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Investigating the Impact of Arts on Student Learning by Introducing Glass Science in the Materials Engineering Curriculum

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Abstract

The research will create an academic program (curricular and co-curricular components) that integrates art concepts into an undergraduate engineering program. The goals of the program are increased student innovation, creativity, collegiality, and entrepreneurship, all while broadening the undergraduate talent pool.

The programmatic elements are focused on integration of arts in STEM (i.e. STEAM) to achieve the stated goals. The centerpiece is the infusion of STEAM content into laboratories and courses distributed throughout a model engineering program in Metallurgical Engineering. Curricular modifications will be facilitated through involvement of a Resident Artist who will be embedded within the academic program.

The research is evidence-based and builds on prior NSF Course Curricular and Laboratory Improvement (CCLI) research that involved highly successful curricular and co-curricular programming associated with integration of blacksmithing into an undergraduate Metallurgical Engineering degree program.

A rigorous external assessment of the research will be conducted and includes the use of a variety of assessment tools including Herrmann Brain Dominance Inventory, Small Group Instructional Diagnosis (SGID), and student focus groups.

Preliminary results from the SGID and student focus group surveys report positive results with the modified curricula that has been integrated into the initial course, Introduction to Metallurgical Engineering. Student surveys were performed with a primary focus on student advancement in areas of creativity, innovation, and technical knowledge. The self-efficacy studies illustrate a general increase in the students' perception of their creative skills and technical knowledge.

Keywords: STEM Education, Women in Engineering, NSF IUSE, STEAM, Innovation, Art + Engineering

Project Background

As a traditional engineering degree program (Metallurgical Engineering), in an overwhelmingly non-diverse professional makeup, compounded by our rural location, we are anxious to address and welcome the certainty of change. Toward this end we have been actively taking steps towards preparing the next generation of Metallurgical Engineers; however, we believe we need to implement far greater steps towards making creativity, innovation, collegiality, entrepreneurship and critical thinking a given.

We strive to understand what motivates students to pursue and succeed in an engineering degree program and the role that an integrated STEAM curriculum can have in this process. The initial impetus for this project was a campus visit by a prospective student who was blacksmithing and forging metal into functional and creative objects. The research presented is evidence-based and builds on prior NSF Course Curricular and Laboratory Improvement (CCLI) research that involved highly successful curricular and co-curricular programming associated with integration of blacksmithing into the B.S. Metallurgical Engineering degree program [1-4].

This project aims to serve the national interest by improving STEM learning environments through the creation of a STEAM-infused engineering curriculum and co-curriculum. The project will investigate a research hypothesis of whether positive outcomes (innovation, creativity, collegiality, entrepreneurship, and broadening of the undergraduate talent pool) can be achieved through strategic curricular and co-curricular modifications that integrate and embrace development of STEAM programs. The quantitative assessment of the above-mentioned outcome will be discussed in more detail later and current data and analysis can be seen in the results.

STEAM, in simple terms, is the inclusion of **A**rt into the now accepted **S**cience-**T**echnology-**E**ngineering-**M**ath (STEM) discipline chain. Dr. John Maeda is often recognized as one of the originators of the STEAM concept at the university level, and the following quotation delineates his vision, *"I believe art and design are poised to transform our economy in the 21st century like science and technology did in the last century"* [5]. The motivation to integrate art with STEM education is often quite diverse but is generally attributed to the potential to i) increase student innovation, creativity, collegiality and entrepreneurship within STEM programs, and ii) increase the talent pool of STEM graduates, by involving traditionally underrepresented STEM participants that can help integrate art into products, primarily in the design cycle.

The origins of the STEAM movement are relatively recent, and often recognized to have fully emerged around the 2008 timeframe when Maeda was the President of the Rhode Island School of Design. Since its inception, the STEAM concept has taken root most heavily in K-12 schools [6-20]. Comparatively, examples of broad-based STEAM programs within university settings are fewer and involve mostly isolated cases of application [21-23]. The concept of STEAM has since taken on many variants. For the purposes of this paper, we define STEAM to be within the original definition and intent of Maeda, namely the full '*integration'* of art into STEM, with particular emphasis within the design process.

