Engineering Studies

ISSN: 1937-8629 (Print) 1940-8374 (Online) Journal homepage: http://www.tandfonline.com/loi/test20

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To cite this article: Emily York (2018) Doing STS in STEM Spaces: Experiments in Critical Participation, Engineering Studies, 10:1, 66-84, DOI: 10.1080/19378629.2018.1447576

To link to this article: https://doi.org/10.1080/19378629.2018.1447576

Published online: 14 Mar 2018.

ENGINEERING STUDIES, 2018
VOL. 10, NO. 1, 66–84
https://doi.org/10.1080/19378629.2018.1447576

Doing STS in STEM Spaces: Experiments in Critical Participation

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ABSTRACT
This is a story of critical participation in engineering and applied science spaces that examines the challenges and opportunities of STS (Science and Technology Studies) experiments in relation to disciplinary identity, institutional values, and the power dynamics at work in the experiment. Comparing my experiences as an STS graduate student negotiating access in a research-oriented nanoengineering department geared toward capital formation, and as an assistant professor in a teaching-oriented applied science department geared toward holistic problem-solving, I highlight the necessity of creating mutual benefit and shared interest for STS approaches to gain traction in these spaces. At the same time, I describe the ways that institutional imperatives and power dynamics enable and constrain the possibilities for doing so. I argue that making STS relevant in STEM spaces requires paying close attention to the language through which scientists and engineers express their perspectives, values, and challenges, and it requires exercising a level of opportunism in identifying ways to make STS insights visible and legitimate. Teaching in a multidisciplinary curriculum builds on shared interest in education, potentially enabling disparate perspectives to come into dialogue as part of mutual world-building.

ARTICLE HISTORY
Received 11 October 2017
Accepted 9 February 2018

KEYWORDS
STS; making and doing; STEM education; cultures of science and engineering; critical participation

Introduction

Though I did not set out to do something called 'critical participation',[1] I now realize that my experiments[2] in bringing science and technology studies (STS) into STEM spaces began in the fall of 2010 – the beginning of my Ph.D. program in Science Studies and Communication

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[1] Downey describes critical participation in terms of

> figuring out ways of doing STS analysis so it maximally inflects the knowledge, expertise, identities, and commitments of those we study and with whom we work. It also means being willing to accept the risks of having our practices of knowledge production, knowledge expression, and knowledge travel inflected by them as well. (Downey and Zhang, "Nonlinear STS," 2015, p. 5)

[2] I use 'experiment' to connote a range of trial and error practices. Varying in levels of formal design, I 'approach participation . . . as an experimental practice' that ideally disrupts rather than stabilizes (Lezaun, Marres, and Tironi, "Experiments in Participation," 2017, p. 210).

at the University of California, San Diego (UCSD). I was interested in how scientists imagine the future and how these future imaginaries might inform their work. A Department of NanoEngineering had just formed at UCSD[3] and was offering its first undergraduate course as part of its new NanoEngineering Bachelor of Science degree.[4] I did not think I was interested in engineering education, but following a mentor's advice, I asked members of the Department if I could observe their undergraduate courses as part of my research project.[5] That became the beginning of a four-year ethnography of one of the first nanoengineering departments and undergraduate majors in the world.

It also became the beginning of my transition from thinking my job was to be an outsider simply critiquing dominant images and practices[6] of technoscience to focusing on how I could reflexively and collaboratively engage scientists and engineers in shared practices of world-making. Six years later, I defended my dissertation and accepted a position as an assistant professor in the School of Integrated Sciences (SIS) at James Madison University (JMU).[7] Here, I work with colleagues predominately from engineering and natural sciences to teach in the Integrated Science and Technology Bachelor of Science program (ISAT), a multidisciplinary applied science and technology program focused on holistic problem-solving. ISAT defines holistic problem-solving as a problem-centric critical thinking framework. Through this framework, students apply the breadth and depth dimensions of the curriculum to solving complex problems by thinking in terms of systems, working within collaborative learning communities, and integrating the social, political, and technological dimensions of the problem.[8] The program's mission is to produce graduates who 'excel in a complex, technological world by empowering them to become critical thinkers and lifelong learners able to provide multi-disciplinary solutions to scientific and technological challenges with sensitivity to social, ethical and global considerations'.[9] This has proven to be a fairly different context within which to critically participate. While the BS in NanoEngineering at UCSD is accredited as an engineering program, and the BS in ISAT is accredited as an applied science program, I hope to show that my insights regarding critical participation in both sites are relevant to engineering education.

My attempts at critical participation have unfolded sometimes haphazardly and humorously, sometimes amidst awkward challenges and disappointments, and other times in genuine and felicitous collaboration. This is a story of minor epiphanies and failures as I have come to recognize, at least for myself, what compromises and trade-offs might be required to achieve a kind of integration that allows for critique and mutual world-building

[3] At the time that UCSD established its Department of NanoEngineering, the only comparable institutionalization in the United States was at the University of Albany, where the Colleges of Nanoscale Science and Engineering were established in 2004. They are now part of SUNY Polytechnic Institute: https://sunypoly.edu/.

[4] http://nanoengineering.ucsd.edu/about-us/overview.

[5] The human subjects protocol for this study was initially approved by the UC San Diego Human Research Protections Program on 11/03/2010 (101734).

[6] Dominant practices of engineering refer to those that have 'become given or taken-for-granted' (Downey, "What Is Engineering Studies for?", 2009, p. 60).

[7] http://www.jmu.edu/isat/. SIS contains three undergraduate programs: a BS in Integrated Science and Technology, a BA or BS in Geographic Science, and a BS in Intelligence Analysis. It also jointly operates a BS in Biotechnology. The BS ISAT program offered its first undergraduate classes in 1993. Its creation was part of a response to a 1988 JMU Greater University Commission report calling on JMU to 'establish a program which builds on the knowledge of science and mathematics but incorporates a commitment to society and human beings' (http://www.jmu.edu/bsisat/about/history/index.shtml).

[8] Conley et al., "Acquisition of T-Shaped Expertise," 2017; "Developing Three-Dimensional T-Shaped Undergraduates," 2017; Biesecker et al., "The Missing Piece," 2016.

