Critical Making and Interdisciplinary Learning: Making as a Bridge between Art, Science, Engineering and Social Interventions

Matt Ratto
& Garnet Hertz

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MATT RATTO & GARNET HERTZ

Critical making is increasingly being adopted to describe design-oriented practices and pedagogies that include both conceptual and technical work[1]. Engaging with definitions and articulations of critical making is important given its increasing circulation. Critical making has found its way into workshops and papers, has been used as a theme for several academic conferences, has become the title for a number of academic courses,[2] and has served as a banner for a number of academic initiatives, including as a visioning principle for the Rhode Island School of Design.[3] It is therefore worthwhile to step back and describe Ratto's original intentions regarding the coining of this term and to articulate our ongoing research and pedagogical work to reincorporate both critical analysis and material making.

The term critical making was initially used by Ratto in 2009 to define a conjoined pedagogical and research practice that used material engagements with technologies to open up and extend critical social reflection.[4] These early experiences coordinating critical making workshops proved a fruitful source to explore theories about the relations between society and technology drawn from fields such as Science and Technology Studies and Philosophy of Science. Most importantly, this work served to articulate the desire 'to theoretically and pragmatically connect two modes of engagement with the world that are often held separate – critical thinking, typically understood as conceptually and linguistically based, and physical "making", goal-based material work'.[5]

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1 Matt Ratto, Kirk Jalbert and Sara Wylie, "Critical Making as Research Program: introduction to the forum on Critical Making." Special Forum issue on Critical Making, *The Information Society* 30(2), 2014: p. 85-95; Matt Ratto, "Critical Making: Conceptual and Material Studies in Technology and Social Life." *The Information Society* 27.4 (2011): p. 252-260; and Matt Ratto, Steve Hoekema, "Critical Making: Conceptual and Material Studies in Technology and Social Life." Hybrid Design Practices workshop, *Ubicomp*, Orlando, Florida, USA, 30 September - 3 October, 2009.

2 Eric Paulos, *Critical Making: Materials, Protocols, and Culture*, Course Syllabus, *UC Berkeley*, 2013, http://www.paulos.net/teaching/2013/CM/; Wayne Osborn, *(2012) CCTP-763-01 Critical Making: Audio and Video*. Course Syllabus, Georgetown University. 2012, http://courses.georgetown.edu/?courseID=CCTP-763; Matt Ratto, *INF2241 Critical Making*. Course Syllabi, University of Toronto, 2009-2014, http://www.criticalmaking.com; Garnet Hertz, 'The Studio for Critical Making', *Emily Carr University of Art and Design: Critical Making*, https://research.ecuad.ca/criticalmaking/.

3 Rosanne Somerson & Mara Hermano (eds), *The Art of Critical Making: Rhode Island School of Design on Creative Practice*, Hoboken, NJ: John Wiley & Sons, 2013.

4 Matt Ratto and Stephen Hockema, 'Flwr Pwr: Tending the Walled Garden', in Annet Dekker and Annette Wolfsberger (eds) *Walled garden*, Amsterdam: Virtueel Platform, 2009. pp. 51-62.

5 Matt Ratto, 'Open Design and Critical Making', in Bas van Abel, Lucas Evers, Roel Klaassen and Peter Troxler (eds) *Open Design Now: Why Design Cannot Remain Exclusive*, Amsterdam: BIS Publishers, 2011, http://opendesignnow.org/index.php/article/critical-making-matt-ratto/.

The concept of critical making has many predecessors, all of which start with the assumption that built technological artifacts embody cultural values, and that technological development can be combined with cultural reflectivity to build provocative objects that encourage a re-evaluation of the role of technology in culture. Concepts coming out of the field of computer science include critical technical practice,[6] values in design,[7] reflective design[8] and adversarial design.[9] In the fields of art and design, similar concepts include critical design,[10] interrogative design,[11] speculative design,[12] para-functional design,[13] dissident design,[14] post-optimal design,[15] and critical engineering.[16] It is worth noting that the term critical making borrows from and builds on these concepts that bridge between critical practice and technological development. In fact, rather than seeing critical making as a distinct practice, we prefer to understand it as a general descriptor for kinds of conceptual-material work.

