The Evolution of the Metallurgical Engineering Junior Design Course

Dr. Katrina J Donovan, South Dakota Mines

Dr. Katrina Donovan received her B.S. degree from South Dakota School of Mines and Technology in 2010. She received her Ph.D. in Materials Science from Oregon State University in 2019, studying the microfluidic investigations of capillary flow and surface phenomena in porous polymeric media for 3D printing. She worked for multiple years at HP, Inc. in the 3D Printing Department. She is currently a Lecturer at South Dakota Mines and Research Scientist at Dragon Materials, LLC, an engineering consulting firm. Her research involve experimental design and technique development for soft materials, complex fluids, and surface phenomena. She a wide range of experience in rheological, thermal, structural, and molecular characterization that she leverage fundamentally for academic purposes as well as industrially for applications. As her three patents can show, designing experiments and creating novel techniques to answer fundamental questions that drive applications and technology forward captivates her interest. She has volunteered countless hours to the community, led multiple STEM Education grants that engage the local K-12 schools of the Pine Ridge Indian Reservation, and has submitted proposals that engage even more tribal communities.

Dr. Jon J Kellar, South Dakota Mines

Kellar is the Douglas Fuerstenau Professor of Materials and Metallurgical Engineering at the SD School of Mines and Technology. He has been on the faculty since 1990, and in 1994 was selected as an National Science Foundation Presidential Faculty Fellow a

Dr. Michael West, South Dakota School of Mines and Technology

Dr. Michael West is an associate professor and head of the department of materials and metallurgical engineering at the South Dakota School of Mines and Technology (SD Mines). Between 2008-2013, he served as site director of the NSF I/UCRC Center for Fri

Dr. Stuart D. Kellogg, South Dakota School of Mines and Technology

Stuart Kellogg is Professor and Head of Industrial Engineering at SDSMT. His discipline research areas of interest include applied probability and stochastic models but his passion over the last two decades rests with STEM Education and STEM Education re

Haley Armstrong, South Dakota Mines

NSF IUSE: The Evolution of the Metallurgical Engineering Junior Design Course

The Metallurgical Engineering junior design sequence at South Dakota Mines underwent an evolution that started in 2022 with the advent of an NSF Improving Undergraduate STEM Education (IUSE) grant which supported a new program called Art + Engineering (A+E). The A+E program goal was to integrate creative components into the curriculum to increase innovation and entrepreneurial mindsets within our students.

This paper focuses on the evolution and assessment of the junior design course over a five-year period. The first two years focused on the indigenous minerals and processing necessary to create simple viable ceramic products from the Black Hills. This was followed by more advanced designs that include metals, minerals, and glass used to create functional musical instruments. These instruments are played by undergraduate students in the annual musical concert called “The Battle of the Bands”.

In the course, the material and specific design guidance are open-ended. From multiple years of external assessment, the A+E leadership team learned that the student cohorts reported more confidence with the approach to the design process. Beginning in 2024 all design projects centered around musical instruments, not generally an area that engineering students would be comfortable with. Students reported that laboratory and faculty resources were sufficient for the design process. Students uniformly stated that the junior design experience was good preparation for the forthcoming senior design experience and communicated that they gained confidence with the collaborative design process.

Evaluation data included student reflections, Small Group Instructional Diagnoses (SGIDs), rubric-based faculty assessment, and external evaluator feedback collected across multiple course iterations.

1. Introduction

This paper documents the evolution and assessment of a junior-level metallurgical engineering design course supported by an NSF Improving Undergraduate STEM Education (IUSE) Art + Engineering (A+E) initiative. This grant supported the creation of the *Art + Engineering (A+E)* program, which sought to integrate creative practice into engineering curricula to promote innovation, curiosity, and entrepreneurial mindset development [1], [2]. Prior A+E efforts demonstrated that incorporating artistic processes into materials engineering courses can positively impact student engagement, confidence, and learning [3]. Across four years (2022–2025), the course transitioned from place-based ceramic fabrication to interdisciplinary musical instrument design. Evaluation data, including rubric-based assessments, student reflections, SGIDs, and external evaluator feedback, indicate increased student confidence with open-ended design and improved preparation for senior capstone experiences.