[9] Mission statement of the BS Integrated Science and Technology degree program. http://www.jmu.edu/bsisat/about/mission/index.shtml.

while avoiding the risks of 'cooptation and social engineering'.[10] And it is a reflection on the necessity of coming to terms with what I hope to achieve as a scholar and teacher in STS. What is my political project? Who am I trying to speak to? What am I trying to do when I engage?

At a high level, I want to help disrupt and reimagine dominant images and practices of science and engineering, and to that end, I want to theorize and develop ways of integrating STS – including feminist and postcolonial frameworks – into science and engineering education.[11] Such integration may contribute to recognizing the role of education in identity formation,[12] embracing the ethical and political dimensions of knowledge, technology, and engineering problem-solving,[13] questioning dominant narratives of progress and technological utopianism, crafting STEM curricula that embrace and make visible political values such as social justice and sustainability,[14] and practicing liberative pedagogies.[15]

Fortunately, I am not the first to consider this, and even as I am learning from many who have been studying, critiquing, theorizing and experimenting in the domain of STEM education for some time, I hope to contribute to the growing literature and community within STS that is embracing 'making and doing'. Downey and Zuiderent-Jerak write that 'practices of STS making and doing . . . draw upon and extend academic critiques of the linear model by enacting two-way, or multiple-way, travels of knowledge production and expression'.[16] That is, the STS critique of knowledge production as linear, from creation to diffusion to utilization, is also reflexively applied to STS forms of knowledge production. By highlighting the co-production of the STS researcher and the researcher's interlocutors, and the knowledge that emerges through their interaction, making and doing is one way of characterizing a mode of doing STS research that flexibly engages the contingency of knowledge production.

My work in STEM education might be characterized in terms of a category of making and doing that Downey and Zuiderent-Jerak describe as 'experiments in participation' or projects that 'formulate, enact, and reflexively learn from novel, STS-inspired practices within their fields of study'.[17] In what follows, I show how I have attempted to enact two-way travels of knowledge production between myself and engineers, and where I have

[10] Downey and Lucena describe the 'twin risks' of cooptation and social engineering:

> The cooptation of a project involves its transformation into something indistinguishable from that which it studies . . . dissolv[ing] the identity of the researcher(s) entirely into the field . . . . Social engineering involves presuming that one's expertise warrants the authority to legislate change through a research project. (Downey and Lucena, "Engineering Selves," 1997, p. 120)

[11] See work by Beddoes, "Feminist Scholarship in Engineering Education," 2012 and Riley, Pawley, and Tucker, "Feminisms in Engineering Education," 2009, with respect to engineering education specifically. I am also inspired by work in feminist and postcolonial scholarship that engages science and engineering education broadly, such as Barad, "Reconceiving Scientific Literacy," 2000, and work at the intersection of science, justice, and pedagogy coming out of the Science and Justice Research Center at the University of California, Santa Cruz: https://scijust.ucsc.edu/.

[12] See, for example, Downey, Lucena, and Mitcham, "Engineering Ethics and Identity," 2007; Downey and Lucena, "Engineering Selves," 1997; and York, "Smaller Is Better," 2015.

[13] See, for example, Boudreau, "To See the World Anew," 2015; Cech, "Culture of Disengagement," 2014; and Neusma and Riley, "Designs on Development," 2010.

[14] See, for example, Leydens and Lucena, *Engineering Justice*, 2017.

[15] See Riley, "Employing Liberative Pedagogies," 2003.

[16] Downey and Zuiderent-Jerak, "Making and Doing," 2017, p. 225.

[17] Downey and Zuiderent-Jerak, "Making and Doing," 2017, p. 239.

fallen short. I offer some reflection on what enabled or constrained meaningful interaction as I moved between the different institutional environments of NanoEngineering at UCSD and Integrated Science and Technology at JMU. These shifts in institutional environments were also accompanied by changes in my role and status, and therefore also the power dynamics within which I attempted to develop my engagement with scientists and engineers.

Part I: where the vision is to create human capital and intellectual capital[18]

The NanoEngineering Department at UCSD is hosted within the Jacobs School of Engineering, which has the vision statement of providing 'the human capital and the intellectual capital to drive our innovation society'.[19] Mission and vision statements may not singlehandedly determine goals and values, but they do percolate down into departments, programs, and courses in meaningful ways. Gaff and Meacham write that the integrity of an undergraduate curriculum and that of an institution are highly connected, organized in part through the university's mission statement:

> The faculty work within organizations, and every organizational policy and practice, many outside the purview of faculty, has at least potential impact, either positive or negative, on the curriculum and the learning of students. If the curriculum is to have integrity, institutional priorities, policies, and resource allocations must all support the most important purposes of undergraduate education. Indeed, integrity in the curriculum requires integrity of the institution. This, in turn, means that educational programs should reflect the institutional mission and enjoy the full and informed support not just of the faculty but also of the board of trustees and the president, the primary stewards of the mission.[20]

I first recognized the significance of the School's vision statement when I heard its sentiment articulated by the Dean at an event welcoming newly admitted undergraduate students. He told them they were the human capital the school was creating.[21] I came to see the NanoEngineering Department – not only its research, but also its culture and pedagogies – as manifesting these goals of capital formation on multiple levels. The possibilities for critical participation in this STEM space were shaped by this logic and imperative.[22]

Listening for my value

Developing a two-way flow of knowledge required me to become open to the ways that engineers in my site perceived and valued my role there. The challenge of aligning and

[18] The Jacob's School's vision statement is: 'The Jacobs School will provide the human capital and the intellectual capital to drive our innovation society' (http://jacobsschool.ucsd.edu/about/mission.sfe).

[19] http://jacobsschool.ucsd.edu/about/mission.sfe.

[20] Gaff and Meacham, "Learning Goals in Mission Statements," 2006, p. 6. Their analysis of hundreds of mission statements for colleges and universities listed in the Princeton Review's *The Best 331 Colleges* shows that few of them mention their educational goals for the undergraduate curriculum. They speculate this may be in part due to the fact that ' . . . in recent decades, some presidents have been selected more for their management skills, fundraising abilities, and public relations expertise than for their educational views' (p. 10).

[21] I witnessed this at two public events welcoming newly admitted students in 2011 and in 2012.