Other elements of the research address the sustainability of the STEAM modifications through i) translation of selected programmatic elements to other campus engineering programs, ii) recruitment of students into the revised degree programs, iii) marketing to the campus/local/state community, iv) involvement of private-sector partners through STEAM-influenced design projects, and v) dissemination to targeted professional societies and associated stakeholders, including local art centers. A rigorous external assessment of the research will be conducted that includes use of Herrmann Brain Dominance Inventory and the Critical Thinking Assessment Test to determine the effectiveness of program outcomes.

STEAM integration herein is being approached in various formats in different courses, see Table 1. This process began in the Fall of 2021 with relevant content integration into Structure and Properties of Materials Lab (MET 231) and Introduction to Metallurgical Engineering (MET 110) courses. For the MET 110 course, the first-year students completed a sketching module, which then translated to crystal structure and 3D Printing modules. Students also participated in other kinesthetic learning modules that included creation of glass pendants, learning welding techniques, and casting artistic aluminum pieces.

In the Spring of 2022, the program integrated curricular activities in a junior level course, Principles of Metallurgical Design (MET 352). The STEAM integration for this course focused on the creation and design of a functional and aesthetically pleasing product based upon local (Black Hills) minerals. The students comminuted (crush, grind, classify), characterized, formulated, and formed clay-based ceramic bodies from the minerals. Throughout this process the students used scientific resources (e.g., x-ray diffraction) to optimize their formulation. To facilitate this process faculty delivered new course modules on i) minerals for ceramics, ii) rheology of clays and iii) fluxes, glazes, and vitrification. Additionally, the program Artist-in-Residence gave a technical kinesthetic lecture on clay forming (e.g., coil, pinch, etc.) At the time of this paper submission this course was ongoing, consequently so no quantitative results are reported for MET 352.

Table 1: Outline of courses prior to and after the NSF IUSE program integration.

Course	Before NSF IUSE program	After NSF IUSE program
MET 110	Curricula included guest speakers, campus tours, blacksmithing, resume building, student success visits, etc. A term project which included optical microscopy.	New curricula included hand sketching crystal structures, 3D printing, casting, welding, and glass working modules.
MET 231	Curricula included grain size, optical microscopy, ASTM standard testing included (Charpy, hardness, and tensile testing), and blacksmithing.	New curriculum introduced in this course was a hand drawn sketch of an object the student would design and create from metal clay. The students would have to account for the effect of shrinkage during the sintering process.
MET 352	Curricula included a semester long design course where two faculty would advise multiple teams. The course is a lecture/lab course and all the lecture portions solely focused on design topics (teaming, design process, literature review)	Faculty from the department gave additional technical lectures relevant to the design project (e.g., ceramic formulation, processing, sintering, etc.). Each team was paired with a single advisor.

Current Results

This NSF-funded project began in October of 2021. Prior to the start date, the project team initiated portions of the proposed curriculum into the Introduction to Metallurgical Engineering (MET 110) course with a specific focus on creativity and a kinesthetic laboratory component. One method used to assess the changes was a structured interview process called Small Group Instructional Diagnosis (SGID). SGID was offered midway through the term to help facilitate improvements in the course as well identify items that are helpful to student learning.

For the creative component/visualization modification (CAD, drawing, sketching), the SGID revealed activities the students found helpful as well as components that they felt were less helpful. Almost all students noted that an introduction to CAD basics was quite beneficial. Most students would have appreciated a more challenging component to the CAD design, and some indicated a desire for a group work component as part of the CAD training. Most students were less enthusiastic about drawing and sketching training compared to CAD training. Some thought that while drawing/sketching was useful, they did not see a lot of relevant application for the work they might be doing. Most students felt it consumed more time that the class could realistically afford given the number of other laboratory and other class projects.

