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Infusing Humanities in STEM Education: Student Opinions of Disciplinary Connections in an Introductory Chemistry Course

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Abstract

The *Next Generation Science Standards* and other educational reforms support the formation of deep connections across the STEM disciplines. Integrated STEM is considered as a best practice by the educational communities of the disparate disciplines. However, the integration of non-STEM disciplines is understudied and generally limited to the integration of art (STEAM). Humanistic STEM *blends* the study of STEM with interest in and concern for, human affairs, welfare, values, or culture. This study looks at an infusion of the humanities into an online chemistry course to see if there is an influence on student connection between course content and cross-disciplinary perspectives. Specifically, students were asked about the course making clear connection to STEM disciplines, between science and non-science, between science and the real world, and a widened perspective of science connection other courses in their degree programs. Items on a Likert scale were presented as part of the end of course evolutions and yielded 59 responses. Although not statistically significant difference in the pre- and post-infusion agreement, it is evident that the additional perspectives did no harm. The positive movement in this pilot study encourages further investigation with stronger infusions of both STEM and humanities content.

Keywords: STEM Education, Interdisciplinary Approach, Student Attitude, Humanistic STEM, Integrated STEM

Introduction

Our world is not neatly arranged by academic disciplines and understanding complex problems requires cross-disciplinary knowledge. Concepts from any field are enriched by the theories and methods from other fields, providing context, intellectual inquiry, and multi-perspective analysis (Stember 1991). Coherence and cohesiveness of these connections combats fragmentation of knowledge (Fogarty 1991). An integrated curriculum connects a STEM discipline to one or more other disciplines in order to enhance student learning. A cohesive integration contains the following disciplinary elements: 1) *scientific inquiry* where students construct their own questions and investigations, 2) *technological literacy* where students make use of instruments, 3) *engineering design* to provide the systematic approach to problem solving, which contributes context and provides the opportunity to apply knowledge and skills while learning from failure, and 4) *mathematical thinking* (*STEM road map: A framework for integrated STEM education* 2015; Kelley and Knowles 2016). Integration can include cross-disciplinary, multidisciplinary, and interdisciplinary perspectives (Jensenius 2012; Stember 1991). Pedagogical elements of integrated STEM include an authentic, relevant, and engaging context, emphasis on application and integration, a student-centered approach, and development of key transferable skills in problem-solving, creativity, and higher order thinking through the use of use of real-world problems, as well as the development of teamwork and communication skills (*STEM road map: A framework for integrated STEM education*2015; Kelley and Knowles 2016; Sanders 2012).

The science, technology, engineering, and mathematics educational communities support integrated STEM as a best practice (Sanders 2012). According to cognition theory, knowing how to apply knowledge and skills is just as important as learning the knowledge and skills themselves (Putnam and Borko 2000). The *Next Generation Science Standards* and other educational reforms support the formation of deep connections across the STEM disciplines (NGSS Lead States 2013).

An integrated STEM curriculum has some challenges, including competing agendas, epistemological and methodological differences, varying cohesiveness and coherence, and identifying the appropriate intersections of disciplines (Honey et al. 2014; Stember 1991; Wang et al. 2011). An integrated curriculum increases the potential for knowledge gaps in faculty (Drake and Burns 2004; Stinson et al. 2009). Some argue that integration limits the content that can be covered (Kelley and Knowles 2016) while others argue that integration increases efficiency, covering multiple disciplinary concepts simultaneously (Drake and Burns 2004).

While there has been recent attention on integration of the STEM disciplines, including interest in STEAM (science, technology, engineering, *arts*, and math), humanities discipline integration into STEM has garnered much less attention (Becker and Park 2011; Hoachlander and Yanofsky 2011). When art is present, it is either not assessed using appropriate learning objectives or is evaluated as a secondary criterion (Perignat and Katz-Buonincontro 2019). A modern approach is humanistic STEM, defined as “a path blending the study of science, technology, engineering, and mathematics with interest in, and concern for, human affairs, welfare, values, or culture” (Bourdeau and Wood 2019). As with STEM disciplines, the arts and humanities disciplines require critical thinking habits of mind, including creativity, contextual perspective, intellectualism and curiosity, an ability and confidence to use reason, perseverance, self-reflection, and both flexibility and adaptability in thinking in order to be open-minded to new ideas (Hamman 2013; Paul and Binker 1990). The humanities disciplines – such as the study of languages, philosophy, logic, and rhetoric – can offer additional perspectives for students (American Academy of Arts and Sciences 2013). Table 1 presents skills used in problem solving across disciplines.

