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Work in progress: Coloring Outside the Lines - Exploring the Potential for Integrating Creative Evaluation in Engineering Education

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Work-in-progress:
Coloring Outside the Lines - Exploring the Potential for Integrating Creative Assessment in Engineering Education

Abstract

Extant cultures within academic institutions that educate and train the next generations of STEM professionals tend to privilege long-held majority perspectives of knowing, thinking, and doing in science and engineering. To more intentionally recruit and include diverse groups of students into our educational programs, it is imperative that we develop and adopt unique pedagogical and assessment approaches that move beyond didactics, leverage experiential learning, and embrace a variety of student backgrounds and identities. In this paper, we demonstrate how visual methods-based assessments can serve as an impactful alternative to more traditional forms. We start by introducing three examples currently used in STEM curricula, and then by describing how these assessments promote autonomy and creativity as students make meaning of STEM and of themselves as STEM professionals. We conclude the description of each assessment example by identifying key considerations for STEM instructors when attempting to implement such assessments in their own contexts.

Introduction

STEM education plays a critical role in maintaining the nation's position as a global leader in technological innovation. Such innovation is necessary for addressing increasingly complex issues such as global warming and cybersecurity and requires a national workforce that consists of diverse perspectives. Yet, extant cultures within the institutions that educate and train the next generations of STEM professionals tend to privilege long-held majority perspectives of knowing, thinking, and doing in science and engineering. Such cultures are perpetuated through course assessments, which students use to define and make meaning of their major (Stevens et al., 2014; Yoon et al., 2019). Therefore, assessments serve not only as tools to assess student content knowledge, but inherently communicate to students what STEM is and who belongs in these fields (Cech & Sherick, 2015; Rafaeli & Worline, 2000; Struyven et al., 2005; Villanueva et al., 2018).

Prior research shows that although students in engineering may value diversity-focused education, there is a misalignment between their expectation and need. Students trained as a result of traditional approaches to engineering education expect facts and figures presented for memorization, rather than situations and authentic interactions encouraging deep dives, critical thinking, and engagement (Lee, et.al., 2021). To more intentionally recruit and include diverse groups of students into our educational programs, it is imperative that we develop and adopt unique assessment approaches that move beyond didactics, leverage experiential learning, and embrace a variety of student backgrounds and identities. Therefore, the purpose of this paper is to explore the potential of employing creative visual methods as a progressive assessment approach in STEM learning. We contend that creative visual methods-based assessments can be used to promote participation among students from minoritized communities by disrupting traditional forms of assessment that tend to emphasize the technical aspects of science and engineering while de-emphasizing the personal and the social. Related prior work demonstrates that creative visual methods such as formulating storylines (e.g., Battel, et.al., 2021 and Mandala, et.al., 2022) creating comics (e.g., Bhaduri, et. al., 2021 and Totman, et.al., 2022), sketching and visualizations (e.g., Ozkan, et.al., 2018) simultaneously embrace the personal, social, and technical by making educational spaces for students to conceptualize, interpret, communicate, and practice science and engineering in ways that afford an opportunity to be most conducive to students' lived experiences.

In this paper, we demonstrate how visual methods-based assessments can serve as an impactful alternative to more traditional forms by introducing three examples currently used in STEM curricula. We start by introducing three examples currently used in STEM curricula, and then by describing how these assessments promote agency and consequently, creativity, as students make meaning of STEM and of themselves as STEM learners and professionals. Scoping this paper, we do not aim to question the effectiveness or validity of traditional evaluation methods as part of this iteration; rather, we present examples in hope of inspiring STEM education administrators, scholars, and practitioners to embrace innovative evaluation methods for diversifying the STEM workforce and pushing the bounds of technological teaching and learning in our engineering classrooms.