The term critical making highlighted the importance of the material in conceptual and analytic processes, a point that has been an increasingly dominant trope in social theories – the so-called 'material turn' that has been noted in a range of disciplines.[17] But perhaps more importantly, the focus on making was also intended to emphasize the value of material production itself as a site for critical reflection. As Ratto notes, shared experiences of making can 'provide joint resources for transforming the socio-technical imagination'.[18] Such an understanding is supported by constructionist pedagogical theories,[19] theory-based articulations regarding the 'push back' of the material world on processes of conceptualization[20] and, more

6 Phil Agre, *Computation and Human Experience*, Cambridge: Cambridge University Press, 1997.
7 Helen Nissenbaum, 'Values in the Design of Computer Systems', *Computers in Society*, (March 1998), pp. 38-39.
8 Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph 'Jofish' Kaye, 'Reflective Design' in *Proceedings of the 4th Decennial Conference on Critical Computing: Between Sense and Sensibility, (2005)*, pp. 49-58.
9 Carl DiSalvo, *Adversarial Design, Cambridge, MA:* MIT Press, 2012.
10 Anthony Dunne, *Hertzian Tales: Electronic Products, Aesthetic Experience and Critical Design*, London: Royal College of Art, 1999.
11 Krzysztof Wodiczko, *Critical Vehicles: Writings, Projects and Interviews*. Cambridge, MA: MIT Press, 1999.
12 Heather Martin and William Gaver, 'Beyond the Snapshot from Speculation to Prototypes in Audiophotography', in *DIS 2000 Proceedings of the 3rd Conference on Designing Interactive Systems: Processes, Practices, Methods and Techniques*, 2000, http://www.gold.ac.uk/media/25martin-gaver.aphoto.dis00.pdf.
13 Dunne, *Hertzian Tales*, pp. 43-68.
14 Craig Badke and Stuart Walker, 'Contextualizing Consumption', in Paul Rodgers, Libby Brodhurst and Duncan Hepburn (eds) *Crossing Design Boundaries*, London: Taylor & Francis, 2005, pp. 89-293.
15 Graham Powell, *Inside the Box (exhibition guide)*, Leamington, KY: Leamington Spa Art Gallery and Museum Royal Pump Rooms, 2005.
16 Julian Oliver, Gordan Savicic and Danja Vasiliev, 'The Critical Engineering Manifesto', *The Critical Engineering Working Group*, 2011, http://criticalengineering.org/.
17 Dan Hicks, 'The Material-Cultural Turn: Event and Effect', in Dan Hicks and Mary C. Beaudry (eds) *The Oxford Handbook of Material Culture Studies*, Oxford: Oxford University Press, 2010, pp. 25-98.
18 Ratto, 'Open Design and Critical Making', p. 253.
19 Seymour Papert and Idit Harel, 'Situating Constructionism', in *Constructionism*, New York: Ablex Publishing Corporation, 1991, pp. 193-206, http://www.papert.org/articles/SituatingConstructionism.html.
20 Bruno Latour, 'Why Has Critique Run Out of Steam? From Matters of Fact to Matters of Concern', *Critical Inquiry* 30 (2) (January 2004): pp. 225-248.

colloquially, by the experiences of the authors. Importantly, the transformation of one's understanding regarding the relations between society and technology may involve an affectual dimension that is often under addressed in both social and technical work: 'Ultimately, critical making is about turning the relationship between technology and society from a "matter of fact" into a "matter of concern". I [Ratto] see this as requiring personal investment, a "caring for" that is not typically part of either technical or social scholarly education'.[21]

The importance of integrative educational initiatives that work to bridge the humanities and technology is highlighted by the adoption of acronyms such as 'STEAM' by directors of mainstream educational initiatives. Here, the more traditional focus on Science, Technology, Engineering, and Math is supplemented with the term Art as a placeholder for the forms of knowledge and pedagogies associated with aesthetic and humanities-based education. Needless to say, it is no more possible to simply add in 'art' – whatever that term is expected to encompass – to pedagogical practices in engineering or science disciplines, than it is to simply add in 'engineering' or 'science' to art-based pedagogies. Some problems relate to institutional divides and the problems inherent in navigating between various organizations. Others relate to the variety of processes and results that are seen as valid forms of knowledge by differing disciplinary groups. Creating interdisciplinary approaches and perspectives that engage the epistemological differences between art and technology or science is not merely an additive process, but requires substantial and novel pedagogical moves.