Table 1: Comparison of Skills for Problem Solving across Disciplines (Alkhatib 2019; Kelley and Knowles 2016; Nurdyansyah et al. 2017)

	Disciplinary Skill			
Core Skill for Problem Solving	**Science**	**Technology & Engineering**	**Mathematics**	**Humanities Meta-Discipline**
Understanding a problem by …	making observations and generating questions	identifying criteria and constraints	creating abstractions of a situation, represented as symbols	identifying the key elements of the problem
Plan an investigation by …	developing an explanation (hypothesize)	analyzing existing solutions	looking for solution entry points	questioning assumptions and identifying existing information
Appropriate tools …	strategically	strategically	strategically	strategically
Perform investigation by …	systematic experimentation and modeling	designing and running models	logic and reason	organizing information
Iteration towards …	understanding	a good enough solution	generalized models and proof	interpretation
Analyze data …	using logical and quantitative thinking	using quantitative thinking to locate optimal design	using quantitative thinking	looking for a pattern using mixed methods
Construct an argument from …	evidence	evidence	evidence	evidence
Informed decision-making and justifying …	conclusions	design decisions	potential solution paths	potential conclusions
Communication of …	ideas, results, explanations, and implications	ideas, design decisions, explanations	potential models	ideas, explanations, and implications
Work and credit are …	shared	shared	shared	shared

While the literature on the impacts of integrated STEM is scarce, it appears that students in integrated curricula outperform those in fragmented curricula (Beane 1993; Becker and Park 2011; Fan and Yu 2017; Hartzler 2000). An integrated approach improves higher-level thinking skills, problem solving, and retention, likely due to the intellectual, practical, and pedagogical implications of integration (Fan and Yu 2017; Fllis and Fouts 2001; Furner and Kumar 2007). There is a need for further research to establish the impact of interventions, scaffolding, and instructional designs (Becker and Park 2011; Kelley and Knowles 2016; Sanders 2012). Because student attitudes towards STEM influence motivation (Becker and Park 2011), it is important to understand how integration influences student attitudes and perspectives. This study explores the impact of a small-scale interdisciplinary infusion into an online course on student perceptions of the connectedness of the course to other disciplines, other courses, and the real world.

H_{a1} More students will agree than disagree that the course made clear connections between science, technology, engineering, and math.

H_{a2} More students will agree than disagree that the course made clear connections between science and non-science topics and issues such as art, history, and the humanities.

H_{a3} More students will agree than disagree that the course made clear connections between science and the world around them.

H_{a4} More students will agree than disagree that the course has widened their perceptions of how science connects to other courses in their degree program.

Methods

Participants

This study was performed at a medium-sized private university in the United States. The pilot study was run in an online introductory chemistry course, available to both STEM and non-STEM majors. End of course evaluations provided data between August 2018 and October 2019. The response rate to the survey pre-intervention averaged 66.1% (±10.7%), with an *n* of 35 respondents. The response rate to the survey post-intervention averaged 67.5% (±9.2%), with an *n* of 24 respondents. For this study, each section of the course was taught in the asynchronous online modality. While demographic data was not collected, the majority of students enrolled in the studied sections were non-traditional students.

Interventions

With the goal of infusing small integrations across the online course, a multi-disciplinary team collaborated on modifications to the course that did not impact assessments, assignment design, or core content (Table 2). For example, the first module's original title of "Introduction to Chemistry" was changed to "Bacon and Gunpowder". The overview for the module opens with a quote from Roger Bacon regarding the connection between mathematics and science. Bacon was an English philosopher who first detailed the production of gunpowder, thus the inspiration for the module title. This overview also includes the added video on the math used in chemistry - dimensional analysis. The module ended with a quote from Democritus (an ancient Greek philosopher who put forward an atomic model in 442 BCE), "We think there is color, we think there is sweet, we think there is bitter, but in reality there are atoms and a void."

Table 2: Integrated STEM infusions

Cross-disciplinary changes	humanistic STEM module titles
	add alchemy videos in two discussion prompts
	embed quotes from philosopher scientists into overview/wrap-up for each module
Interdisciplinary changes	add video on the math used in chemistry
	edit two discussion prompts to include technology and engineering perspectives
	add video on interdisciplinary applications of specific chemistry content

Measuring Impact

The impact of these interventions on student perceptions of course connections was measured by adding customized end of course evaluation questions. Using a 5-point Likert scale, respondents were asked to state their level of agreement with the following statements:

- This course made clear connections between science, technology, engineering, and/or mathematics.

- This course made clear connections between science and non-science topics and issues, like art, history, and the humanities.
- This course made clear connections between science and the world around me.
- This course has widened my perceptions of how science connects to other courses in my degree program.

The surveys were completed anonymously; all data were aggregated with no individual identifiers. The Institutional Review Board deemed this study exempt, therefore informed consent was not obtained.

As an additional measure of impact, student final course grades were collected for the terms studied. Data was collected after conclusion of the courses and was provided to the researchers in aggregate with personal identifiers removed.