2. Course Context and Methods

2a. Course Background

Historically, MET 352: Principles of Metallurgical Engineering Design consisted of multiple short design modules led by a single faculty member. This structure was later revised to a semester-long team design project supported by two faculty members. Following the NSF IUSE award in Spring 2022, the course was substantially redesigned to align with A+E goals and incorporate higher levels of faculty engagement and interdisciplinary creativity. Students were organized into teams, with each assigned at least one faculty mentor. Design problems were intentionally open-ended, with minimal prescriptive constraints on materials or final form. This approach reflected A+E pedagogical strategies emphasizing innovation, community engagement, and authentic design experiences [2], [4]. To support student success in this open-ended design environment, instructional scaffolding evolved to include milestone-based check-ins, structured feedback through faculty-developed rubrics, and increased mentor interaction throughout the semester.

2b. Assessment Approach

The evolution of MET 352 was informed through an evidence-informed, mixed-methods assessment approach aligned with the goals of the NSF IUSE A+E initiative. Assessment data were collected across multiple course iterations (Spring 2022–Spring 2025) to capture student perceptions, design performance, and preparedness for subsequent senior design experiences. Given the instructional focus of the course and the iterative nature of the redesign, assessment emphasized formative and descriptive measures rather than controlled experimental comparisons.

Several sources of assessment evidence were used: *Faculty-Developed Design Rubrics, Student Reflections, Small Group Instructional Diagnoses (SGIDs), External Evaluator Feedback*, and *Faculty Observations and Project Reviews*. Assessment emphasized convergence across multiple qualitative data sources rather than reliance on a single instrument, as seen in Table 1. Claims presented in the Results section are supported by at least two independent data sources.

As part of the NSF IUSE grant, external evaluators periodically reviewed course artifacts, student work, and assessment practices. Their feedback informed refinements to project scope, scaffolding, and mentoring structures. Faculty-developed design rubrics and representative course materials are available from the authors upon request to support adoption or adaptation by other programs.

Table 1: Assessment Data Sources Used to Inform Course Evolution (2022–2025).

Source [Date]	Purpose and Confirmation	How It Informed Results
Faculty-Developed Design Rubrics [Spring 2022–2025]	Evaluated engineering rigor, materials selection, feasibility, iteration, teamwork, and communication	Documented increased technical ambition and improved integration of engineering justification over time; informed claims about design maturity and preparedness
Student Reflections (Spring 2022–2025)	Captured student perceptions of open-ended design, creativity vs. engineering balance, confidence	Supported claims related to reduced discomfort with ambiguity, increased confidence, and perceived readiness
SGID [Spring 2025]	Provided structured, aggregated feedback on course strengths, challenges, and relevance	Corroborated reflection trends; supported claims of value for senior design preparation and teamwork skill development
External NSF IUSE Evaluator Feedback [Annually]	Reviewed course artifacts, assessment practices, and alignment with A+E goals	Guided iterative refinements to project scope, scaffolding, and mentoring; strengthened validity of longitudinal observations
Faculty Observations and Project Reviews [Throughout semester]	Identified recurring student challenges, team dynamics, and technical growth	Informed interpretation of reflection and SGID data; contextualized changes in project complexity and outcomes

Assessment data were analyzed qualitatively to identify recurring patterns, points of friction, and areas of growth across cohorts. While formal coding schemes were not employed, multiple instructors independently reviewed reflections and SGID summaries to ensure consistency in interpretation. Claims made in the Results section are grounded in convergence across at least two assessment sources (e.g., reflections and SGIDs, or rubrics and evaluator feedback).

3. Results

3a. Spring 2022: Initial Implementation

The initial implementation of the redesigned junior design experience in Spring 2022 revealed both strong student engagement and notable challenges. Students recognized the novelty and value of an open-ended, creativity-driven project but frequently expressed uncertainty regarding expectations and evaluation criteria. SGID feedback and faculty observations indicated that students without prior exposure to ceramics or artistic fabrication initially struggled to translate metallurgical knowledge into unfamiliar material systems, sometimes characterizing the project as “more artistic than engineering.” In response, instructors revised the design rubric to more explicitly foreground engineering justification, materials processing

Fig. 1. (a) A slip casted model of the school mascot "Grubby".
(b) Ceramic slip casted product from a 3D scan of the Metallurgical Engineering Departments Head.

decisions, and feasibility. Faculty also began explicitly framing ambiguity as a core feature of professional engineering design rather than a lack of structure. Despite early discomfort, reflections at the end of the semester indicated increased student comfort with open-ended problems and greater appreciation for iterative design. Fig. 1(a) and 1(b) illustrate representative ceramic artifacts from this first iteration, demonstrating successful translation of conceptual designs into fabricated components despite limited prior experience.