[22] Leydens and Lucena show how institutional factors including ABET accreditation criteria, and the presence of relevant professional societies and journals, have made it increasingly possible to innovate in engineering education since the 1980s. They write that "both the institutional and scholarly landscapes are different now and will continue to change. If we are aware of their dynamic features, contours, and possibilities, strategically we can make a difference" (Leydens and Lucena, *Engineering Justice*, 2018, p. 168).

reconciling my value and purpose as an ethnographer with the desires of the community I work with are not unique to STS ethnography. However, my experience with this can be usefully framed within what Downey and Zuiderent-Jerak describe as 'feedback and reframing', an attribute of making and doing related to how the STS researcher handles the feedback she receives from participants in the research.[23] This feedback may include claims about who the STS scholar is and what might constitute her role and value in the STEM space.

Initially, I was mystified by how the nanoengineers in my site persisted in describing me differently from how I presented myself – but by resisting their perspective I was missing an opportunity. When I first met with a leading member of the NanoEngineering Department, I was surprised when he did not ask why I was interested in the department.[24] But he did express why he was interested in my research. He indicated that as a new undergraduate program, they would eventually apply for ABET accreditation,[25] and might therefore benefit from having had an outside observer. There was no *quid pro quo*, but I agreed to provide a summary of my observations.

This initial interaction helped me to recognize that any integration or engagement has to offer some possibility of mutual benefit. This can be a difficult hurdle for STS in a STEM space, because there are frequently no institutional or financial incentives for involving social sciences in STEM research or pedagogy, and often no tradition of doing so. In an institution that privileges entrepreneurialism and capital formation, my potential to help their accreditation process or to promote their work fit their needs more than my interest in researching how their assumptions about the future might inform their work. Moreover, faculty members already have many demands on their time and attention. And any STEM–STS engagement might begin with mutual critique, distrust, or even colliding worldviews. With some naiveté, I had not approached the NanoEngineering Department with any clear sense of how my research might benefit them. At the time I was figuring out what my project was even about. Fortunately for me, they had immediately identified a potential benefit to having me there, relating to the undergraduate program.

Yet the undergraduate program was what I cared least about. Whenever I introduced myself to NanoEngineering faculty or students, I said I was interested in how a new scientific discipline forms, what nanoengineering is, and how nanoengineers imagine the future, repeating that I was not in educational assessment and was not there to evaluate the education program. Then, to my surprise, NanoEngineering faculty would often introduce me as someone who was evaluating their education program. How was this disconnect happening? I was only focusing on the undergraduate program because it offered entrée into other aspects of disciplinary formation. I was an aspiring STS scholar, after all, already picking up on cues about what was and was not valued in my own discipline. Engineering education did not seem high on the list. I was thinking about theory, knowledge production, and making my way into the laboratory.

[23] Downey and Zuiderent-Jerak, pp. 228–229.
[24] This preliminary meeting occurred in the fall of 2010.
[25] ABET is a nonprofit organization that accredits science and engineering programs in the United States. An institution voluntarily requests to undergo the peer-reviewed ABET accreditation process to ensure their program is recognized as meeting standards. A requirement of ABET accreditation is that the program must have at least one graduate the year before the program review begins: http://www.abet.org/accreditation/new-to-accreditation/eligibility-requirements/.

At the same time, I was increasingly intrigued by what I was observing in the classroom and learning from my interviews with students. I began to realize that I was narrowly constructing what might constitute engineering education and undervaluing the significance of the undergraduate program. In the classroom, I began to see how this four-year degree program in nanoengineering was a deeply cultural production that was consolidating nanoengineering as a very particular kind of endeavor.[26] It became evident to me how institutional histories and values – from UCSD's biotech beach days in the 1980s to the Jacobs School's vision statement of producing human and intellectual capital – permeated the construction of nanoengineering. Nanoengineering's histories and futures, its promises and imaginaries, its ethos and worldview, were all here in the undergraduate classroom. The co-production of matter and meaning, of nanoengineering as technics and as culture, was materializing in front of me.[27] Engineering education *already was* engineering-in-society education. The changing public university, the evolving cultures of capitalism, the pressures and demands of innovation economics, and the precarity of labor, were here in these spaces where undergraduate students were learning how to become nanoengineers. These factors were critical in shaping a nanoengineering identity. And I realized: I was absolutely studying their undergraduate program. I was evaluating it, too. I had thought they did not understand my role properly, and I kept resisting their framing and attempting to correct it. Had I been more open to their feedback and reframing, I might have recognized much sooner that there were multiple pathways and possibilities for this experiment in critical participation.

Moreover, they had been telling me how they were willing to receive me and how they could value me. Once I listened, I found new ways – however small and informal – of voicing my concerns and critiques, a point I will return to. Ultimately, I was not consulted regarding their ABET accreditation. But once I recognized how they could value me, I found that even if we had different ways of understanding my role, we had a common interest. The NanoEngineering Department's initial proposal for the undergraduate major states that the undergraduate program is the 'heart and soul' of the department.[28] I think this is not hyperbole. The undergraduate program is, in multiple ways, key to the department's entire existence and the broader disciplinary formation of nanoengineering. By listening to their reframing, I began to recognize how I could feasibly have traction in this space, and it was by connecting to that heart and soul.

Owning my multiple identities

Once I became more open to their feedback and reframing, it occurred to me that I might have something else to offer. Downey and Zuiderent-Jerak argue that another element of STS making and doing has to do with 'expertise and identities', writing that 'who an STS scholar is sometimes figures in specifying the pathways across which making and doing practices can or cannot travel'.[29] Yet initially I was so invested in my new identity as an STS

[26] For additional analysis of education as cultural production, see Downey, "The Engineering Cultures Syllabus," 2008; Lenoir, *Instituting Science*, 1997; and Levinson, Foley, and Holland, *The Cultural Production of the Educated Person*, 1996.

[27] I elaborate on this in York, "Smaller Is Better," 2015 and York, "Nanodreams and Nanoworlds," 2015.

[28] 'Our proposed NanoEngineering degree program is the very heart and soul of our department. We could not place any higher value on it, as the NanoEngineering degree is essential to our namesake and existence' (Proposed Undergraduate Program Leading to Bachelor of Science in NanoEngineering, Jacobs School of Engineering, 2009, p. 5).