Statistical Analysis

Cross sectional survey research was used to evaluate student perceptions on if the course made a clear connection to STEM fields, Humanities, the world around them and how science connects to other courses in their degree program. Students did not realize that they were involved in a research study avoiding any "John Henry or Hawthorne" effect. A total of 59 student survey responses were examined. All data were viewed as nominal and evaluated using the appropriate χ^2 (chi-square) test using StatDisk 13. Although a 5 point Likert scale was used, the "Strongly Agree" and "Agree" answers were grouped into the "Agree" category. "Neutral", "Disagree" and "Strongly Disagree" answers were grouped into the "Disagree" category. Since all four questions involved science and student's perception of science, a Bonferroni corrected alpha was used ($\alpha = .0125$) (Gay et al. 2006).

Final course grades between the pre-intervention and post-intervention groups were compared using an independent samples t-test.

Results & Discussion

The four research questions were evaluated using two different Chi-square tests (Table 3). Pre and post intervention data were examined using a Chi-square goodness-of-fit test for each question. Pre and post-intervention perceptions were also evaluated using Chi-square contingency tables to test for a difference of proportions.

Table 3. Survey Results: Pre and Post-Treatment

	Pre Treatment				Post-treatment				Pre and post treatment comparison	
	Agree	Disagree	χ^2	p	Agree	Disagree	χ^2	p	χ^2	p
Clear connections between science, technology, engineering and mathematics	31 (89%)	4 (11%)	20.829	<.001*	23 (96%)	1 (4%)	20.167	<.001*	.968	.325
Clear connections between science and non-science topic and issues such as art, history and the humanities	26 (74%)	9 (26%)	8.257	.004*	21 (88%)	3 (12%)	13.5	<.001*	1.534	.216
Clear connections between science	33 (94%)	2 (6%)	27.457	<.001*	23 (96%)	1 (4%)	20.167	<.001*	.071	.79

and the world around them										
Widened their perceptions of how science connects to other courses in their degree program	30 (86%)	5 (14%)	17.857	<.001*	20 (84%)	4 (16%)	10.667	.001*	.062	.803

Note: p values identified with an asterisk are statistically significant using a Bonferroni corrected alpha (α = .0125). Percent values shown are rounded to the nearest whole number.

Significantly more students agreed than disagreed that the course made a clear connection to STEM fields, Humanities, the world around them, and improved their understanding of how science connects to other courses in their degree programs. This was evident in both traditional (pre-intervention) and interdisciplinary (post-intervention) methods. The changes making the course more interdisciplinary appeared to be just as successful at making these connections as the course with fewer disciplinary infusions.

While the difference between pre-intervention (traditional) and post-intervention (interdisciplinary) were not statistically different from each other, the positive movement on first two measures is encouraging. STEM discipline connectedness moved from 88.6% agreement pre-intervention to 95.8% post-intervention. STEM and humanities connectedness moved from 74.3% to 87.5% post-intervention. The intervention in this study used a small-scale cross-disciplinary infusion of perspectives. It is possible that with further course modifications to emphasize humanities disciplines, a statistically significant change in student perceptions could be seen here. Real-world connectedness was already very high, at 94.3%, leaving very little room for a statistically significant impact of an intervention.

Final course grades were compared between the pre-intervention (mean = 72.31) and post-intervention (mean = 70.39) groups. With a t Stat of 0.36 (df = 70, P = 0.72), the difference between the two groups is not statistically significant. The infusions did not statistically influence student content mastery as measured through final course grades, which is a desirable outcome because the small infusions did not interfere with the learning of the chemistry concepts.

Several key limitations of this study influence must be analyzed. A primary limitation of this survey is sample size. This pilot study was performed to ensure that an infusion of cross-disciplinary perspectives would not negatively impact student perceptions prior to a larger scale investigation of the student impacts on this type of intervention. A second limitation is nonresponse error. While census data was sought, survey completion was not mandatory nor was it incentivized, resulting in a response rate ranging from 57.1% - 83.3%. Voluntary survey responses can introduce bias, with over-representation of strong opinions, both positive and negative. This limitation is challenging to overcome in survey research, but due to the benign nature of the questions, is unlikely to have significantly impacted results.

Conclusions

In this study, the data supported the idea of infusing interdisciplinary perspectives in an introductory chemistry course. It can be argued that we live in a very interdisciplinary world yet our academic courses are structured along strict disciplinary lines. One would think an interdisciplinary approach would better prepare our students to understand the world around them and effectively work with people who have different backgrounds and disciplines.

Aligned with design-based research, future work will ramp up the presence of humanities perspective in the course to see if a stronger infusion can achieve statistically significant results. In the next iteration, validated instruments to measure student attitudes will be used (e.g. learning attitudes about science (Adams et al. 2006)) and data collection will include assessment of content mastery with and without infusions.