The 'Critical' in Critical Making

We believe that 'critical' is an essential attribute for such interdisciplinary practice, including reflective thinking about the value propositions and epistemic boundaries and practices within traditional disciplines. We also see criticality as including expansive thinking about the site and social import of the objects and forms of knowledge that emerge from one's work. Second, we believe that productive project-based 'making' is an important mode of production for interdisciplinary work because it can operate as a non-disciplinary middle ground for different communities and groups. The linking of personal investment, critical theory, and material production is what marks critical making as a unique mode of engagement with the world. The authors, each in their own way, have continued these developments, looking to establish educational initiatives and curricula that work to develop critical makers with appropriate skill sets and understandings that engender critical innovations and experiments regarding the sociotechnical.

By 'critical', we tend to see this as following the interventionist and transformative theoretic work associated with the Frankfurt School of Critical Theory. The scholars most associated with the Frankfurt school included Herbert Marcuse, Theodor Adorno, and Max Horkheimer. These scholars – and many others – shared a conception of a 'critical theory' understood as adjacent from the dominant academic concept of 'theory' present in scientific work of that time. Rather than focusing on generalizable descriptions of current conditions, critical theory

21 Matt Ratto, 'Critical Making: Conceptual and Material Studies in Technology and Social Life', *The Information Society* 27, no. 4 (2011: p. 259.

was primarily concerned with understanding and constituting 'reasonable conditions of life'.[22] According to Horkheimer, doing so required a rejection of such normative valuations of theory as 'better, useful, appropriate, productive, and valuable',[23] due to the ways in which research associated with such valuations were both predicated by and worked to reinforce current social situations. Social transformation and an increase in 'human emancipation' required non-normative theory that strove to transform rather than describe. Here it is important to note the differences between 'critical' understood as merely reflexive and hermeneutic, and 'critical' as defined here and linked to the overt goal 'to liberate human beings from the circumstances that enslave them'.[24]

Certain academic disciplines such as political economy, philosophy, and cultural studies have promoted 'criticality' as an intrinsic aspect of their work and have actively developed pedagogical processes to help students adopt and practice critical approaches. However, we do not believe that criticality is an intrinsic aspect of any specific academic discipline. Instead, criticality can be understood as a present though often somewhat hidden aspect of all disciplinary practice. This is revealed by technical disciplinary engagements that have focused extensively on criticality as part of a technical practice.

Within the framework of technological design, criticality tends to first delete – or at least put aside – current value propositions associated with technology. Three critical material-conceptual practices can be singled out as illustrative of specific attention to the variety of naturalized values typically associated with technology and technological development. First, critical design as described and practiced by Dunne and Raby[25] addresses the dominant focus on commercialization and for-profit interests within the world of design, using the design and exhibition of objects to reveal these interests and provide alternatives. Their aim is to make consumers more aware of the values, ideologies, and behavioral norms inscribed in the designs that are used in their everyday lives.[26]

Second, critical technical practice[27] focuses on the value propositions embedded in specific technical disciplines and associated training, using engagements with critical literature from the humanities and social sciences as a way to trouble and contextualize the instrumental logics associated with computer science and engineering. Phil Agre's work is particularly meaningful for the development of critical making since his overt goal is the bridging of disciplinary mindsets that serves as a precondition to hybrid multi-disciplinary practices. Finally, Agre's concepts of critical technical practice have been extended into the field of design for human computer interaction under the term 'reflective design'.[28] Whereas critical technical practice

