"Making" a Bridge: Critical Making as Synthesized Engineering/Humanistic Inquiry

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Introduction

Over the past decade, considerable attention has been devoted to "making" practices: celebrating the potential of making to reinvigorate the US manufacturing base and economy; highlighting the democratization of technology development as ordinary people directly create the products they will use; and anticipating the possibility of a whole new generation of students primed for science, technology, engineering, and mathematics (STEM) education and careers. Making practices, facilities, and integrated makerspaces have been enthusiastically embraced within engineering education programs at high school and university levels, and are proliferating rapidly within diverse educational settings. Perhaps surprising to many within engineering and other STEM fields, making practices are also being embraced and adapted within the humanities,[1] particularly a branch of humanistic inquiry labeled "digital humanities."[2] As humanists organize research practices and supporting theoretical frameworks around making, new possibilities arise for using making practices to integrate technical and liberal educational goals within the context of engineering education.

This paper provides an overview of contemporary work in digital humanities involving making activities and the potential of this work to inform engineering education making activities in a way that bridges technical and humanistic concerns. It highlights how making practices themselves can be understood as a form of inquiry, with modalities drawing on—but distinct from—traditional engineering and humanities epistemologies. The paper draws on a larger research-and-teaching initiative at Rensselaer titled, "Making as Critical Inquiry," which is currently being integrated into our interdisciplinary undergraduate Programs in Design and Innovation (PDI). PDI has a well-established history of bridging content from engineering and liberal education, but the making activities that are currently being carried out have not yet been theorized as one of the mechanisms through which technical-social integration is achieved. In the paper, we provide specific examples of making practices and projects that exemplify the desired integration, and then argue that even engineering-centered design pedagogy can make use of making activities as a vehicle for integrating critical social inquiry and humanistic educational frameworks.

Background: Making in the Context of the Digital Humanities

As in engineering (and STEM fields generally), making activities have been embraced in the humanities and interpretive social sciences. In fact, wide-ranging making activities have long been and are currently being carried out in service of diverse humanities research, educational, and artistic goals as well as other creative production goals.

While, as a practice, digital humanities has arguably existed since flirtations with computational humanities in English departments in the late 1980s,[3] the more contemporary movement in the humanities can be traced to informal scholarly collaborations and edited collections in the mid-2000s and to a series of panels that served as a type of coming-out party for making research at the Modern Language Association's 2009 annual conference. Though the subfield represents a diverse array of practices, most early research involved the application of data-mining and algorithmic platforms to augment classical humanistic inquiry. Such examples include data-driven textual analysis of Shakespeare for the purposes of cross-referencing and meta-analysis,[4] development of pedagogical methodologies for teaching various formats for archiving material texts,[5] and data-mining Flickr and Tumblr platforms to crowdsource visual collections of contemporary cultural heritage.[6]

In the early 2010s, digital humanists began expanding their use of digital platforms, moving beyond data analysis and towards digital media production as alternative vehicles for research. Projects such as "Experiments in the Future of Art History," founded and directed by digital humanities scholar Charlotte Frost,[7] and the currently in-stasis journal, *Vectors,* have experimented with forms of media production as alternatives to writing for producing and disseminating scholarly work. Both of these projects focus on the production of new media forms, such as web pages, games, and interactive digital art pieces, as the result of scholarly work, rather than merely as methods for producing more traditional written/publication material.

More recently, thanks largely to the proliferation of 3D printing hardware and related grants from the National Endowment for the Humanities and the Andrew Mellon Foundation, digital humanists have begun incorporating making practices into their research and pedagogy. Makerspaces and critical design labs such as those at the University of Victoria, the University of Toronto, the University of Washington, and Davidson College represent some of the more established humanist makerspaces at the forefront of this new wave of interest. At the University of Victoria and Davidson College, especially, these methods of making have largely been tied to experimental pedagogical inquiry, focused on both digital skills building for humanities students (i.e., through coding), and embodied learning practices—how learning occurs bodily in addition to cognitively. Examples include "materially hacking" books by physically attaching and programming open-source hardware to classical humanist texts,[8] and using 3D printers and shop tools to re-create no-longer-existing technologies from patents and schematics discovered in historical records.[9] Both projects seek to expand students' understanding of the material aspects of humanistic texts by having students engage directly in physically augmenting or building those texts.