[29] Downey and Zuiderent, 2017, p. 227.

scholar that I failed to appreciate other aspects of my expertise and identity that might facilitate additional pathways for participation. These included my identity as a Ph.D. student in Communication (who started out with a BA in English Literature and whose professional communication skills had been honed in the industry), and an MS in Computer Science with almost 10 years working in software development and software project management. At the time, I undervalued these aspects of my identity and even felt that mentioning them might misrepresent my STS motivations for being there.

However, leveraging my communication identity facilitated another means of creating mutual benefit. I had been analyzing the Department's newsletters with a focus on how they communicated their values, goals, research, and teaching. The newsletters were fascinating in terms of my research interests, but the faculty energy and enthusiasm I had encountered in person did not translate to the newsletter. I thought that an effective redesign that included engaging stories about their research, along with interviews and high-quality images would be worth their while. That is when I recalled how often they had picked up on aspects of my biography that I had underemphasized. Though I always spoke of the Science Studies Program, they recognized my location in a Communication Department in terms of science communication. That makes sense, but despite my location in a Communication Department, I still did not totally understand how I fit into communication. My program was not about science journalism, and certainly, my department's insistence that its name was 'communication' not 'communications' – an indication of our theory-driven approach to communication – would make little sense to outsiders. But however slow I was to realize it, I *was* studying science communication – particularly how scientists and engineers communicate to the newest members of their community (undergraduate students). *I* was somebody who could redesign their newsletter even if media production was not the focus of my own study or of my department's curriculum.

They needed someone with the time and communication skills to invest in their newsletter, and I needed access to faculty who had very busy schedules. So I proposed to redesign their newsletter based on faculty interviews. They were open to this idea. I scheduled interviews, included my Institutional Review Board (IRB) form, and communicated in the interview that I was also asking questions that pertained to my research project. And I also asked questions that were appropriate for a science journalism role. I recorded and transcribed these interviews, drafted stories, submitted the stories for faculty review, solicited images from them, and produced final drafts.

At first, I had three concerns. One was that I would not redesign the newsletter well, but I was soon satisfied that my redesign would be an improvement over the status quo. Second, I worried there might be something dishonest in offering to do their newsletter when my motivation was rooted in my research needs. I decided that as long as I fully informed them, had them sign the IRB, and genuinely did my best to produce a newsletter to their satisfaction, I had fulfilled my ethical responsibilities. Finally, I was concerned that producing the newsletter might risk my cooptation in that I would be promoting their stories without my critical lens. On this score, I reminded myself that the stories for the newsletter *were* their stories, not mine. It would be their newsletter. My research would not entail analyzing my own writing in these stories – my analysis would be based on my interviews, and the insights I might gain from studying how they worked toward presenting themselves to the public. Unfortunately, for reasons outside my control and as far as I know, having nothing to do with me or the newsletter, it was never published. But in the process of producing it, I was able to provide something they wanted, I was able to gain access to faculty, and I was able to see how faculty members responded to and revised my draft stories.

As in the case of engineering education, I had originally been reticent about owning my relationship to science communication. This was in part because I was invested in my STS identity, and in part because I had been learning in my training, however implicitly, not to value science communication as a field. My own disciplinary boundaries as a graduate student desperately trying to understand her place in the halls of academia had limited my ability to see how my relationship to science communication could be an advantage in attempting to find purchase within STEM communities.

Finding ways to make STS insights and alternate images relevant

Making STS insights and alternate images relevant requires making them visible and legitimate – and this may entail thinking creatively about how different frames might co-exist. For example, nanoengineers in my site frequently reference the 'real world' in relation to various aspects of their work and nanoengineering education. Attending to how some forms of knowledge production and some practices are privileged with 'real-world' status, and the ways this might routinely exclude humanities and the liberal arts, I perceived these references as attempts, however unintentional, to devalue knowledges and practices that are critical to responsible world-making. Yet, I have set my critique to the side. While I am still wary of the political work that real-world discourse may do, by acknowledging the range of demands and experiences connoted by the 'real world' I am better able to find intersections and overlaps between my concerns and the concerns of scientists and engineers with whom I wish to engage in reflexive, collaborative work.

Downey and Zuierent-Jerak posit that 'frictions and alternate images' are a key element of making and doing, writing that 'all images make some things visible while hiding others'.[30] What I have found is that making STS insights relevant is a process, and that frictions do not resolve by just replacing dominant images with alternate images. Instead, my experiments – in some cases, experiments in language – are attempts to find out how alternate images might sidle up to those dominant images, at least for a time, as a practice of centering what has been traditionally excluded or sidelined.

As I began writing my dissertation, I struggled with the question of who I was speaking to, and what impact I hoped to make. If I only spoke to my own dissertation committee or by extension to my disciplinary community, I did not see how I would have any impact on how cultures of science and engineering are reproduced. Yet if I wanted to speak to the nanoengineers, it was not clear why they should listen to anything I had to say. I had spent years observing the nanoengineering courses, spending time in the department, attending events, interviewing students and faculty, and observing one of the laboratories. Yet I did not feel that I had been successful in creating collaboration or mutual dialogue. Indeed, my desire to do this only developed over time, as the dominant image of STS I had perceived in my training had not made critical participation visible or legitimate to me. I also found myself focusing on my dissertation on precisely the things the nanoengineers largely found

[30] Downey and Zuiderent-Jerak, 2017, p. 227.

irrelevant.[31] Much of my argument analyzed how the boundaries between relevance and irrelevance were cast, and with what consequences.

