of harmony and conflict between the practice of the STEM disciplines.

### *STEM 101: Integrative Freshman Seminar*

The main objectives of STEM 101 are to increase interdisciplinary thinking in STEM and introduce science and mathematics as ways of knowing. The course focuses on four primary content areas: the nature of scientific inquiry, interdependence of the STEM disciplines, skills for academic success, and professional development.

To gain a better understanding of the nature of scientific inquiry, students are led in discussions that compare science and pseudoscience, explain the scientific method, and address public perception of scientific inquiry. The interdependence of the STEM disciplines is explored by defining various science and mathematics disciplines by describing what they study and highlighting the differences between basic science and applied science disciplines. Students explore the required foundational courses for STEM degrees cementing how each major depends on a variety of STEM fields. Students learn skills for academic success through conversations and exercises related to study skills, time management, critical thinking, and degree completion. Lastly, professional development is achieved through conversations about getting involved in undergraduate research and an activity to explore STEM careers.

Each semester, the course focuses on an interdisciplinary theme. Prior offerings of the course have focused on the themes of energy (2 semesters), food (1 semester), and science vs. pseudoscience (3 semesters). The primary assignment for the course has groups of three to five students representing different STEM majors select a topic related to the course theme and develop a video or website that addresses a problem within that topic. Projects must highlight the contributions of various STEM fields to a potential solution. Projects go through two rounds of peer review - at the storyboard/sitemap stage and a first completed draft - giving participants an opportunity to have their work reviewed and an opportunity to engage in peer review of the work of others. The course includes workshops on web design using Google Sites and copyright and fair use. To further explore the course theme, students participate in an online discussion of articles in the press or scientific literature.

Some course assignments target personal development as a student, including development of an academic plan of courses for completion of a degree in a STEM field, a time management log and reflection on time usage from a typical week, and analysis of results from the Learning Assessment and Study Strategies Inventory (LASSI) (Weinstein, 2016). To develop as scientists, students are expected to attend and report on scientific research seminars throughout the semester. Students are assessed on their development of interdisciplinary thinking via pre- and post-course completion of the Research on the Integrated Science Curriculum (RISC) survey (Lopatto, 2019).

The target audience for participants of this class are first-semester freshman students who are interested in a degree in STEM. It is particularly well-suited for students who are interested in STEM fields but are uncertain which STEM field they would like to major in. Several scholarship programs have made enrollment in the course a requirement for participants.

### *STEM 105: Integrative Inquiry Seminar*

STEM 105 has the main objective to increase research preparedness of class participants. The majority of the content and assignments center around helping students develop independent research proposals. The four major themes of the course are: defining research, framing research, communicating research, and the ethics of research.

To help students understand the nature of research, the instructors review the scientific method and practical applications of the scientific method in the research lab. Students are mentored in selecting a topic for their research proposal. Topics are expected to represent potential research avenues that would be viable in a college-level research lab. (Some students must be pressed to think at a higher level than what would be found in a high school science fair.) To gain a better understanding of current research, students are also expected to attend and report on research seminars and colloquia hosted by our STEM departments and the University's Student Research Conference. A panel of successful junior and senior students share research experiences in one class discussion.

Case studies are used to guide discussions of appropriate conduct in research and academics. Instructors describe the purpose for the Institutional Review Board (IRB) and the Institutional Animal Care and Use Committee (IACUC) including when and how to pursue approval from those groups. Groups of students develop Responsible and Ethical Codes of Conduct in Research.

Two course sessions are devoted to demonstrations on searching for relevant primary literature and approaches for reading papers from the literature. Students develop an annotated bibliography that will serve as the foundation for the literature review and justification of their research proposal.

A key aspect of research preparedness is the ability to communicate science effectively. We discuss sources for scientific information and framing the message for different audiences. To practice this, students are expected to prepare three diverse short talks: an elevator talk, the kitchen table talk, and a 24/7 talk. The elevator talk is a brief, in-depth description of the research topic, such as might be used if you were sharing an elevator with another scientist at a professional conference. The kitchen table talk is a short (less than 5 minute) description of the research to a non-scientific family member. The 24/7 talk is a 24-second summary of the research topic followed by a 7-word title for the topic (Kaswell, 2018). Alley's scientific writing principles and assertion-evidence style for oral presentations guide students in preparing their written and oral research proposals (Alley, 1996 and Alley, 2003). Students are assessed based on their adherence to these principles. Additional topics include designing a poster presentation and appropriate handling and display of data.

The course culminates in students submitting a written research proposal and giving an oral defense of their proposal. To aid in development of these projects, each student is assigned to a faculty mentor and a classmate who serves as a Co-Principal Investigator (Co-PI) for the project. The mentor meets with the PI and Co-PI multiple times during the semester and Co-PIs are expected to contribute to idea development, editing, and revisions throughout the semester. The written proposals go through two independent peer reviews (after a completed first and second draft) by other members of the class prior to submission of the final proposal.

This course is open to all STEM majors with permission of the course instructors and fulfills a writing-enhanced degree requirement. The target audience for participants of this class are second-semester freshman students, but inclusion of some upper-level STEM majors has enriched the discussions and raised the bar for the rigor of the research topics. The goal of the course is to prepare students to enter into a research lab with a strong foundation in STEM communication skills. This course is used for all STEM-based McNair Scholars as part of their proposal development requirement. Some students have submitted their research proposals for the University's summer research program, a competitive internal grant program for current students. While typically a Spring-semester course, to aid sophomores in completing their proposals just prior to the January application deadline, this course was offered as a Fall-semester course for the first time in Fall 2018. Some students' research proposals correspond with summer field-based study-abroad research courses that require a research plan. Some upper-level students have used their proposals for senior-level Analytical Chemistry courses where they have to develop or modify an instrument as a major course assignment.