Ethical Approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent: The research was deemed exempt, therefore informed consent was not obtained.

References

Adams, W. K., Perkins, K. K., Podolefsky, N. S., & Dubson, M. (2006). New instrument for measuring student beliefs about physics and learning physics: The colorado learning attitudes about science survey. *Physical Review Special Topics - Physics Education Research*, 2(1), 1.

Alkhatib, O. J. (2019). A framework for implementing higher order thinking skills (problem-solving, critical thinking, creative thinking, and decision-making) in engineering and humanities. *2019 Advances in Science and Engineering Technology International Conferences (ASET)*, Dubai. 1-8.

American Academy of Arts and Sciences. (2013). *The heart of the matter: The humanities and social sciences for a vibrant, competitive, and secure nation.* Cambridge, MA: American Academy of Arts and Sciences.

Beane, J. A. (1993). *A middle school curriculum: From rhetoric to reality* (2nd ed.). Columbus, OH: National Middle School Association.

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations and Research*, 12(5/6), 23-37.

Bourdeau, D. T., & Wood, B. L. (2019). What is humanistic STEM and why do we need it? *Journal of Humanistic Mathematics*, 9(1), 205-216. https://doi.org/10.5642/jhummath.201901.11

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum.* Alexandria, VA: Association for Supervision and Curriculum Development.

Fan, S. C., & Yu, K. C. (2017). How an integrative STEM curriculum can benefit students in engineering design practices. *International Journal of Technology and Design Education*, 27(1), 107-129. https://doi.org/10.1007/s10798-015-9328-x

Fllis, A., & Fouts, J. (2001). Interdisciplinary curriculum: The research base: The decision to approach music curriculum from an interdisciplinary perspective should include a consideration of all the possible benefits and drawbacks. *Music Educators Journal*, 87, 22-68.

Fogarty, R. (1991). Ten ways to integrate curriculum. *Educational Leadership*, 49(2), 61-65.

Furner, J., & Kumar, D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science, & Technology*, 3(3), 185-189. https://doi.org/10.12973/ejmste/75397

Gay, L. R., Mills, G. E., & Airasian, P. W. (2006). *Educational research: Competencies for analysis and applications* (8th ed.). Upper Saddle River, New Jersey: Pearson Education, Inc.

Hamman, K. (2013, April 12). First they came for the drama department: Why STEM should care about the humanities. Retrieved from https://www.chronicle.com/blogs/conversation/2013/04/12/why-stem-should-care-about-the-humanities/

Hartzler, D. S. (2000). *A meta-analysis of studies conducted in integrated curriculum programs and their effects on student achievement* (Doctoral dissertation). Available from ProQuest. (9967119).

Hoachlander, G., & Yanofsky, D. (2011). Making STEM real: By infusing core academics with rigorous real-world work, linked learning pathways prepare students for both college and career. *Educational Leadership*, 68(3), 60-65.

Honey, M., Pearson, G., & Schweingruber, H. A. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research.* Washington, D.C.: National Academies Press. doi:10.17226/18612

Jensenius, A. R. (2012, March 12). Disciplinarities: Intra, cross, multi, inter, trans. Retrieved from http://www.arj.no/2012/03/12/disciplinarities-2/

Kelley, T., & Knowles, G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(11), 1-11. https://doi.org/10.1186/s40594-016-0046-z

NGSS Lead States. (2013). *Next generation science standards for states, by states*. Washington, D.C.: National Academies Press.

Nurdyansyah, N., Siti, M., & Bachtiar, S. B. (2017). Problem solving model with integration pattern: Student's problem solving capability. . *1st International Conference on Education Innovation (IEEE),* Pune. doi:10.2991/icei-17.2018.67

Paul, R. W., & Binker, A. J. A. (1990). *Critical thinking: What every person needs to survive in a rapidly changing world*. Rohnert Park, CA: Center for Critical Thinking and Moral Critique, Sonoma State University.

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity,* 31, 31-43. https://doi.org/10.1016/j.tsc.2018.10.002

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher,* 29(1), 1-12. https://doi.org/10.3102/0013189X029001004

Sanders, M. E. (2012). Integrative STEM education as "best practice". *7th Biennial International Technology Education Research Conference,* Queensland, Australia.

STEM road map: A framework for integrated STEM education (2015). In Johnson C. C., Peters-Burton E. E. and Moore T. J. (Eds.), (1st ed.). New York: Routledge.

Stember, M. (1991). Advancing the social sciences through interdisciplinary enterprise. *The Social Science Journal,* 28(1), 1-14. https://doi.org/10.1016/0362-3319(91)90040-B

Stinson, K., Harkness, S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics,* 109(3), 153-161. https://doi.org/10.1111/j.1949-8594.2009. tb17951.x

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, 1(2), 2. https://doi.org/10.5703/1288284314636