Critical Making: Making as Inquiry

The creation of knowledge—and, perhaps more important, the epistemic boundaries of what is considered legitimate knowledge—within traditional disciplines is largely influenced by normative standards determined by social and historical contexts.[10, 11, 12] However, as digital humanist Ian Bogost argues, all practices, including but not limited to writing, involve the creation and application of diverse forms of knowledge.[13] Bogost refers to making not as an epistemic practice of engineering or design, but rather as one of "carpentry." The label of carpentry, perhaps more than engineering, evokes imagery of hands-on, material creation, where abstract concepts and blueprints serve as guides, but where knowledge about the grain of the wood, a feeling for tensile strength, and last-minute aesthetic and formal experimentation are as important to the production process as the initial design concepts. Carpentry, in other words, draws upon embodied and experimental knowledges that are often undervalued in mainstream contemporary educational settings. In an effort to expand the kinds of knowledges that humanistic education can train for, as well as to critique formalist forms of education, maker movements associated with the digital humanities have embraced a set of practices collectively known as "critical making."

Coined by Matt Ratto,[14] who now directs the Critical Making Lab at the University of Toronto, critical making seeks to redefine the boundaries of what is usually considered legitimate STEM inquiry by including hands-on, craft-based, engaged carpentry practices.[15, 16] Critical making practices emphasize process over product and so, contrary to most engineering design work, is less concerned with a "working" end product.[17, 18] Borrowing from conceptual and making work done at Goldsmiths and by Dunne and Raby,[19] critical making casts the design and making processes as vehicles for critical inquiry. This is achieved by reflexively problematizing the very process taking place as it takes place (and afterward), as well as by using the design process to create (and anticipate), rather than solve, social problems.

In critical making, then, the making process itself becomes both an object of inquiry and a vehicle for inquiry. For example, in Jeremy Hutchinson's critical design project, *Err*, the designer emailed manufacturing plants asking for single copies of an intentionally mis-manufactured product.[20] The factory workers were allowed to select the object, as well as decide how to "mis-manufacture" it—how to intentionally design and build in flaws; Hutchinson agreed to purchase whatever the factory workers produced.

Err produced critical material artifacts, in the form of the faulty products, but also in the form of email chains between Hutchinson and plant management. Some plant managers "thought he was joking, others were insulted; they couldn't understand why anyone would purposefully commission products with errors, or as one factory manager said: 'Everyone in the world strives to improve, not to create error.'"[21] In addition to creating sometimes-beautiful, sometimes-haunting objects, like a wooden comb without teeth, or a walking stick broken in half, tied together with a piece of rope, *Err* exposed the assumptions of and served as a physical disruption to the norms of engineering, and examined the technical, social, and material conditions that shape engineering practices. When re-contextualized in an engineering-focused school, these kinds of disruptions afforded by critical making can provide room for conceptual re-imagining and re-valuing of the wide variety of practices and work that occurs within the domain of engineering.

Critical Making's Contribution to Engineering Epistemologies

By taking making itself as a form of inquiry, critical making moves beyond reductive instrumentalist framings of making merely as a means to a straightforward material end: a new product or component, a new prototype or proof of concept, a new technology or technical system. In dominant engineering epistemologies, making practices are framed as the *application* of engineering knowledge, but not as engineering-knowledge creating in themselves. The knowledge being applied via making in engineering is, foremost, based in the engineering sciences, grounded in theoretical insight or empirical testing. Making practices are understood as skill-based to be sure, but they are understood as experiential and embodied and not of the same order of legitimacy as the presumably universal laws of the sciences.[22]