Background

Traditional assessment methods in STEM are dominated by numerically-driven techniques that can limit or convolute the perceived effectiveness of educational interventions on student learning. For example, one common way to assess students' understanding of basic statics concepts, such as equilibrium, is to have students generate mathematical equations that depict the concept. However, as course and curricular outcomes become more complex, there is a need for increased flexibility and innovation in assessment approaches that allow instructors to improve student learning with less resources. While prior scholarship specific to STEM assessments has remained largely limited, scholarship on pedagogy has been extensively explored. Namely, approaches such as critical pedagogy and culturally-responsive pedagogy provide unique opportunities to develop and implement assessments that not only contribute to innovative teaching practice, but also support broadening participation in STEM (Olayemi and DeBoer, 2021).

The number of minoritized students (e.g., racially and ethnically underrepresented students, women, individuals with disabilities) going into STEM fields have remained consistently low (Lichtenstein et al., 2014; NCSES, 2021; Roy et al., 2020). To address this issue, a variety of national and localized initiatives have called STEM educators to develop and incorporate pedagogical and assessment approaches that engage students from minoritized backgrounds and foster more equitable pathways into these fields (Bevan, Barton, & Garibay, 2018; Saw, 2020). Although these efforts have made strides in how different student groups are recruited and retained in STEM, traditional assessment mechanisms still counter the intention of broadening participation in STEM fields. If the goals of federally funded programs are to attract diverse students to spur innovation, critical thinking, and creativity, then assessments must reflect, value, and emphasize the diverse assets of these students (Mejia et al., 2018; Minichiello, 2018).

Visual Methods for Assessment Design and Visual Critical Pedagogy

Visual methods rely on participant-constructed images as data sources used instead of or alongside verbal/written data (Shannon-Baker & Edwards, 2017). These images are often used to convey lived experiences and perspectives through an alternative means of expression (Prosser, 2007). While visual methods are a growing practice in social research, the potential for using this approach as a means of student assessment is less common. However, we argue that visual methods can not only provide a useful frame for instructors to develop assessments that examine what students are learning, but also make space for students to articulate to what extent they understand and relate to content in ways that are most conducive to them. This use of visual methods as an assessment tool aligns with previous applications of visual methods-based assessment in fields such as student affairs and management education (Rohn, Arnold, & Martini, 2022; Ward & Shortt, 2013; Su, 2012). While the applications of these methods may have been to measure different constructs, rationales for applying visual methods as educational measurement tools share many commonalities. Most prevalent of these commonalities are using visual methods to blend the cognitive (content and concept focused aspects of learning) and affective domains (feelings, emotions, and attitudes of learning) (Ward & Shortt 2013).

Critical pedagogy examines the role in which school environments contribute to sustaining the social dynamics of general society. As McLaren (2019) states, the primary function of critical pedagogy is to "*...critique, expose, and challenge…"* the ways in which learning environments impact the political, social, and cultural lives of learners. Moving beyond narrative and dialogue-dependent practices, some proponents of critical pedagogy have criticized the reliance on dialogue as it can sometimes be insensitive to different forms of cultural communication, the varying values of members of different groups, and the historical conflicts that have omitted marginalized and oppressed communities from public and educational forums (Burbules, 2002). As such, visual critical pedagogy emerged as a framework through which visuals are integrated with pedagogical practices to enhance the representation and visibility of learners while challenging practitioners to be critical designers, beholders of deep knowledge of the system, and hold a profound understanding of the competencies needed to survive in the aforementioned system (Gil-Glazer, 2020). Put more simply, visual critical pedagogy engages the exploration of critical pedagogy through a visual lens through which both learner and educator can engage the complexities of culture, society, and self in educational settings.