For example, faculty in the NanoEngineering Department frequently talked about the 1966 science fiction film *Fantastic Voyage*[32] in the undergraduate curriculum to show how the science fiction vision of miniaturizing technologies for precision medicine was now being realized through nanoengineering. Yet they would routinely leave out what to me was crucial – the fact that it centrally revolves around a Cold War quest to use miniaturization technologies to create new weapons of mass destruction. How could I suggest they should make time in the classroom – time already strapped in trying to cover a broad multidisciplinary curriculum – to talk about something they considered to be just the Hollywood part?[33] Likewise, they repeatedly emphasize in the classroom that smaller is better. Why should they take my suggestion to include examples in which smaller is problematic?[34]

And much of my argument could be perceived as focusing on aspects outside their control – the pressures to obtain funding, commercialize whenever possible, and do research and teaching in a public university that is slowly being privatized. These institutional and cultural factors constitute the 'real world' of doing science for them. The nanoengineers who invited me into their classrooms and laboratories were amazing people trying to develop knowledge and technologies that could treat cancer and make solar energy more viable. These faculty members were also hired in part because they were perceived as the kind of entrepreneurial risk-takers the Department wanted.[35] At best my critiques of the emphasis on capital formation and its impacts on how nanoengineering was being constituted would likely be received with versions of 'this is the real world'.

I had to recognize that the 'real-world' indexes a range of ways that science and engineering are enabled and constrained by external factors. Listening more closely, I tried to find where our concerns might overlap, and then to reframe my questions and suggestions in ways that might travel. Although this occurred only toward the end of my research project, I was able to informally test the ground with some faculty and students. I appealed to utility and instrumentality as I highlighted potential alignments in educational goals.

For example, I argue that ethically grounded science requires an on-going critical mindset that asks: Who and what will *not* benefit from this? What could go wrong? For whom

[31] Downey and Lucena likewise describe how boundaries get drawn to render irrelevant anything outside the ideal mathematical framework of problem-solving: 'All the nonmathematical features of a problem, such as its politics, its connections to other sorts of problems, its power implications for those who solve it, and so forth, are taken as given.' Downey and Lucena, "Engineering Selves," 1998, p. 127.

[32] The film was written by Harry Kleiner, based on a short story written by Otto Klement and Jerome Bixby and starring Stephen Boyd and Raquel Welch. It is often associated with nanotechnology – see Berger "Another Nanotechnology Step," 2010; Freitas, "Nanomedicine Art Gallery," 2000; Farokhzad and Langer, "Small Is Fantastic," 2012; Loguidice, "Nanotech in 2009," 2009; Wyss Institute, "A Fantastic Voyage Through the Future of Nanomedicine," http://wyss.harvard.edu/viewpage/476/; and Kurzweil and Grossman, *Fantastic Voyage*, 2004.

[33] I discuss this in some detail in an article about the role of the film in the formation of a nanoengineering identity in York, "Nanodreams and Nanoworlds," 2015.

[34] I provide an analysis of how lectures and problem sets teaching students scale and scale conversion create a broader ethos and worldview centered on the dictum that smaller is better in an article in York, "Smaller Is Better," 2015. Similarly, Donna Riley makes the point that expanding the range of examples used in a thermodynamics class facilitates broader accessibility for students in relating course material to their own experiences, in Riley, "Employing Liberative Pedagogies," 2003.

[35] Interview on January 25, 2012 with a Department member in a leadership position.

might this *not* constitute progress and why? Who else might have insights relevant to this? A challenge for promoting this approach within the NanoEngineering Department stems from a widespread attitude that nanoengineering *is* good and therefore basic coverage of professional ethics before students graduate is sufficient. Yet if we only think we have to engage these questions when there is an obvious ethical dilemma, we may overlook the multiple plausible futures that might be enabled and constrained through our high-tech innovations, collectively sleepwalking through massive technological changes.[36] Moreover, if critical thinking and ethical reasoning are habits of mind – and if we want these practices to be part of an engineering identity[37] – they must be developed and sharpened through practice.

Nevertheless, alignment is possible. Whether success is maximizing social benefit or maximizing profits or just being first to create a new application, a mindset that reflexively and repeatedly analyzes and assesses a project with an eye toward who or what will not benefit and what could go wrong is better positioned to make the interventions and modifications that can steer it toward success. I can make this pitch to engineering faculty, and it resonates. This framing may not insist on attending to exclusion or failure for political reasons, but I do not see this as cooptation. Finding ways to meaningfully engage STEM practitioners in ways that move toward mutual critique, discovery, and world-building, requires keeping open to multiple frames. This entails not just replacing dominant images with alternate ones, but recasting and reframing dominant and alternate images in ways that make the alternate images recognizable and interesting.

This recalls some of the different perspectives on using the word 'feminist' in engineering spaces described by Beddoes in her 2009–2010 study of educators and researchers who engage in feminist engineering education. Some participants avoided using the term in some contexts whereas others felt that not using the word 'feminist' was academically unethical. I reflect on this in relation to context and purpose. For example, when I applied for my current position at JMU, I included 'feminist' in my cover letter because I had decided that if the department did not want someone with explicitly feminist perspectives, it was not a good fit. On the other hand, I consciously changed the label of one my course modules from 'feminist and postcolonial philosophies of science' to 'critical philosophies of science', because I wanted to make sure there was space to reach students who might benefit from a gradual introduction to these terms.[38]

While my developing approach of experimenting with dominant and alternate images of science may not have resulted in big changes at UCSD, it was critical to being offered a job in a STEM department where I would have an opportunity to collaboratively integrate STS into STEM learning. It also alerted me to the possibilities and potential rewards of accepting such a position within a science and technology department, where I might take critical participation to a new level.

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[36] The idea of sleepwalking through technological change comes from Langdon Winner's discussion of 'technological somnambulism' in Winner, "Technologies as Forms of Life," 2004.

[37] Downey and Lucena discuss the ways that 'as students become transformed into engineering problem solvers, what gets weeded out is everything else', and relate this to questions of identity and personhood (Downey and Lucena, "Engineering Selves," 1998, p. 128).

[38] Beddoes, "Feminist Scholarship in Engineering Education," 2012, p. 222.