Making practices have been steadily squeezed out of engineering curricula over the past 50 years and more, only recently to see a resurgence connected with relatively new interest in engaged pedagogies and other initiatives to connect with student interests, including increased attention to design in engineering education. Engaged pedagogies are motivated by a range of goals, but prominent among them is to attract and retain a greater number and diversity of engineering students.[23] Often, students in engineering experience alienation in educational contexts not because of the difficulty of the course content, but because the boundaries of what counts as engineering are often drawn in ways that exclude the kinds of knowledge production and embodied experiences that they associate with technical problem-solving approaches, such as hands-on making.[24, 25, 26]

Inspired by critical making's imperative of weaving together conceptual and practical dimensions of critical inquiry, the authors see a complementariness between new conceptual models to attracting more diverse students and new engineering making practices to imagining what engineering's future may hold. Not only does critical making weave the practical and conceptual dimensions of inquiry; it also aims to contribute to knowledge generation both practically (via knowledge dissemination) and conceptually (via knowledge transformation). Hence, critical making entails not just giving tools to students from marginalized groups to allow them to "make" their way out of poverty or other situations of disenfranchisement (although those are important, too). Rather, making is "critical" in that it is reflexive: Making in order to explore and push the boundaries of knowledge generation within disciplinary domains. It is also "critical" in that it is literally vital: Making is both important and embodied. It serves as a physical disruption to the norms of engineering education, particularly in the first years, and also takes into account the living bodies, physical exertions, spaces, and energies of techno-social-material intra-action.

Case Study: "Making as Critical Inquiry"

At Rensselaer, faculty members in the Science and Technology Studies (STS) Department are employing making-centered inquiry as a bridge between the intellectual and pedagogical commitments of our School of Humanities, Arts, and Social Sciences (HASS) on one side and Rensselaer's predominant focus on engineering and the sciences on the other side. Within HASS, an overarching framework simultaneously drawing on and guiding these activities is entitled, "Translational Humanities." Translational Humanities is a School-wide conceptual and strategic framework for re-centering humanistic concerns within an institution focused on more instrumentalist frameworks for research and education within engineering. Translational Humanities is an expansive initiative aimed at rethinking the role of humanistic inquiry in interdisciplinary problem solving, including by restructuring our students' educational experiences around humanistic perspectives.

One specific research-and-education initiative within the larger Translational Humanities project is being spearheaded by the authors. Titled "Making as Critical Inquiry," this initiative entails the creation and augmentation of a series of undergraduate and graduate STS classes focused on making, small research teams of undergraduate and graduate students experimenting with critical design methods, and multiple funding proposals submitted to both the National Endowment for the Humanities (awarded) and the National Science Foundation (at the time of this writing, under review). Making as Critical Inquiry experiments with ways of doing conceptual, critical, and political work via digital-material making practices in the context of an engineering-focused educational institution. Our goal is not only to generate new forms of humanistic scholarship that leverage the physical and social affordances of digital technology, but also to do so in ways that ally the social-scientifically informed design programs at Rensselaer more closely with the important critical and theoretical work pursued in the digital humanities and humanities disciplines as a whole. Ideally, Making as Critical Inquiry will connect to engineering educational frameworks in a way that makes our humanistic orientation directly relevant to engineering students' intellectual development and professional identity formation.

For the purposes of this paper, the authors wish to highlight the impact that early Making as Critical Inquiry initiatives have had when integrated into the late stages of the Programs in Design and Innovation at Rensselaer. Both humanistic inquiry and making activities have long been a part of PDI; however, these two have not yet been theorized as complementary, nor explicitly taught and assigned as a synthesized series of making projects or activities. Over the past three semesters, Making as Critical Inquiry has been iterated into our STS Senior Project course, a requirement for all PDI students at Rensselaer. While the Capstone course was traditionally envisioned as a space for STS students to write a culminating STS research thesis, the relatively small number of STS majors, particularly when compared to the number of students enrolled in PDI, led to a kind of programmatic mismatch. The vast majority of the students in the course each term (usually around 15 of the 18 enrolled) were trained in interdisciplinary design, most of whom were interested in careers in engineering or product design. These facts notwithstanding, our STS Senior Project course required students to produce a thesis-length, social scientific research document that few had the skills or the desire to complete. Needless to say, student satisfaction with the course was low, and in a few unfortunate cases, students dropped their dual major in PDI altogether because of their inability or unwillingness to complete the thesis requirement.