22 Max Horkheimer, *Critical Theory: Selected Essays*. London, New York: Continuum, 1972, p. 199.
23 Horkheimer, Critical Theory, p. 199.
24 Max Horkheimer, *Critical Theory*, New York: Seabury Press, 1982, p. 244.
25 Anthony Dunne and Fiona Raby, *Design Noir: The Secret Life of Electronic Objects* Berlin: August/Birkhäuser, 2001.
26 Jeff Bardzell and Shaowen Bardzell, 'What is "Critical" about Critical Design?', Proceedings of ACM Conf. Human Factors in Computing Systems CHI'13 (Paris, France), 2013, pp. 3297-3306.
27 Agre, *Computation and Human Experience*.
28 Paul Dourish, Janet Finlay, Phoebe Sengers and Peter Wright, 'Reflective HCI: Towards a Critical

focused on encouraging and supporting reflection and overcoming of disciplinary divides, reflective design encourages the development of technical objects intended to encourage reflection on the part of users. In doing so, reflective design practitioners aim to denaturalize the passivity of the typical relations between technology consumers and producers.

What unites the above approaches is a focus on material-conceptual processes that bring together reflexivity and intervention. For each of the practices above, the process of being critical starts by denaturalizing standard assumptions, values, and norms in order to reflect on the position and role of specific technologies within society. However, in addition, a specific goal of each is to tactically intervene and disrupt traditional models of technological development by giving engineers, designers, and in some cases, the public, an opportunity to break out of the cycle of overworking, overproducing, and overconsuming – to step back and reflectively reconsider a broader spectrum of human experience and culture.[29] If technology is to improve society, it must be critically reflective and designed for the complexities of what it means to be human.

The 'Making' of Critical Making

As noted above, use of the term 'making' was initially intended to highlight the importance of material production and participation as key to critical thinking and conceptualization regarding technology. Equally, Hertz's position is that the term 'maker' is relevant to this work because in some ways it stands at the intersection of traditional media arts practice, product design, craft, and computer science research. Because of this, we find it useful as a model for interdisciplinary pedagogy: it is a materially-based mode of tactile practice that primarily sits outside of academic disciplines.

The term 'maker' took on a specific usage in 2005 when Dale Dougherty founded Make magazine, which he used as a term to rebrand and sanitize the term 'hacker' to be more acceptable to the public, schools, and potential sponsors. The term maker can be seen as a move toward craft-style practices and a distancing from the two definitions of what 'hacking' is: 1. breaking into security systems for malicious or criminal purposes (i.e. cracking), or 2. the clever subversion of making things work in unexpected ways (i.e. a clever hack). The concept of maker started out by highlighting ordinary people making in their garages and backyards, but eventually also enveloped work in the experimental media arts, open source hardware, and hackerspace culture.

Over the past fifteen years, the term 'making' has come to describe grassroots-oriented electronic hobby projects and initiatives that blend clever physical construction, craft, microcontrollers, robotics, and open source ideals based on the free sharing of information. As community-organized hackerspace studios, open source 3D printers, and DIY-style physical computing platforms have become more widespread, the concept of making has also grown considerably.

Technical Practice' in *CHI'04 Extended Abstracts on Human Factors in Computing Systems*, 2004, pp. 1727-28; Sengers et. al., 'Reflective Design'.

29 Phoebe Sengers, 'Phoebe Sengers - Research', Cornell University Faculty Website, https://www.cs.cornell.edu/people/sengers/index.php?page=Research.

However, the increasingly widespread adoption of the term 'maker' has not come without some costs. While we find the term 'making' useful as a method for democratizing the fabrication of technological objects, we also see that with this larger social adoption, the adversarial, political, and tactical components at the heart of many tech-oriented DIY practices have been largely removed and replaced with a singular interest in technological skill or craft. In other words, the popular concept of maker has unified an interest in a hands-on involvement in technology development, but has done so by subtracting critical engagement from the process. While some residual critical aspects remain, they have a milder resemblance to their ancestors, including a belief in open source accessibility of technologies and a belief that the tactile production of technological objects is important to human well-being.

Making has emerged as a powerful concept in unifying technological and social crafts, but we believe that the field needs to be more self-reflective and critical if it is to progress. Critical making raises questions such as: What are the relations between particular social agendas and technical objects and systems? How might sociotechnical systems be integrated with wider and more emancipatory values? What can we build to sustain and foster social equality and justice? What technologies are worth making? The definition of critical making contains the potential for its interdisciplinary mission: Making requires 'hard' skills of technology while criticality requires conceptual thinking. We see technical exercises of making an LED blink with an Arduino or 3D printing an object as fundamental first steps in education, but questions about the design, purpose, and cultural value of created things are important next steps in the process of making.