## Results

### *Increasing interdisciplinary thinking*

Students were given the pre-course and post-course Research on the Integrated Science Curriculum (RISC) survey as a tool to measure increases in interdisciplinary thinking in STEM 101. In the pre-test, students score their level of experience and mastery on a five-point scale. In the post-test, students score their perception of gain on a five-point scale. The mean student response for the entire course is reported along with that year's national mean response. In 2013, a Biology Freshman Seminar course (BIOL 145) was given the surveys to serve as an internal control group. For analysis of the data, the questions were divided into categories of items related to course mechanics and interdisciplinary items.

The class experience and types of assignments the students encountered were classified as course mechanics. In the pre-test, the STEM 101 participants matched the national average in all measures but one; they reported significantly less experience in working on a project or problem that is entirely of student design. Following the course, students reported significantly greater gains than the national average in the areas of working on a project entirely of student design, spending the entire course on one or a few problems, having input into the process or topic of a problem, and critiquing the work of other students. The special topic that the course is built around each semester focuses the course on a single problem. Most of the assignments in the course center on the group project, which students have broad flexibility to develop their own focus related to the course topic and subsequently peer review other groups' work.

For topics related to interdisciplinary thinking, the STEM 101 participants entered the course reporting less comfort than peers nationally on nine of the fourteen measures in this category. They reported significantly less previous experience in the areas of approaching problems in different and conflicting ways, working with peers from other disciplines, finding similarities and differences between disciplines, judging the relative contributions of disciplines to a solution, asking questions that implicate more than one discipline in the answer, reading primary literature from multiple fields of study, gaining new insights to problems from considering multiple disciplines, talking with faculty members from other disciplines, and studying problems with multiple, interactive causes. In the remaining five measures, they were comparable to the national mean.

In the post-test, the STEM 101 participants reported gains above the national mean in ten of the fourteen interdisciplinary thinking measures, including all of the above categories, except for the last two. They also reported gains above the national mean in integrating ideas from more than one science in problem solving, studying an interdisciplinary problem, and understanding that disciplinary knowledge must be accurate and fair. The STEM 101 participants reported greater average gains in all categories compared to the Biology peer group, demonstrating the value of the course in increasing interdisciplinary thinking among science majors. Overall, while students reported experiences that were similar to comparison groups in course mechanics, they reported significant gains in interdisciplinary thinking due to the focus of the STEM 101 course.

### *Involvement in Undergraduate Research*

The major objective of STEM 105 was to prepare students to engage in undergraduate research. Thirty-five of the course participants applied to a total of 117 summer research experiences in the summer following their sophomore year. Fourteen (40 %) of these students received offers from a total of 17 different opportunities and thirteen of the students accepted the offers. In the period from 2014-2017, 29 course participants presented research at the University's Student Research Conference.

### *Student feedback for STEM 101 and 105*

A year after taking the courses, each cohort of students was asked to reflect on the value of the courses and what they learned. Their feedback was used in driving course renovations and to understand whether the courses were ultimately meeting their learning objectives. By collecting this feedback a year after completing both courses, the students had a chance to reflect on the practical impacts of the courses on their college and career paths.

The main objective of STEM 101 was to increase interdisciplinary STEM thinking. Many students were able to reflect on the importance and impact of other STEM disciplines on their study within a STEM major. One student wrote "It really helped me realize how no particular field is one-sided and even though I am majoring in Biology, I will use Chemistry, Physics, Math, etc." Another student wrote "I definitely see the need to experience other majors and their classes. It seems once you get into your major, you become too biased and think too narrowly about issues that concern others. It's good to have other perspectives." Students related that they were developing degree plans that included additional courses in diverse STEM fields as a result of the course. One student wrote "I used to think of Biology as one sole field, but now I understand that it can combine with many others and it is also why I started taking more computer science and chemistry to make myself a better biologist" and another student stated that it "Helped me see the depth of Biology. There's math, physics, and chemistry all in there too." Some students commented that seeing the connections and value of the other STEM support courses in their major made them enjoy their major more.

Several students commented that the interdisciplinary introduction to the STEM fields made them realize that there were broader options for their future careers. One student commented "It encouraged me to pursue Biochemistry in graduate school" and another stated "I'm planning on pursuing an interdisciplinary doctorate in Computational Biology." One student said that the discussions about research made them want to pursue an M.D./Ph.D. program so they could fully engage in research.

The objective of STEM 105 was to increase research preparedness. Many students reflected on the value of preparing their own research proposal. One student wrote that "Writing a proposal really showed just how much work goes into research prep and more work will need to be done" and another wrote "At first I hated the research paper, but later on I discovered I learned how to write a research paper properly". One student highlighted the value of the peer review process in scientific writing in saying "Critiquing and reviewing proposals also gave me an insight into what is needed/expected in scientific literature." Students indicated that their experiences in this class made them more comfortable in applying for summer research experiences. Two students used their research proposals that they developed in the course as the foundation for the required research proposal as a part of successful applications to the University's competitive summer research program.

## Summary

In conclusion, a two-semester sequence of courses were designed and implemented to provide students with an introduction to the interdisciplinary nature of the sciences and to prepare them to engage in scientific research. The students who participated in STEM 101 developed deeper interdisciplinary thinking and gained experiences working in diverse groups. In STEM 105, students learned the value of research, practiced developing scientific communications skills, and engaged in undergraduate research following the course. The students in these courses are better prepared to complete and thrive in a STEM degree.

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