The STS Senior Project course was in desperate need of restructuring to meet the realities of the educational inclinations and preparation of our student body; however, the STS faculty (the authors included) were reticent to redesign the course as a design-centered capstone that removed the literary research and written social analytic components considered integral to an undergraduate education in the humanities and social sciences. After several conversations with Nieusma, Malazita (who teaches the course) redeveloped the course to center on critical making, in what would ultimately become a kick-starter for Making as Critical Inquiry. Under the new Senior Project course structure, PDI students worked in teams and were required to apply theoretical insights from STS scholarship to the design and prototyping of a "critical design thesis artifact." This artifact needed to make, support, or extend—in and of itself—a critical argument in STS that had been made in peer-reviewed literatures in the humanities or social sciences.

The critical design project served as a unique challenge for PDI students. On one hand, they were generally happy to be applying their engineering and design skills in an STS class; on the other hand, their deeply engrained engineering epistemologies—in spite of their PDI education—often produced conceptual roadblocks. Like the process engineers and factory workers in Hutchinson's

Err project described above, our students' impulse was to use their making skills to conceive and design an object that: 1) identified a problem; 2) solved that problem; and 3) did so in a way that was easy and enjoyable for the user. In contrast, the critical design project forced the students: 1) to identify a problem; 2) to design an artifact that made that problem *more evident*; and 3) to design the artifact in a way that forced its users to reflect about the process of using the design, rather than having the use be intuitive and, hence, transparent. Furthermore, instead of having the Senior Project students write up either a thesis or a traditional professional design report, student teams were required to write a critical design document, which incorporated a humanities-centered literature review as well as critical analysis and user-testing reflections into the traditional design document format.

As the Senior Project course design has iterated over the past three semesters, and Malazita becomes more experienced in teaching critical design, the projects produced by the students have become more polished and more conceptually sophisticated. One project from the Fall 2015 semester, for example, incorporated an actor-network theory[27] analysis of the production of consumer coffee to design and build a functional coffee maker that forced users to select the quality of environmental, labor, and trade practices they wanted in their coffee and to pay accordingly: the more exploitative the practices, the less expensive the coffee. At the other end of the design spectrum, a different team—made largely of industrial and management engineering students—redesigned the first-year engineering curriculum at Rensselaer to incorporate diverse making practices and social theory, while still fulfilling all ABET requirements addressed in the students' current first-year coursework.

These successful projects notwithstanding, the prime example to date of a well-executed critical design project was produced in the Fall of 2015 by PDI students Sarah Bogdan, Alexia Ioannou, and Xiaohan Li. Their project excelled in terms of both material production and critical theoretical engagement. Titled Velcube (see Fig. 1), the project leveraged feminist STS literatures promoting the concept of "neurodiversity" as a positive conceptualization of diverse brain states and alternative to the negatively inflected concept of "mental disability." The students' project successfully integrated STS, design theory, game theory, and humanistic and psychological research to develop a tactile puzzle game that privileges pattern recognition, tactile sensation, and topological identification over interpersonal negotiations and competition-based play. The project resulted in a game design that tends to be easier for neurodiverse autistic individuals to play than for the general population.

Figure 1: Velcube, fully assembled

Velcube was comprised of 27 individual cubes (see Fig. 2, next page) that could be arranged into a larger, 3x3 cube; a hook (scratchy) or loop (fuzzy) strip of Velcro was fastened to each face of each cube. The ratio and arrangement of hook and loop cube sides appears random at first, but it was in fact methodically designed: there is only one combination of cubes that allows a player to construct the full-sized, 3x3 cube so that no same-quality (hook-hook or loop-loop) sides are touching each other.

Based upon early (and in no way scientifically valid) play-testing, players who approached the game by sorting the individual cubes into hook-loop orientation categories, and then systematically assembled the larger cube, were able to complete the game in 5 to 15 minutes. Players (including Malazita) who attempted to assemble the cube by slowly building out from a corner piece and feeling their way through sculpting the final shape took anywhere from 30 to 60 minutes to finish the game (or, in the case of Malazita, gave up). Pattern-based approaches, like those that neurodiverse autistic individuals would be more likely to apply to problem solving, appeared to be a better strategy for completing the game.