Part II: where the mission is to prepare students to be educated and enlightened citizens who lead productive and meaningful lives[39]

As I said in the introduction, the ISAT program is located within the School of Integrated Sciences, which in turn exists in the College of Integrated Science and Engineering at JMU. JMU is a comprehensive public university predominately focused on undergraduate education, with an enrollment of 22,667 as of Fall 2017.[40] There is no engineering school, although the College that hosts ISAT also includes a department of engineering. In Part I, I emphasized the Jacob School's vision statement of providing human and intellectual capital because this vision permeated the Department of NanoEngineering and shaped the possibilities for how I might participate there. Here I have emphasized the university's mission statement for the same reason with respect to the BS-ISAT program – therefore offering an asymmetrical comparison between a school and a university, and a vision and a mission statement. Because JMU is a smaller, undergraduate-focused university without a separate engineering school, I suggest the weight of these vision and mission statements is equivalent in terms of impact on the respective departments and programs. In comparing the vision and mission statements, I am unabashedly drawing out the greatest contrast because it emphasizes the different imperatives that guide each institutional space: the former focused on human and intellectual capital and the latter focused on educated and enlightened citizens leading productive, meaningful lives. Both are focused on creating an interdisciplinary engineering or applied science degree that will prepare students for further education or jobs in industry, and both value entrepreneurship and innovation. Nevertheless, the cultural production of what it means to be a technologist is invariably embedded within these contrasting institutional imperatives and is therefore differently articulated, and differently amenable to STS interventions.

While the naming and accreditation also highlight another potential difference – between engineering and applied science – the NanoEngineering Department at UCSD was originally proposed as the Department of Nanoscience and Engineering, with the recognition that this very young field would be engaged in basic science, applied science, and engineering.[41] It became 'NanoEngineering' through negotiation, but understands itself as a multidisciplinary field operating in a space where distinctions between science and engineering do not apply. There is considerable overlap between the NanoEngineering and ISAT BS degrees: in both cases, the curriculum draws on a broad foundation of sciences, allowing the students to focus on one or two particular areas, and emphasizing breadth over depth. In neither case do I perceive breadth as indicating a peripheral status for particular courses.[42] Rather, each program claims that to achieve its objectives, the curriculum must be multidisciplinary. In NanoEngineering, multidisciplinarity and breadth are demanded by the requirements of working on the nanoscale. Students choose to focus on bioengineering, mechanical engineering, materials science, electric engineering, or chemical

[39] JMU's mission statement is: 'We are a community committed to preparing students to be educated and enlightened citizens who lead productive and meaningful lives.' Its vision statement: 'To be the national model for the engaged university: engaged with ideas and the world.' https://www.jmu.edu/jmuplans/about.shtml.

[40] http://www.jmu.edu/about/fact-and-figures.shtml.

[41] Esener et al., "Proposal for the Creation of the Department of Nanoengineering," 2007, pp. 161–162.

[42] I am referencing Downey's argument that 'breadth' in the context of a traditional engineering program is problematic because it tends to suggest the peripheral status of courses that supplement traditional engineering perspectives, in Downey, "PDS," 2015, p. 8.

engineering.[43] In the BS-ISAT degree, multidisciplinarity and breadth are demanded by the complexity of sociotechnical problem-solving and the kind of teamwork and stakeholder engagement required by industry. Students here concentrate in either biotechnology; information and knowledge management; energy; production systems (recently renamed from 'engineering and manufacturing'; environment; or telecommunications, networking, and security.[44]

Even as I highlight the overlaps between an engineering and an applied science degree, the BS-ISAT program does exist in a college that also has an engineering program, and ISAT often if informally highlights its distinctiveness by emphasizing its approach to holistic and systems-based thinking. Each year, the ISAT program receives transfers from the engineering program, and further research would be necessary to determine the range of motivations for students to transfer from engineering to ISAT. Interestingly, the Student Outcomes for ABET accreditation (Criterion 3) between engineering and applied science provide little insight into the substantive distinctions between engineering and applied science from an accreditation standpoint – the outcomes overlap considerably, with the word 'engineering' replaced by 'applied science' or eliminated.[45] More research would be necessary for me to characterize the specific distinctions between the ISAT and Engineering BS programs that are both housed within the same college; however, I want to make one point about ISAT and then one point about how my experiments in critical participation within ISAT might be relevant to persons working in engineering education specifically.

First, the ISAT curriculum models alternative pedagogical strategies for developing STEM graduates that might align well with needs in engineering education. For example, in considering the challenges facing engineering education, Gary Downey offers an alternative image of engineering as 'problem definition and solution (PDS)', writing that, 'One way of formally recognizing the core human dimensions of engineering work is to acknowledge that engineering problem solving has always included activities of collaborative problem definition.'[46] He goes on to recommend incorporating 'early involvement in problem definition', 'collaboration with those who define problems differently', 'assessing alternative implications for stakeholders', and 'leadership through technical mediation'.[47] One of the significant ways the ISAT BS differs from the NanoEngineering BS is precisely in how it takes up these approaches to problem-solving and leadership. It truly embraces the argument made by Bucciarelli and Drew that 'the problems engineers might face in practice do not appear so thoroughly decontextualized'.[48] The ISAT curriculum emphasizes multidisciplinary teamwork and active learning through which students learn to define complex problems with peers who are focusing on different areas of the curriculum. They learn methods of stakeholder analysis and mapping. They are asked to propose and assess various solutions with attention to different stakeholder interests. And the challenges of mediating among different perspectives, values, and stakeholder interests are explicitly incorporated

[43] See this presentation posted for Admit Day that introduces the undergraduate program: https://drive.google.com/file/d/0B99uwcA75V_YUnNZOU9BczU4a1U/view.
[44] http://www.jmu.edu/bsisat/about/program-overview/index.shtml.
[45] Referring to 2018–2019 ABET accreditation requirements for engineering and applied and natural science, the distinctions are in outcomes c, e, h, and k, with the most difference in c. http://www.abet.org/accreditation/accreditation-criteria/.
[46] Downey, "PDS," 2015, p. 9.
[47] Downey, "PDS," 2015, p. 9.
[48] Bucciarelli and Drew, "Liberal Studies in Engineering," p. 105.

into elements of a new portion of the curriculum that incorporates these learning objectives through a core sequence of classes that students take over the four years of the program.[49]