Three Examples of Visual Methods Embedded into STEM Education Assessment

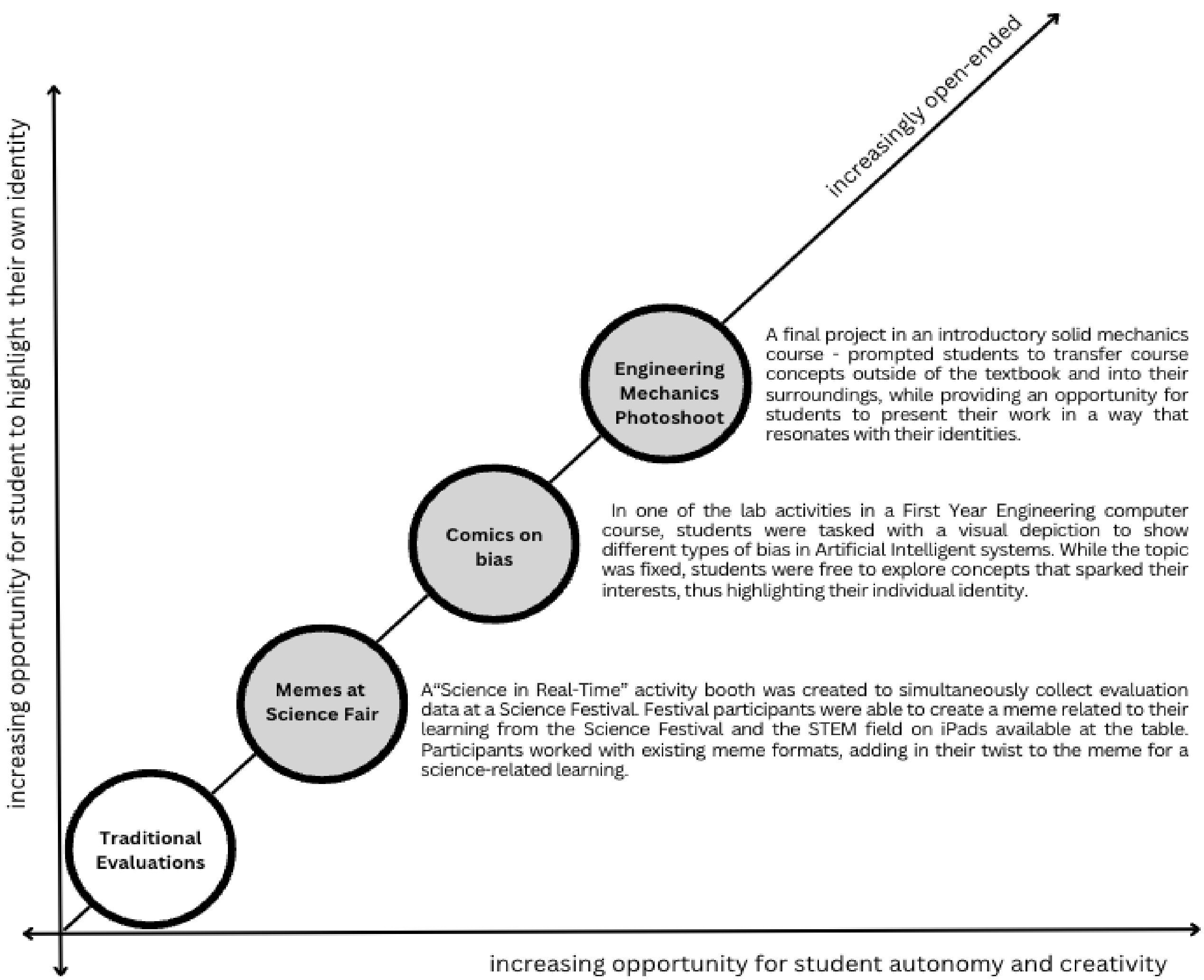

Figure 1: Illustration of case studies highlighted, plotted against increasing opportunity for student autonomy and creativity vs. increasing opportunity for students to highlight their identity.

In this paper we introduce three examples of visual assessments that have been implemented in a science festival and two engineering courses. We posit that increasing opportunities for student autonomy and consequently, creativity can encourage students to integrate their sense of self into thinking, knowing, and doing STEM. With the infusion of pedagogy grounded in arts-informed visual practices, the changing tides of teaching and engagement practices in STEM fields necessitates a similar shift in the evaluation methods leveraged to measure them and the assessment of the students participating in them. Designed to encourage learners to engage in critical pedagogy through visual arts-informed methods, the cases put forth in this paper illuminate how STEM learning environments have long progressed beyond didactic approaches moving towards practices that not only allow for critical thinking but also critical agency in learners.