Critical Making in the Classroom

In this section we provide examples of our own research and teaching practices, demonstrating our commitments to developing critical makers – transdisciplinary individuals with the ability to link technical practices drawn from computer science and engineering-related disciplines and conceptual understandings and theories drawn from arts, humanities, and the social sciences.

Ratto's Teaching Experiences

I am an Associate Professor in the Faculty of Information, Bell University Labs Chair in Human-Computer Interaction, and direct the Critical Making Lab[30] at the University of Toronto. My work focuses on developing theories, practices, and pedagogies that increase understanding and human agency regarding the complex relationships between information technologies and society. For me, critical making is both a research object and the means for studying that object.

An important outcome of my work on critical making is academic writing aimed at increasing the uptake of material practices within traditionally language-based critical disciplines. The results of this work are often typical academic objects – journal articles, book chapters, edited

30 http://criticalmaking.com.

collections, and monographs. I see this work as a necessary part of critical making given the predilection of higher education for abstract and linguistic artifacts. But these works are themselves built upon the traces of what I term 'critical making experiences', events that I and my students curate, where material production and conceptual insights and vocabularies are conjoined.

These events share the following characteristics: first, they are engendered by an ambiguity, contradiction, or disjuncture at work within one or more conceptual theories; second, they require participants to engage with the above conceptual uncertainties through a construction process that is more or less materially constrained; and third, though objects are produced through such processes, these objects are not the main outcome. Instead, the intended results of these experiences are personal, sometimes idiosyncratic transformations in a participant's understanding and investment regarding critical/conceptual issues. I have shared these experiences with a range of individuals in a range of contexts including private companies, public workshops, academic symposia and conferences, and, notably, within my own teaching. I have been teaching a class in critical making in the Master's of Information program at the University of Toronto since 2009. The class includes master and PhD students from the aforementioned program as well as students from engineering, architecture, and visual studies.

The critical making experiences that I have developed have addressed a variety of topics but for the most part have focused on issues associated with the increasing movement of digitally-influenced processes and value propositions into all aspects of the human social world. Depending on the year and current issues in the media, we discuss recent decisions regarding handgun legislation, developments around climate change, or issues about surveillance or privacy. I give students the specific prompt: 'Build a moral technology'. They have one week to design, build, and explain their project. In the following class, each group shows their results, describes how and in what ways it is a moral technology, and provides an overview of their process. These performances are followed by facilitated class discussions where issues, ambiguities, and outcomes are debated and described. These experiences are therefore motivated and supported by work from fields such as Science and Technology Studies and the Digital Humanities that highlights concerns related to digitality and information more generally. Scholars such as Donna Haraway, Leigh Star, Geoff Bowker, Bruno Latour, and many others have examined some of the dimensions of what we might generically term 'technoscience' and its emancipatory or constraining aspects.

Individual classes are organized as follows. Every class contains a conceptual exploration and making section. In the first few weeks of the class, the making section mainly provides some basic skilling around microcontrollers, electronics, and simple programming. Following the introductory weeks, we move towards more specific conceptual material explorations organized around a particular theme or question. Again, the class involves a set of specific readings around morality and technology, accompanied by a particular design prompt. Students build a response to the design prompt, show it, and discuss it with the rest of the class. Students are then tasked with writing a reflection paper in which they describe the project, talk about the process of building it, and link to course readings and readings from other contexts. The course ends with a final open show, a public exhibition of the traces of critical making.

The above pedagogical design has been remarkably successful in deepening student engagement and understanding of critical theories and sociotechnical issues. This is demonstrated in the sophistication of the written work done by students as well as the conversations carried out in class. Equally, in many cases, the objects that have been created have turned out to be quite evocative and interesting in their own right. However, I encourage the students to remain focused on the process of creation rather than on the results. Specifically, these objects are not typically exhibited or described outside of the course context. I believe the most important results of critical making should be critical makers – individuals with an enhanced ability to parse the complexity of our sociotechnical world.