For the kinesthetic learning (laboratory component) modifications (welding, casting, blacksmithing, glass working), the SGID revealed activities the students found helpful as well as components that they felt could be improved. Overall, the students felt that the laboratories helped with their understanding of metallurgical processes as well as facilitating their understanding of the variety of and applicability of different materials and metal alloys. Most students had an appreciation for the hands-on components of the labs and felt coverage of basic materials processes provided a beneficial overview. If possible, they felt a Metallurgical Engineering lab tour should occur earlier in the term. Some respondents also mentioned the possibility of seeing real applications in industry by visiting local manufacturing companies.

For the MET 110 course, pre- and post-activity surveys were completed with questions focusing on self-efficacy in topics relating to creativity, metallurgical knowledge, and anxiety related to completion of a kinesthetic learning opportunity. Self-efficacy is an individual's belief in his or her capacity to execute behaviors necessary to produce specific performance attainments [24]. The self-efficacy surveys were used to evaluate how the incoming first year Metallurgical Engineering students viewed their skills in creativity and their knowledge of the field of metallurgy. The pre- and post responses represent their feelings at the beginning of the term (pre) and at the end of the term (post).

Figure 1, plot on the left, is a graphical representation of the MET 110 student responses (n=18) to a creativity question, note that the left-hand side of the x-axis represents no truth with regard to a self-efficacy statement and the right-hand side of the x-axis represents an exact truth. For the creativity question, the students were asked to respond according to the following prompt, *"I think of myself as an individual with creative skills."* When analyzing creativity, five students at the beginning of the term rated themselves at the lower end (Not at all True and Hardly True) of the spectrum (orange bars). When evaluating the students' creativity at the end of the term (gray bars), two students continued to select the lower end for the truth, and three students changed their creativity rating to a higher value at the end of the course.

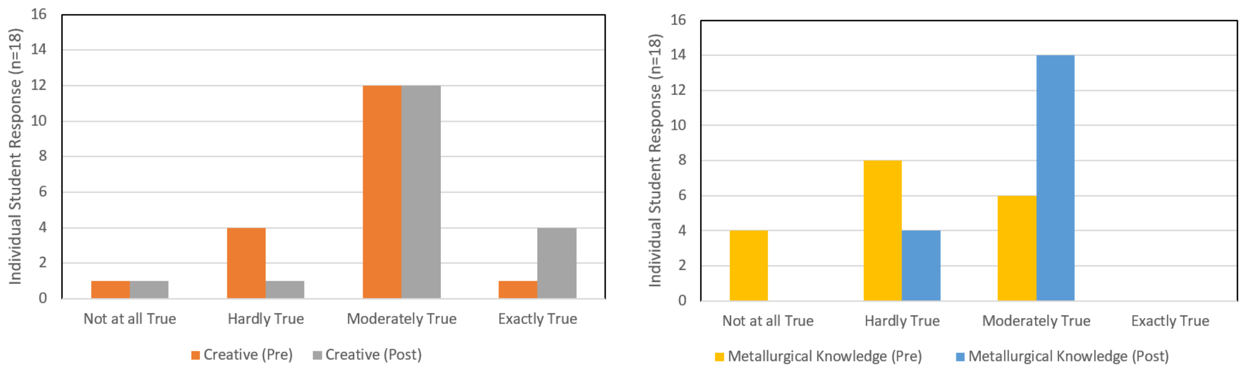

Figure 1: Plot of the student responses to self-efficacy questions regarding creativity (left) and Metallurgical Engineering knowledge (right).

For the metallurgical knowledge question, the students were asked to respond according to the following prompt, *"I think of myself as an individual that is expertly knowledgeable about metallurgy."* In Figure 1, plot on the right, twelve students at the beginning of the term rated themselves at the lower end of the spectrum for their Metallurgical Engineering knowledge. At the end of the term, fourteen students reported on the upper end of the data, specifically in Moderately True. No students in the pre- or post-survey groups selected "Exactly True" for the Metallurgical Engineering knowledge question. The results are not surprising given that the students surveyed are first-year students and the purpose at completion of the B.S. in Metallurgical Engineering degree is for students to obtain a more "expert knowledge" upon graduation.