These three case studies are presented progressively along the model presented in Figure 1 to showcase how the use of visual methods can allow for student autonomy and creativity within assessment processes. As illustrated in Figure 1, our three examples vary in extent of being open-ended with their prompts (e.g., focused on a single topic within a course, versus exploring a course topic more broadly). Each case study begins with an introduction case, the problem it tackles, and an overview of results. It then provides details custom to that case studies circumstances before providing a structured summary the identifies the visual method, its benefits, use case, and additional considerations.

Example One: Memes as a Barometer for Science Festival Success

Our first case describes a “Science in Real-Time” activity booth that was created to simultaneously collect evaluation data on the Virginia Tech Science Festival while also serving as an exhibit on the process of collecting and analyzing data. Science Festival evaluation has a known issue with regard to accurate representation of target audience and actual attendees; older, higher wealth, caucasians are typically over-represented when current festival evaluation methods are used. The preliminary data analysis of both the work products and phenotyping of those who participated supports the idea that event organizers can effectively use memes as a data source to gain insights into visitor experiences and perceptions while simultaneously ensuring more accurate representation in the evaluation process at a STEM engagement event.

Our primary objective was to develop a proof of concept application for incorporating memes (participant-produced artifacts) as a way to collect data at large-scale events in formal and informal learning spaces that will draw a more diverse set of opt-in participants. In the case of the meme activity, three iPads were set up with a free meme-creator app and allowed access to the internet for participants to search for their own images. Using these iPads, festival participants were able to create a meme related to their learning from the Science Festival or the STEM field in general on iPads. After the event, the created memes, which were saved in the app, were examined as was the phenotyping data collected at the main entrance of the festival and on each participant at the meme station. This phenotyping provided contextual information to compare who was attending the festival itself and see how well the evaluation participants represented the target population.

The use of attendee or participant-created memes as a data source can be an impactful alternative to traditional forms of assessment. Using a meme creation station as data collection effort for event evaluation offers several innovative features that distinguish it from traditional forms of assessment. It can provide a more engaging and accessible method of evaluation. By enabling visitors to create and share memes related to the event, the station can capture a diverse range of perspectives and experiences in a playful way, which can be an impactful alternative to traditional forms of assessment.

One of the key benefits of the meme creation station is its ability to gain the perspective of the target audience. By gathering feedback from a broader range of participants, event organizers can gain more accurate insights into visitor experiences and perceptions, which can inform future event planning and development that aligns with the target audience perspective. The preliminary results of the meme analysis show that meme creation has great potential as a way to explore participants thinking, particularly for demographic groups that have a history of non-participation (teenagers and historically marginalized populations).

Figure 2: Examples of memes created.

In summary, the visual method used in this case study is the creation of memes by participants as a form of data collection and evaluation. The benefits of using a meme creation station as a data collection effort for event evaluation include its ability to provide an engaging and accessible method of evaluation, capture a diverse range of perspectives and experiences in a playful way, and gain the perspective of the target audience. The use case presented is for large-scale events in formal and informal learning spaces, providing a more accurate representation of the target audience in the evaluation process. Considerations for this method include the need for technical resources to set up the station, ensuring internet access for participants, and determining appropriate data analysis techniques for memes as a form of data. This method offers an opportunity for student autonomy and creativity while highlighting their identity within the evaluation process in ways that traditional evaluation methods do not.

Example Two: Understanding Bias through Creating Comics

Our second case is a lab activity in a first-year engineering computing course that has undergone a revision to teach engineering as a sociotechnical field. There are three sociotechnical tenets guiding the revision of this course - (1) Technology is not inevitable and does not always improve society, (2) Data, algorithms, and technology are neither neutral nor objective, and (3) The effects of technology are unevenly felt across groups of people and more-than-human actors. Aspects of this NSF-funded project have been studied elsewhere (e.g., Ozkan & Andrews, 2022).