Hertz's Teaching Experiences

I work as Canada Research Chair in Design and Media Art at Emily Carr University, where I regularly advise and teach graduate students. When initiating studio-based design projects with my students, I often encourage them to start out with the following methodology adapted from Sengers et al's[31] process of reflective design:

1. *Identify disciplinary metaphors and assumptions*: Identify core metaphors that guide and shape a discipline. For example, in the field of personal computing this could be 'desktop'. General assumptions of engineering include efficiency, reliability, convenience, and pervasive connectivity. Identifying metaphors can be the result of literature review, observation, or other research methods.
2. *Research metaphoric occlusions*: Carefully recognize and research what the metaphors and assumptions exclude, marginalize, or occlude. In the case of a computing desktop, embodied movement or position is marginalized. What disciplines, groups, or users are excluded by these metaphors?
3. *Invert occlusions*: Invert the core metaphor of the discipline by bringing the marginalized things to the center. Consider building a computer interface that uses the entire human body, for example. What would the new thing look like and how would it work? What if we designed only for occluded things?
4. *Build the inversion*: Physically build a new alternative that embodies the inversion. Low cost open source DIY tools, including digital design tools for physical fabrication, can accelerate this process. It is important to actually fabricate the thing because it has a tangible legibility, documents well, and has the potential to act as a meeting point or disruptor between different users and communities. Built things are 'real' and constructively propose how a system is envisioned differently.
5. *Deploy the object*: Disseminate the project through high quality video production, online documentation, and exhibition in a public setting. Depending on the project, qualitative data collection in the form of surveys, interviews, observations, or usability tests can be of substantial use in understanding the impact of the project, especially in measuring how it challenges and disrupts biases.

31 Sengers et al. 'Reflective Design'.

In addition to using this process of 'occluded' or 'inversive' design to help my graduate students, I use it as a method for my own studio work. I generally emphasize the made object more than Ratto does: I aim to build 'things to think with' that aim to be evocative things with their own form of agency. I see them operating somewhat like boundary objects[32] or boundary negotiating artifacts.[33] These devices – functional prototypes that are exhibited in public art galleries, documented online, and published as case studies in academic papers – work to expose the hidden assumptions and values embedded in technological systems. The purpose of these objects is to enable individuals to reflect on the personal and social impact of new technologies, and to provide a provocative, speculative, and rich vision of our technological future that avoids the clichés of consumer or industrial design.

Unpacking Hidden Assumptions and Values

The pedagogical explorations described above differ in a number of important regards, including the communities and disciplines in which the work is situated and, in a related way, the role and purposes of the final made objects. Hertz uses a five step process to build for occluded values, with the aim of building objects to provoke critical thought. Ratto uses tools and practices drawn from the maker community to directly engage with critical sociotechnical theory. However, both experiences share an emphasis on unpacking and opening up the hidden assumptions and values associated with modern sociotechnical life. Drawing upon work associated with domains such as critical design, critical technical practice, and reflexive design (among others), the critical making pedagogies of the authors make use of strategies familiar to art and design practice such as defamiliarization and aestheticization, leverage resources from the humanities and social sciences such as hermeneutic and metaphoric analysis, and engage with substantive tools and materials drawn from engineering and natural science fields. Critical making as a pedagogical strategy thus offers possibilities for truly engaged interdisciplinary work that directly confronts the difficult epistemological issues encountered when bridging disciplines. Finally, we want to note that the value of the term critical making is not that it replaces other descriptors of critical hybrid conceptual/material practice, but instead that it works to connect the diversity of tropes, themes, and disciplinary contexts from which such practices emerged. Refocusing our attention as artists, scientists, engineers, and scholars on the development of critical makers is an important step in the development of truly trans-disciplinary interventions into the sociotechnical world.

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32 Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out: Classification and its Consequences*, Cambridge, MA: MIT Press, 1999.

33 Charlotte Lee, 'Between Chaos and Routine: Boundary Negotiating Artifacts in Collaboration', *ECSCW* 16 (3) (2005): pp. 387-406.

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