Second, the relevance of my experiences in ISAT for engineering education may be assessed in terms of considering the institutional and professional factors shaping the possibilities for critical participation. One enabling factor is that I am in a department that, while focused on applied technology and technical solutions, embraces multidisciplinarity. There are approximately 40 faculty primarily affiliated with the BS-ISAT undergraduate program, coming from almost as many different disciplinary backgrounds – agroforestry, statistics, biomedical engineering, archaeology, mechanical engineering, transportation technology and policy, computer science, electrical engineering and theoretical physics, and political science, just to name a few.[50] Although my background in communication and science studies is unique, I am on a team of faculty in the social contexts part of the BS-ISAT curriculum. The founders of the program – who largely came from industry – believed that critical problem-solving with science and technology requires a broad, interdisciplinary education that includes a keen awareness of the social dimensions of problems and potential solutions.[51] Though faculty members have varying understandings of what social contexts means, how it should be integrated, and how much emphasis it should have, we share an interest in being in a teaching-oriented multidisciplinary science and technology program that embraces holistic and systems-based thinking, including engaging the social contexts of science and technology. Another enabling factor in my critical participation is that my tenure-track location is within the ISAT department, I was hired to do what I am doing with STS and ethics in the curriculum, and this work counts in terms of tenure and promotion.[52] Additionally, my department values scholarship of teaching and learning (SOTL) research and publication, meaning that I can embrace teaching as an act of critical participation and scholarship, and this work counts.

That said, the challenges of making STS pedagogies and approaches accessible to my colleagues and my students are still present, and there is a demand to be able to demonstrate to colleagues and students the utility and applicability of what I teach. It is not a given for students when they enter my class that what I offer, or that the social contexts part of the curriculum more generally, is essential to their education, training, or future careers. So, similar to the challenges Downey describes in teaching an Engineering Cultures class, my courses must contend with the question of 'alternative knowledge' and students' preconceived notions that social contexts courses are about opinions. My teaching must work to integrate and make the liberal arts approaches I offer relevant for students who see themselves as technologists and engineers.

49 Biesecker et al., "The Missing Piece."

50 http://www.jmu.edu/bsisat/people/index.shtml.

51 The program was established as the College of Integrated Science and Technology in 1990 in response to a JMU Greater University Commission report that recommended developing a 'program which builds on the knowledge of science and mathematics but incorporates a commitment to society and human beings'. The new faculty hires had experience in industry and government. http://www.jmu.edu/bsisat/about/history/index.shtml.

52 Lehr makes the point that in order for liberal studies to be integrated into engineering, the participation of liberal studies faculty needs to count toward their part of their full-time jobs. Lehr, "Co-creating Liberal Studies," 2015, p. 124.

Teaching as critical participation

It is in this context that I have begun to experiment with teaching as critical participation through which I make STS approaches accessible and useful for STEM students and the STEM faculty members with whom I collaborate and co-teach classes. I have to show the utility of STS approaches in ways that fit within the applied orientation of the program. In so doing, I hope to contribute to the production of a STEM culture that embraces reflexivity and ethical engagement as integral to its ethos.

In the classroom, this means I focus on finding ways to incorporate STS approaches into activities and projects in ways that make social sciences and humanities perspectives clearly relevant to technology problems, while achieving several objectives.[53] First, I want them to recognize dominant narratives of progress, learn to specify what they mean when they invoke progress, recognize who or what may be excluded from this progress, and critically assess their own ideas about what kinds of social benefit they are hoping to produce in their careers. Second, I want them to recognize and analyze the ways that market logics inform, enable, and constrain high-tech innovation, while understanding how the ideals and values of science are necessary for democracy[54] and for achieving what they hope to do in terms of contributing to the public good. Third, I want them to develop critical communication skills that include understanding how communication reflects and shapes the political dimensions of science, technology, and innovation. Fourth, I want them to habitually employ critical thinking and ethical reasoning when deploying science and technology to solve problems.

These objectives informed my approach to teaching a required 200-level course in the major, Political Economy of Technology and Science. With student input, I assigned students into groups of four or five at the beginning of the semester and assigned each group a technology area: hydraulic fracturing, drones, internet of things, wind energy, the 'future of transportation', and genetic testing. Individuals within each group could focus on a more granular level within their topic area. Over the semester, students individually produced a professional report examining the political economy of their specific topic (for example, within transportation focus areas included autonomous vehicles, smart roads, and electric bikes). Elements of the report – including political, economic, and international dimensions applicable to their technology – were drafted over the course of the semester, where a key requirement was to incorporate independent research and apply course concepts to their topic. Students created visual elements, such as concept maps, stakeholder maps, and infographics. The reports were completed individually, but students worked in groups on shared bibliographies and class activities.

One of the first activities was to brainstorm reasons their technology could fail that were not strictly technological. Several activities involved challenging students to identify

[53] Flath writes that 'duplicating the student experience at an engineering college is not our goal. We want our engineering directed graduates to embody the critical thinking-based liberal arts approach to life and profession that is the strength of the education we provide', in "A Role for Engineering," 2015, p. 204. This course is one opportunity I have to challenge our technical students to learn foundational knowledge in liberal arts that we hope to develop and integrate in upper division technical courses.

[54] Bijker, "Constructing Worlds," 2017; Collins and Evans, *Why Democracies Need Science*, 2017; and Jasanoff, "The Essential Parallel," 2009.

how they might frame their technology in terms of the public good, and then how they might challenge that idea of public good and/or identify perspectives that would critique it. Ideas of public good and ethical reasoning were incorporated into abbreviated scenario analysis and design fiction activities where groups endeavored to identify and extrapolate from the most critical uncertainties driving their technology forward. Other activities were designed to better understand how the government shapes innovation. For example, students read and compared the FY2017 science and technology budget memo under the Obama Administration with the FY2019 science and technology budget memo under the Trump Administration. They were asked to reflect on how their technology areas might be enabled or constrained under each, how they might pitch a request for funding to best justify their technology under the terms of the budget priorities, and how hype might play a role in how they frame their budget requests. At the end of the semester, the students in each group had to collaborate to develop a presentation for the class that would integrate their different approaches to the topic and present for the class what a 'political economic analysis' of their technology area would show. Although more SOTL research on this experimentation would be necessary to better characterize my results, my assessment of their final presentations and reports was extremely encouraging and justifies further development of this approach. Student engagement was facilitated through the combination of individual research with its attendant challenges but also opportunities to immediately apply course concepts in a concrete application area; frequent in-class activities designed to challenge students' assumptions about risk, uncertainty, public good, and 'the' future; group presentations that challenged students to integrate their work and teach each other; and iterative development of a professional report.[55]

Advising capstone projects and team teaching with my STEM colleagues provide additional modes of teaching as critical participation. For example, I am co-advising a capstone project on autonomous vehicles that includes four faculty members and seven students. All of the students work in the lab building a vehicle prototype while also engaging the societal dimensions of autonomous vehicles. My faculty colleagues on the project have backgrounds in software engineering, mechanical engineering, and political science, so we model collaborative problem-solving as we guide them in effective teamwork.