Another aspect of the course, the kinesthetic learning lab, was an additional modification that the Project Team wanted to investigate. The kinesthetic labs (welding, casting, blacksmithing, glass working, and metal quenching) within the MET 110 course required the students to create a product at the end of the lab. Some of these labs involved high temperature activities (quenching, molten metal, and glass) which can be intimidating to students that may not have ever worked with materials at elevated temperatures. The results from selected kinesthetic learning labs (metal casting and glass pendant creation) can be seen in Figure 2.

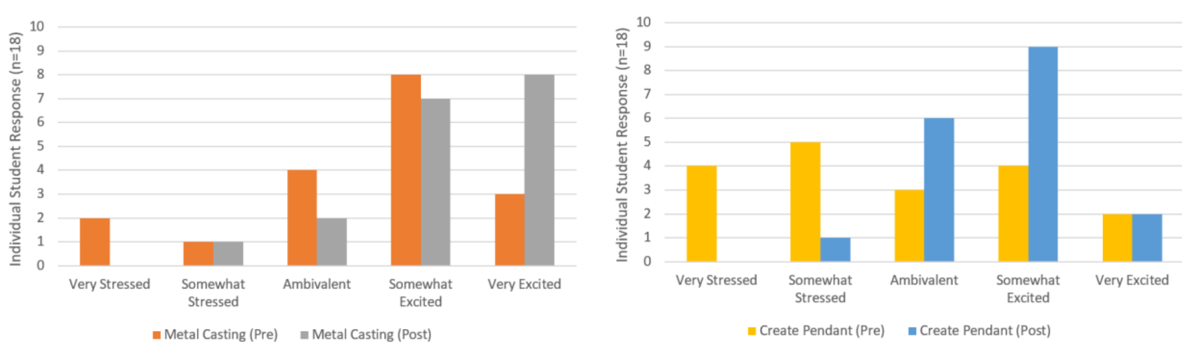

Figure 2: Plot of the student responses to prompts regarding their reaction to being told to perform a metal casting (left) or create a glass pendant (right) in a kinesthetic lab.

The prompt for the metal casting was for the students to rate their emotional response to the following prompt, *"I would have had the following emotional reaction to being given a problem statement that had the following phrasing "Student will cast a...""*. At the beginning of the term, three students stated that they would feel some form of stress (very or somewhat stressed) and 11 students selected that they would feel some level of excitement (very or somewhat excited). After completing the metal casting, only one student would feel somewhat stressed when prompted with a problem statement requiring a metal casting and fifteen students reported some level of excitement when given a prompt to perform a metal casting task, see Figure 2 plot on left.

The second prompt was for the glass pendant, *"I would have had the following emotional response to being given a problem statement that had the following phrasing "The student will create a glass pendant...""*. Prior to completing the kinesthetic learning lab, nine students selected that they would feel some level of stress associated with the lab, and six students selected that they would have some level of excitement. After completing the lab, one student stated that they would feel some level of stress in relation to receiving the prompt regarding pendant creation. The results for the post lab demonstrate that the student excitement for the lab almost doubled in number pre (six students) and post (11 students), see Figure 2 plot on right.

Although the level of excitement prior (pre) to the casting prompt was much higher than the glass pendant prompt. The difference between the two prompts is not surprising as the program is a Metallurgical Engineering program, therefore many students in the program come in with some experience working with metals (casting, welding, blacksmithing, etc.). Notably, for the metal casting and glass pendant creation the same student selected "somewhat stressed" after having completed the casting and glass working kinesthetic lab. All other student results showed an increase in confidence, or at the very minimal, no increased stress after having completed the kinesthetic learning assignment.

Ongoing and Future Research

At the time of writing this manuscript, the Spring 2022 semester is currently ongoing, with several project components in implementation. Specifically, as mentioned earlier, the program team is currently in the process of integrating modified curriculum into two courses, Principles of Metallurgical Design (MET 352) and Structures and Properties of Materials Laboratory (MET 231).