3b. Spring 2023: Improved Scaffolding and Technical Grounding

By Spring 2023, assessment evidence indicated improved alignment between creativity and engineering rigor. Student reflections more frequently referenced prerequisite coursework (e.g., mineral processing and applied ceramics) as essential scaffolding that enabled technically defensible design decisions. Concerns about the project being "overly artistic" were less prevalent, and students more consistently described the work using engineering language related to materials selection, processing constraints, and performance trade-offs.

Fig. 2. Three perfectly tuned ocarinas capable of playing Twinkle Twinkle Little Star were made from 100% Black Hills minerals.

Faculty mentorship supported technically grounded innovation and iterative risk-taking. Fig. 2 shows examples of tuned ceramic ocarinas fabricated entirely from locally sourced minerals, illustrating successful integration of materials processing, dimensional control, and functional performance. While teamwork challenges persisted, students increasingly characterized these challenges as representative of professional engineering practice rather than as shortcomings of the course design.

3c. Spring 2024–2025: Mature Design Implementation

By Spring 2024 and Spring 2025, all design projects centered on musical instruments, including cast horns, ceramic drums, and redesigned metal triangles. While some teams perceived stronger connections to metallurgical fundamentals than others, most students reported gains in creativity, collaboration, and confidence. Across these cohorts (~44 students total), SGID data and student reflections consistently indicated that MET 352 was perceived as strong preparation for senior capstone design. Students reported increased confidence navigating ill-defined problems, managing team dynamics, and communicating technical decisions to both technical and non-technical audiences. While some teams reported stronger perceived connections to metallurgical fundamentals than others—depending on instrument type—most students described gains in creativity, collaboration, and design confidence.

Fig. 3 illustrates a set of bronze carillon bells cast by student teams. As noted in faculty rubric feedback, this artifact exemplifies the maturation of the design experience, requiring coordinated alloy selection, mold design, casting execution, dimensional control, and acoustic tuning. Rubric-

Fig. 3. Five cast carillon bells in a variety of notes.

based assessments further indicated that the technical ambition and level of integration demonstrated in these projects exceeded those observed in earlier iterations of the course.

Workload intensity was identified as a concern in SGID feedback; however, students consistently indicated that the level of effort was appropriate given the perceived value of the experience and its relevance to professional preparation.

4. Alignment with ABET Student Outcomes

ABET Outcome 2 (Engineering Design): Students applied engineering design principles to develop materials-based solutions under open-ended constraints, consistent with established definitions of engineering design as iterative and ill-structured [5], [6].

ABET Outcome 3 (Communication): Students communicated design intent and technical justification through reports, presentations, and demos to both technical and diverse audiences.

ABET Outcome 5 (Teamwork): Team-based design, faculty mentoring, collaboration, and goal-setting, consistent with best practices in team-based engineering education [7].

ABET Outcome 7 (Lifelong Learning): Students independently acquired new knowledge (e.g., acoustics, ceramics, glass processing) and applied it to unfamiliar contexts, reflecting lifelong learning behaviors [8].

5. Discussion

Collectively, these results indicate that iterative scaffolding, clearer assessment alignment, and a consistent yet open-ended design context can improve student confidence and preparedness without diminishing creativity. The evolution of MET 352 demonstrates how interdisciplinary, creativity-driven frameworks can be effectively embedded within a junior-level engineering design course. Initial student discomfort with ambiguity mirrors findings from prior A+E curricular interventions [3], yet longitudinal assessment shows that repeated exposure, improved scaffolding, and structured mentoring lead to increased confidence and acceptance of ill-defined problems [2]. The progression from ceramic products to functional musical instruments reflects a shift toward authentic, public-facing design experiences, aligning with broader project-based learning literature [9], [10]. Importantly, the course redesign strengthened alignment with professional engineering practice by emphasizing teamwork, communication, and self-directed learning. The program has extended beyond the classroom, as student-designed instruments have been selected for use by the Black Hills Symphony Orchestra, a large ensemble of approximately 90 musicians, in their February 2026 concert. Depending on the composition, instruments developed by student teams were incorporated into the performance.

6. Conclusions

MET 352 evolved from a traditional junior design course into a mature, interdisciplinary design experience that integrates creativity with metallurgical engineering rigor. Through iterative refinement informed by student feedback and A+E pedagogical research, the course enhanced student confidence, creativity, and readiness for senior design. This work contributes to the growing body of evidence supporting the integration of art-inspired, open-ended design experiences within core engineering curricula.

IRB Statement: This study was reviewed by the Institutional Review Board of South Dakota State University and determined to be exempt from further review under Exemption Category 2 as outlined in 45 CFR 46, §104(d). The approved exemption protocol number is IRB-2106010-EXM.

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