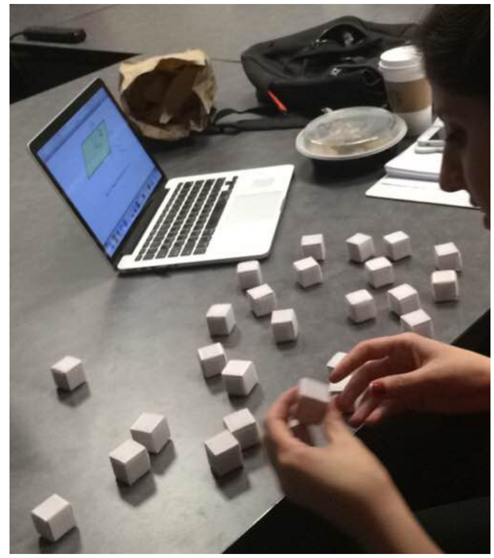

Figure 2: Velcube, pieces in play

The Velcube is certainly not a test for autism, and the basic premise of the project—namely, that autistic individuals will find it easier to complete the game—is not necessarily true. But as a critical design piece, scientific validity isn't the goal. The goal is to create new ways of engaging with, of understanding, problems in the world. While playing through the game, all of the players engaged in conversations with the design team and with the artifact itself. (These were conversations of different kinds, but they were conversations still.) Every participant in the interaction began explicitly working through notions of neurodiversity and counter-narratives to ableism during play sessions. Several players even reported back to the design team that their conceptualizations of varied brain states and disabilities had been challenged or changed through their play-plus-conversation. Thus, regardless of the admittedly shaky scientific grounds of the design, the critical aims of the project—to challenge users to think differently through use of the artifact—seem to have been successful.

Transferring the Model

While our Making as Critical Inquiry initiative is still in its early stages, we already see potential for extending the model. Most immediately, our goal is to integrate the Making as Critical Inquiry approach explicitly and systematically into PDI. The opportunity space here is large, for a variety of reasons. First, our students are already primed to be working at the intersection of social and technical dimensions of design, and they already have an appreciation for the mutual shaping of technology (and other material objects and practices) and society (and its wide range of human-to-human and human-to-artifact interactions).[28] Having them apply Making as Critical Inquiry strategies to their current design project work will reinforce the application of critical inquiry to their design problem solving.

Second, applying Making as Critical Inquiry strategies can also help students slow down their solution generation and to circle back on their problem formulation and definition.[29] Reframing design problems—that is, pulling back from the problem as given or the problem as initially defined—is one of the hallmark skills of PDI students, as we encourage students to reject fabricated disciplinary bounding of messy real-world problems and to reject, after initial exploration, their own instinctual solution concepts. By going wide from the start, and then iterating back and forth between problem definition and the most compelling solution concepts, students develop robust maps of the design space within which their projects ultimately unfold.

Third, our students tend to utilize making practices in their design process in very traditional ways. Even when they are encouraged to prototype early in their process, before their final solution concepts become crystalized, the making activities almost always seek to embody a chosen concept, even a tentative one, in a straightforward way—physically manifesting or representing the concept. Integrating Making as Critical Inquiry into our prototyping practices can help open students to more exploratory making practices and conversations that question taken-for-granted assumptions around the project's goals, the students' problem-solving processes, and even a given assignment's overarching strategy for achieving course learning objectives.

Beyond PDI, we see potential for transferring this approach to other institutions with liberal arts-oriented engineering programs and even more traditional engineering programs with a design orientation, especially ones that prioritize innovation and creative problem solving. Because of Making as Critical Inquiry's reliance on a form of critical inquiry practiced most consistently in the humanities, liberal arts-oriented engineering programs will likely be better prepared for integrating Making as Critical Inquiry activities: faculty will likely have more exposure to the intellectual foundations of Making as Critical Inquiry and students will likely have more practice in and tolerance for ambiguity, non-instrumental orientations toward education, and facility with exploratory problem solving.