In one of the lab activities in this course, students were tasked with a visual depiction to show different types of bias. The details of this activity and resultant student visual depictions will be discussed in this section. The lab for this week consisted of a 75 minute course block with a reading and question prompts assigned for after the lab period. In the lab, the first activity for students was to discuss and define the word bias with their peers. At this point in the semester, students have not encountered a formal statistical definition of bias in data. In the next step, students were tasked to read a comic inspired by Dr. Joy Buolamwini's work on gender shades (Buolamwini & Gebru, 2018). This comic was drawn by Vreni Stollberger and published in NPR as, "How a computer scientist fights bias in algorithms" (Cala, Stollberger, Johnson, 2022). After reading through the comic, students discussed their understanding of alleged neutrality and power in small groups to build on their previous discussions. Students were then introduced to different types of bias in data–non-representative data bias and representative data bias but with historical social bias. These types of bias are also detailed in an interactive article titled, The Myth of the Impartial Machine (Feng & Wu, 2019). After some peer discussion connecting these types of bias to their previous peer discussions, students were tasked with choosing a type of bias to depict in a comic.

We provide an example from each in Figures 3 and 4 below.

In summary, the visual method used in this case study is the creation of a visual depiction by students, in this case, comic strips, to show different types of bias in data. The benefits of this method include engaging students in critical thinking about socio -technical issues, such as how technology may not always improve society, how data, algorithms, and technology are neither neutral nor objective, and how the effects of technology is unevenly felt across groups of people and more-than-human actors. The use case presented is for a first-year post-secondary STEM course. Considerations for this method include the need for guidance in creating effective visuals that convey complex concepts and ensuring that students understand the importance of accurately representing sociotechnical issues in their visual depictions. This type of method offers a strong opportunity for student autonomy and creativity while highlighting their identity within the assessment.

Figure 3: Example of comic on Representative Data Bias (and implications for design)