I am additionally developing a year-long course with a colleague, whose background is in computer engineering, called 'Privacy in a Connected World'. It will engage cybersecurity and cyberphysical systems to model the 'integrated' aspect of our curriculum by focusing on holistic problem-solving and systems thinking. We proposed this topic because we felt it would attract a broad cross-section of our majors even if their focus is not on computing, and because we thought it would be conducive to practicing collaborative problem-solving that integrates multiple kinds of expertise as well as social contexts. As we develop this course together, I anticipate building in opportunities for researching how to effectively integrate STS into students' technical work.

[55] Reports ranged from 20 to 40 pages. I believe if I had assigned a 40-page report at the beginning of the semester, many students would have been intimidated. Instead, there was no page requirement. Students submitted drafts of some sections over the course of the semester, building confidence. In many cases, they became very invested, going well beyond the minimal requirements, and working with me to develop the report into a 'portfolio' piece they could present to a potential employer.

Conclusion: critical participation as mutual world-building

Opportunities to experiment in participation where knowledge and dialogue really move in multiple directions may be limited in a world where science is often distrusted or only valued when it can be commercialized, where the imperative of innovation often demands obeisance to the free market, where social sciences and humanities are routinely discounted and devalued, where critical thinking is often either omitted or remapped to linear problem-solving, where critique of any aspect of technoscience is often taken as a critique of every aspect and where critique of capitalism is often taken as obnoxious ignorance, where political fragmentation and a failing politics cannot even seem to solve the most pressing problems much less engage in long-term planning, and where progress and exploitation still too often remain kin. I choose to focus on how we enculturate scientists and engineers to understand science-in-society, and that includes how they imagine and dream their narratives of progress, how they approach problem-solving, how they engage with ethical reasoning, and how they relate to the institutional, cultural, economic, and political imperatives within which they will have their careers. Undergraduate STEM learning is one formative place where science culturally reproduces itself.[56] Whether a student goes on to graduate education or finds a job in industry, there is much that students will continue learning beyond their undergraduate degree about what it means to be a scientist or engineer. Yet I am optimistic that BS-ISAT students will retain some notion that innovating and reflexively thinking about the implications of innovation go hand-in-hand[57] and that approaching sociotechnical problems with sensitivity to social, ethical and global considerations is just common sense.

This brings me back to vision and mission statements. There are many factors that have shaped my experiences in each of these places. At the same time, I do not think it is too simplistic to suggest that in an institution in which the production of capital is the dominant imperative, any participation I might have would need to nominally adhere to that logic. How am I contributing to the production of human and/or intellectual capital? Likewise, in an institution in which the dominant imperative is the development of engaged citizens approaching sociotechnical problems with social and ethical sensitivity, any participation I might have would need to nominally adhere to that logic. How am I contributing to the development of such engaged citizens? And it is in the latter that I see a more comfortable fit for experiments in critical participation – particularly since my experiments are connected to teaching. Here it is easier to identify and articulate mutual benefit – shared values and concerns if not always shared vocabularies make it more possible to engage in mutual critique and world-building. In such a setting, it becomes possible to imagine something like an integrated science and technology degree that emphasizes holistic and systems-based thinking and engagement with the societal dimensions of innovation. And it becomes possible to imagine participating in inter- and multi-disciplinary research projects with my science and engineering colleagues where an authentic

[56] See Sharon Traweek's classic work on the cultural production of high-energy physics, which includes interesting analysis of both the undergraduate and graduate training, in Traweek, *Beamtimes and lifetimes*, 1988.

[57] I am referencing work by Karen Barad, in which she emphasizes the need to make doing science and thinking about science interconnected activities, in Barad, "Reconceiving Scientific Literacy as Agential Literacy," 2000.

collaborative engagement can emerge out of our shared concerns for teaching these students.[58]

My impacts may be modest, but when I consider where my students will go next, and the influence they may derive in part from their STEM credentials, I suspect that these impacts may have ripple effects I could not possibly trace or measure. In the fall of 2017, two undergraduate students that I co-advise came to 4S to present their work on autonomous vehicles. Their work integrates computing, engineering, STS, ethical reasoning, and design fiction. In watching them present, I realized they were not only articulating alternate images of science, but enacting a critical and reflexive mode of knowledge production – and demonstrating the potentially transformative impact of critical participation.[59]

Acknowledgements

I would like to thank Gary Downey for his thoughtful engagement with my work, as well as the very helpful feedback of my reviewers. Additionally, I would like to thank the many scientists and engineers at UCSD and at JMU who have worked with me and who help to make this a creative and collaborative process.

Disclosure statement

No potential conflict of interest was reported by the author.

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[58] Other places that have STS and humanities integration built into a STEM degree program in ways that go beyond a token ethics class include Lyman Briggs College at Michigan State University, http://lymanbriggs.msu.edu/mission.cfm and the STS program in the Department of Engineering & Society at the University of Virginia, https://engineering.virginia.edu/departments/engineering-and-society/academics/science-technology-society. Additionally, see the conversation on integrating liberal studies into engineering in volume 7 of *Engineering Studies*, specifically, Bucciarelli and Drew, “Liberal Studies in Engineering,” 2015. Leydens and Lucena also describe the integration of social justice into engineering education, and highlight Colorado School of Mines and University of San Diego as leaders in this (Leydens and Lucena, *Engineering Justice*, 2017, p. 146).

[59] See the blog post written by Colin Garvey, the panel organizer, that describes my students’ presentation at the 4S meeting in 2017: http://sites.library.queensu.ca/transmissions/making-sense-of-autonomous-technologies-40-years-later/. This was a project that I co-advised with my colleague Shannon Conley.

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