For more traditional engineering programs, whether innovation-oriented or not, design coursework is an obvious place for utilizing Making as Critical Inquiry activities. While most engineering design courses have students move relatively quickly to problem definition, or even provide to students the problem definition as a given, it is now widely recognized that the early step of problem definition locks in (or out) the vast majority of creative potential available (and costs that will ultimately accrue) over the entire design process—engineering design's manifestation of the Pareto Principle. Making as Critical Inquiry works against this impulse, but applied in its truest sense may well go too far in this regard for most engineering design course instructors, who need students to settle on a problem definition relatively early and to do so following a structured protocol. Still, Making as Critical Inquiry could be used in a distilled manner, say by having students read about some dimension of a complex, real-world problem before introducing a Making as Critical Inquiry activity that has them explore that particular dimension in a hands-on way. The output of the making activity would then swing back around and serve as fodder for reflexive conversations about the complexity of the problem to be solved and the limitations of any singular approach, including technology design, in responding to complex problems.

We also see potential of using Making as Critical Inquiry as a tool for facilitating interdisciplinary collaboration around engineering design projects. Even in PDI, we have difficulty getting many humanities and social sciences faculty members into the design classroom, despite the fact that these courses are administered by our own STS Department. For true engineering design courses, the barriers to entry for H&SS faculty members are likely to be very high in most educational settings. (We suspect the main exceptions here are where H&SS faculty members are literally assigned those roles, including by being hired directly by engineering programs.) Using Making as Critical Inquiry to facilitate interdisciplinary collaboration is likely to attract participation by H&SS faculty, perhaps especially those from the humanities, by providing them a non-trivial role in the assessment and steering of student work.

In terms of facilitating interdisciplinary collaboration around design among engineering and H&SS faculty members, or even co-teaching, we imagine Making as Critical Inquiry could be most powerful if employed early in the engineering curriculum, especially first-year courses that serve as introductions or orientations to engineering. In addition to establishing a strong precedent for integrated social-technical inquiry, such courses could play a retention role as well. Presumably, many students who switch out of engineering in the first year do so for reasons of fit, especially those students who expected engineering to entail more hands-on, creative, or open-ended problem solving. As with design courses generally, the next most obvious place for a Making as Critical Inquiry course in the engineering curriculum would be as a capstone experience. Indeed, it is in our own Senior Project course that we have first experimented with Making as Critical Inquiry pedagogies. While early and late in engineering curricula are obvious places for Making as Critical Inquiry activities, we also recognize that the “middle years” are the least accessible for non-technical curricular revisions and where the narrow-technical engineering epistemologies are cemented for students. This challenge deserves additional attention.

Conclusion

Our emphasis on the transformative potential of making is not to say we envision a return to early 20th Century shop-culture engineering. Rather, we envision the potential as a theoretically sophisticated response to a clear shortcoming of most engineering undergraduate educational programs, particularly during the initial years, that are biased toward abstract analytic math and science skills at the expense of making knowledge, technique, and experience in a variety of material domains. As STS scholars have long argued, knowledge building is more than the summation of abstract information. The perceived structures and boundaries of knowledge are always informed by one’s social situatedness and embodied actions, so knowledge creation is a blending of social context, interpreted meanings, and material experience.[30, 31, 32, 33]

Where our program diverges from these classical STS approaches, however, is the application of these critiques to the production of material designs as physically manifest “arguments.” As such, Making as Critical Inquiry at Rensselaer aims to leverage humanistic and STS scholarship to better understand and teach the nuanced, complex, and non-determinist ways in which the technological and the social interact, as well as to highlight and include the diverse community of stakeholders who are impacted by technological development, all through the leveraging of situated making practices. Making as Critical Inquiry strives to be not only a radically interdisciplinary approach to scholarly problem definition and engineering education pedagogy, but also an innovative approach to addressing the enduring challenges of diversification within the engineering profession.

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