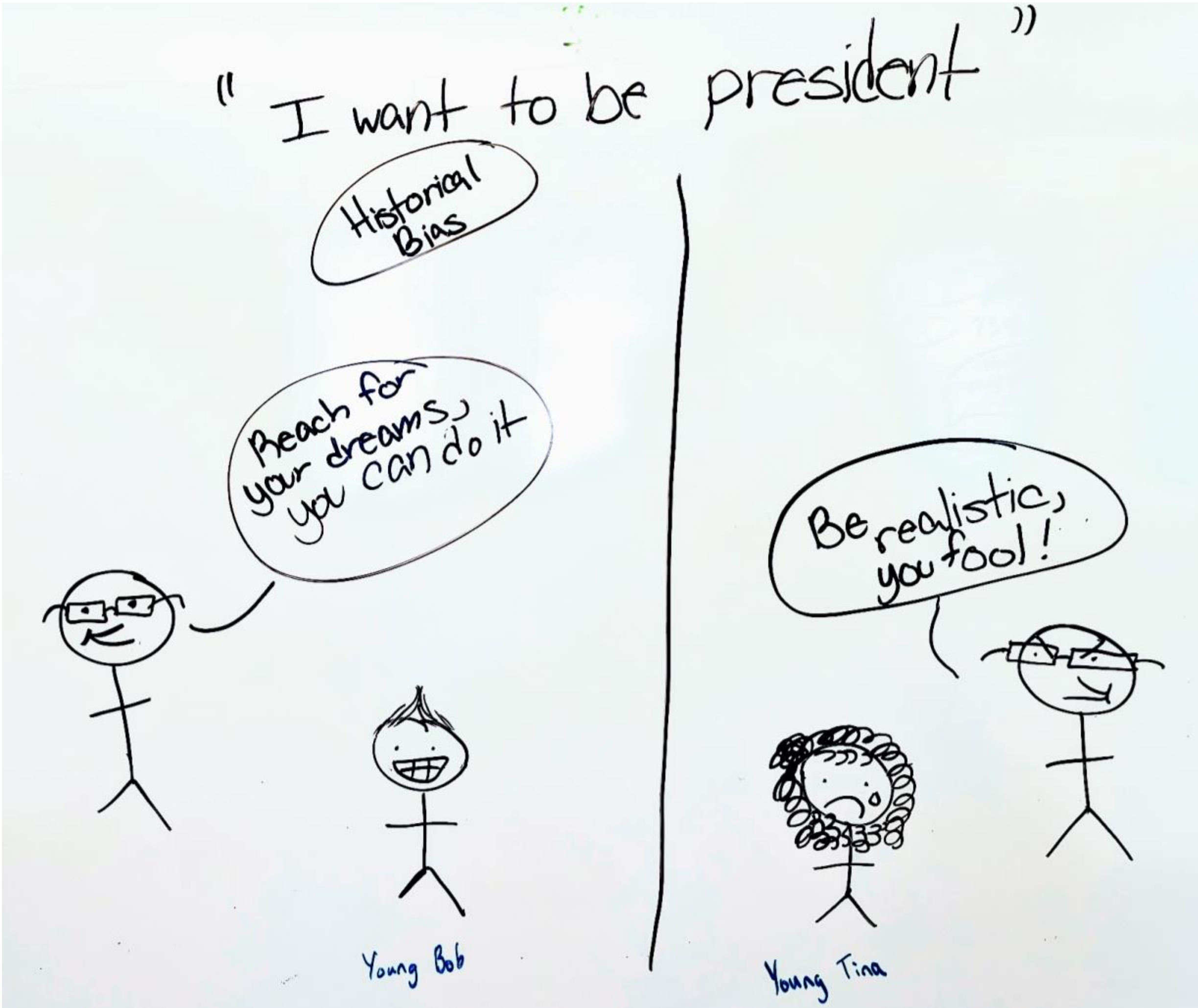

Figure 4: Example of comic on Historical Social Bias.

Example 3: Fashion in Engineering Mechanics Photoshoot

Our third example is a final project embedded within an introductory solid mechanics course for second-year undergraduate engineering students. Like Statics (Venters et al., 2018), this course requires students to make the notoriously challenging connection between understanding the course's core concepts (e.g., stresses, strains, etc.) and the mathematical procedures used to model them. Because conceptual understanding is assessed using the correctness of mathematical calculations, students tend to focus on these calculations and often leave the course without fully understanding its underlying concepts (Venters et al., 2018). To address this issue, an assessment was designed to (1) enhance conceptual learning by prompting students to transfer concepts from the textbook into their physical surroundings, and (2) promote student creativity and autonomy by allowing them to present their work in a way that resonates with their skills and interests.

Student groups, consisting of 4-5 students, were tasked with conducting a photo shoot in which each group was required to identify, photograph, and calculate internal normal and shear stresses for a structure that is loaded in compression, tension, direct shear, torsion or twisting, and behaves as a beam. To accompany their photos, students were also required to write a paragraph describing the rationale for choosing the structure as well as its material, dimensions, and location. Students were also tasked with identifying and listing relevant assumptions to mathematically model structural behavior using the procedures and concepts discussed in class. For structures that students could not observe close-up (e.g., a beam supporting a bridge deck), they needed to research probable materials, structural dimensions, and material properties (e.g., the modulus of elasticity, E). Students were allowed to submit their final project in any format they chose as long as it was presented as a single, cohesive group project, not a collection of separate individual analyses. Each project was assessed on five criteria: completeness, cohesion, peer evaluation/contributions of team members, creativity, and correctness.

In this case, we highlight the work of one student team who decided to submit their project as a fashion magazine and established the 'firm' name of High End Engineering. A magazine spread from their final project submission is shown in Figure 5. Each required project component is labeled in Figure 5 using the following scheme: (1) image of student with structure, (2) free body diagram (FBD) of the structure under consideration (in this case, a bolt holding a train track together), (3) structure description, (4) list of assumptions, and (5) stress calculations. All photos, sketches, text, and layouts were completed by student team members.