In MET 352 the STEAM integration has an artistic/mineral processing focus. The students will be required to process (crush, grind, classify, formulate) clay bodies to characterize the components of the clay body. All minerals utilized will come from local (Black Hills, SD) ore sources. After characterization the students will formulate a clay "recipe" to fire in a kiln to create a ceramic body (pottery). The students will use advanced characterization and scientific resources (e.g. x-ray diffraction) to optimize their formulation, which commonly includes a portion of clay, a fluxing agent, and a filler. Faculty will deliver new course modules on i) minerals for ceramics ii) rheology of clays and iii) fluxes, glazes and vitrification. In addition, design components will include training on the iterative nature of the design process, and, from an artistic perspective, the students will learn the challenges faced when manipulating a material into a shape along with balancing the chemistry and mechanics associated with the clay body of interest. Like the previously mentioned MET 110 modification the final design project will involve significant kinesthetic and aesthetic components.

A Metal Clay Lab is currently being integrated into the MET 231 course. The laboratory will consist of working with hands and tools to create a metallic piece from Metal Clay (a combination of micron-sized metal particles and cellulose). Prior to firing the artistic piece, the clay body "green body" is formed by the students. The green body sculpture developed is unique for each student, facilitated through interactions with the program's Artist in Residence. Upon firing the piece to sinter the metal particles, the cellulose burn off leaving a solely metallic (bronze) piece. In addition to artistic (kinesthetic and aesthetic) components, students will gain understanding of scientific/engineering principles (phase diagrams, sintering, and mechanical properties) in the new laboratory.

In the future, a rigorous external assessment of the research will be conducted and includes the use of the following tools i) Herrmann Brain Dominance Inventory, ii) Assessment of Behaviors, Attitudes, Knowledge, Attributes, and Skills Test, iii) Critical Thinking Assessment Test, iv) Small Group Instructional Diagnosis (SGID), and v) student focus groups. In addition, the curriculum development will be expanded throughout the remainder of the undergraduate Metallurgical Engineering program.

Conclusions

The team has made good progress in the initial phase (six months) of STEAM integrations into the Metallurgical Engineering curriculum. The preliminary results from the surveys and SGID are promising with regard to the creativity and innovation component of the overall Research Hypothesis. To date, the current results are from surveys and a SGID assessment, future work will include additional assessment.

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References

1. J. Kellar, S. Howard, M. West, D. Medlin, and S. Kellogg "The Samurai Sword Design Project and Opportunities for Metallurgical Programs." *MS&T Proceedings 2009: Status of Metals Engineering Education in the United States.*
2. M. West, D. Medlin, J. Kellar, D. Mitchell, S. Kellogg, and J. Rattling Leaf, "Back in Black: Innovative Curricular, Outreach, and Recruiting Activities at the South Dakota School of Mines and Technology." *MS&T Proceedings: Status of Metals Engineering Education in the United States*. 2009.
3. D. Medlin, D., Mitchell, D., Kellar, J. and Kellogg, S. (2009). "Improved Materials Science Understanding with Blacksmithing." *American Society for Engineering Education*. American

Society for Engineering Education 2009 Annual Conference & Exposition, Austin, Texas. 10.18260/1-2—5751
4. W. Cross, J. Kellar, G. Crawford., S. Howard, D. Medlin, and M. West. "Development of an Integrated Research, Curricular, Historically-informed and Extracurricular Learning Environment." *2012 MRS Spring Meeting, Symposium ZZ*, Manuscript ID: MRSS12-1472-ZZ04- 08.04.2012, San Francisco
5. Office of Congresswoman Suzzane Bonmici, *"Reps. Bonamici and Schock Announce Bipartisan Congressional STEAM Caucus,"* https://bonamici.house.gov/press-release/reps-bonamici-and-schock-announce-bipartisan-congressional-steam-caucus accessed 1/16/2021.
6. J. Maeda, "STEM to STEAM: Art in K-12 is Key to Building a Strong Economy." *Edutopia: What works in education. 2012* https://www.edutopia.org/blog/stem-to-steam-strengthens-economy-john-maeda accessed 1/16/2021
7. Women in STEAM and STEAM for Women, https://www.empowerwomen.org/en/who-we-are/initiatives/ict-for-development accessed 1/6/2021.
8. The Resilient Educator, *"The Benefits of Teaching STEAM Lessons,"* https://resilienteducator.com/classroom-resources/benefits-of-teaching-steam/ accessed 1/16/2021.
9. NSF Award Abstract, *"SCC: I4all (Interests for All): A Smart Socio-Technical Infrastructure to Identify, Cultivate, and Sustain Youth STEAM Interests in a Diverse Midsized American City,"* Award Abstract #1831685, https://www.nsf.gov/awardsearch/showAward?AWD_ID=1831685&HistoricalAwards=false accessed 1/16/2021.
10. NSF Award Abstract, *"Scaling up an Innovative STEAM (Science, Technology, Engineering, Arts, & Mathematics) Learning Environment through Two Partnership Models with Industry and Schools,"* Award Abstract #1657438 https://www.nsf.gov/awardsearch/showAward?AWD_ID=1657438 accessed 1/16/2021.
11. NSF Award Abstract, *"Collaborative Research: Advancing Professional Development and Broadening Participation in Informal Science Learning via the Integration of the Science and Art of Color,"* Award Abstract #1713276, https://www.nsf.gov/awardsearch/showAward?AWD_ID=1713276&HistoricalAwards=false accessed 1/16/2021.
12. NSF Award Abstract, *"Collaborative Research: Project STEAM: Integrating Art with Science to Build Science Identities among Girls,"* Award Abstract #1223363 https://www.nsf.gov/awardsearch/showAward?AWD_ID=1223363&HistoricalAwards=false accessed 1/16/2021.
13. Wonder Women Tech, https://wonderwomentech.com/ accessed 1/16/2021.
14. C. Tzou, P. Bell, M. Bang, R. Kuver, A. Twito and A. Braun. "Building Expansive Family STEAM Programming through Participatory Design Research." *Reconceptualizing Libraries: Perspectives from the Information and Learning Sciences*, pp. 72-93. 2018
15. P.T. Sullivan, L.C. Conner, M. Guthrie, S. Pompea, B.K. Tsurusaki, and C. Tzou, "Colorful Chemistry." *Science and Children*, 54(8), pg. 34. 2017
16. C. Tzou, L. Conner, S. Pompea, and M. Guthrie, "Colors of Nature: Connecting Science and Arts Education to Promote STEM-related Identity Work in Middle School Girls." *International Society of the Learning Sciences* Boulder, CO. 2012
17. J.C. Oh, J.H. Lee, J.A., Kim, and J.H. Kim, "Development and Application of STEAM Based Education Program using Scratch-focus on 6th Graders' Science in Elementary School." *The Journal of Korean Association of Computer Education*, 15(3), pp. 11-23. 2012.
18. D. Henriksen, "Full STEAM Ahead: Creativity in Excellent STEM Teaching Practices. *The STEAM Journal"*, *1*(2), pp. 15. 2014

19. B.K. Tsurusaki, C. Tzou, L.D. Conner, and M. Guthrie, M. "5th–7th Grade Girls' Conceptions of Creativity: Implications for STEAM Education." *Creative Education*, *8*(02), pp. 255-271. 2017
20. B. Magerko, J. Freeman, T. Mcklin, M. Reilly, E. Livingston, S. McCoid, and A. Crews-Brown. "Earsketch: A Steam-based Approach for Underrepresented Populations in High School Computer Science Education." *ACM Transactions on Computing Education (TOCE)*, *16*(4), pp. 14. 2016
21. J. Vanscoder, "3D Printing as a Tool for Teaching and Learning in STEAM Education." *Society for Information Technology & Teacher Education International Conference*, Association for the Advancement of Computing in Education (AACE), pp. 188-191. March 2014
22. S. Pauls. "Biomimicry a "Natural Lesson" in STEAM." *The STEAM Journal*, *3*(1), pg. 33. 2017
23. C. C. J. Chung. "Integrated STEAM Education through Global Robotics Art Festival (GRAF)." *2014 IEEE Integrated STEM Education Conference*. IEEE, pgs. 1-6. March 2014.
24. A. Bandura "Self-efficacy: The exercise of control." *The nature and structure of self-efficacy*. W H Freeman/Times Books/ Henry Holt & Co. 1997.