In their project submission, each member of the student team not only identified and analyzed their chosen structures, but they also brought other personal interests into the work. For example, Emily showcases her passion for ballet and dancing as captured in each photo, Krissy integrated her interests in graphic design and media art in the spread design and layout, Rachel leveraged her love of writing to create a pun-laden description of the structure. In another example not shown here, Kaitlyn connects her passion for physical fitness by identifying a structure in the university gym that she observed while working out. Together, these students used this project as an act of advocacy for women in engineering. In their "Letter from the Editors" section, they state:

> *A stigma that has been long held in the scientific world shall stand no longer. Math can be pretty and displayed with an aesthetic outside of times new roman (it's fine but it's boring). This creates a stuffy barrier between the world of art and the world of STEM. The mission of ENGR magazine is that by breaking down these walls, science can have a new place in our world. Women and girls can see that being in science does not limit femininity and that femininity does not limit science. It never has. Lastly, we would like to thank Dr. Cassandra McCall for her contributions and inspiration behind the project. Thank you for giving us a space to learn and be creative!* [sic, emphasis original]

Figure 5: Spread from High End Engineering fashion magazine analyzing a structure in direct shear (used with permission from the student group).

While the advocacy portion of the project was not a requirement imposed on the students by the instructor, this team positioned the project as an opportunity to not only demonstrate content knowledge and interests, but to advocate for the inclusion of women in engineering and challenge traditional conceptions of engineering as a masculine space.

In summary, implementing this type of assessment requires a form of structured flexibility in that the instructor establishes clear guidelines for project requirements and expectations without stifling opportunities for student creativity and autonomy. Project requirements ensure that students' visual presentations include necessary technical information and calculations, whereas allowing options for visual presentation ensures that students can access and use the tools necessary to effectively communicate their ideas. Rather than separating technical content from the social and personal aspects of students, this project provides the space for students to merge their personal and professional selves by communicating engineering concepts and procedures using their own places, things, and voices.

Discussion

STEM education is currently facing challenges in engaging minoritized and marginalized communities (Taylor, et. al., 2017). Of particular interest is that traditional pedagogical practices grounded in comparing, ranking, and classifying students contribute to the dehumanization of learners, especially those from underrepresented and marginalized communities (Broom, 2015). Moreover, reducing students to empty vessels for knowledge diminishes their culture, lived experience, and identity, further marginalizing them (Broom, 2015). These trends can be even more detrimental to minoritized communities in STEM education as they can exacerbate feelings of exclusion. Thus, there is a need for innovative approaches to STEM education that promote inclusivity, engagement, and empowerment of minoritized and marginalized communities.

We seek ways to help historically marginalized populations build connections between who they are and their place in STEM. Integrating creative visual methods in STEM classrooms offers a unique opportunity to engage students by increasing their choice and agency, so that they are motivated to approach learning in the classrooms similar to pursuing talents and hobbies outside of engineering (Bhaduri and Matusovich, 2017). The examples presented in this paper illustrate some practical ways to integrate creative visual methods in STEM education informed by critical pedagogy. More importantly, the three cases offer vital insights into how and why infusing innovative visual methods in STEM pedagogy provides a model of evaluation that aligns with the learning objectives of the respective courses while providing an evaluation model that empowers learners.

To move this opportunity forward, we have identified two primary areas for further exploration of visual methods-based assessment and evaluation in STEM education. First, a more concrete comparison to traditional methods regarding effectiveness and validity is necessary. The second area is more internalized, where we further explore the benefits and consequently, limitations of visual methods in assessment and evaluation, particularly to identify what circumstances best fit specific visual method options. More generally, future research should focus on developing effective *and ethical* practices for integrating visual methods in STEM education assessment to promote inclusivity, engage learners, and empower underrepresented and marginalized communities. Such research can then inform future pedagogical practices, curriculum design, evaluation plans, and resource allocation to contribute to a more inclusive and diverse STEM learning environment and resultantly, the future STEM workforce.

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