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Futures labs: a space for pedagogies of responsible innovation

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ABSTRACT

Lab spaces can teach STEM ethics by highlighting and creating opportunities to practice the four key dimensions of the AIRR framework of Responsible Innovation (RI): anticipation, inclusion, responsiveness, and reflexivity. In this paper, we introduce 'Futures Labs'~ as a pedagogical approach to train students in RI skills and encourage them to become aware of, and more concerned about, the broad social, political, ethical, and environmental dimensions of innovation. Our approach additionally trains students in a wide range of explicitly employable capacities (such as scenario building, foresight, communication, and collaboration skills). We conceive of the Futures Lab as a part of a broader permeation of RI-oriented educational practices within STEM institutions. Through practical experience in Futures Labs, students learn not only how to apply RI frameworks, but also get a feel for why doing so matters. The paper concludes with a practically-oriented discussion of exercises employed at each institution's Futures Lab.

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Introduction

STEM educators have increasingly recognized the value of learning labs and maker spaces for training students in creativity and innovation (see Gershensfeld 2005; Robinson 2017, Resnick 2017, Wagner 2012). The growing popularity of maker spaces may be attributed to their functional polyvalence. They have been, for example, touted for fostering the innovation skills essential for finding employment in tomorrow's workforce (Brynjolfsson and McAfee 2014). They have also been shown to stimulate the innovation and innovation skills required for addressing our grand challenges (Sachs 2015). Yet the idea of developing maker spaces explicitly aimed at training students not only to be innovate, but to do so in an ethical and responsible way, has been less developed. This is unfortunate, since innovators with no grounding in the responsible use of creativity are likely to continue generating 'unanticipated consequences' (Jasanoff 2016) with their innovations, applying themselves to creating novelties that will not only fail to

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address social challenges but will also create new social, environmental, or political problems. With the aim of meeting this need this paper introduces the ‘Futures Lab’ pedagogy, an approach to making maker spaces grounded in RI (Responsible Innovation) thinking and models.¹

We primarily adopt Stilgoe et al.’s (2013) concise framing of responsible innovation as ‘... taking care of the future through collective stewardship of science and innovation in the present,’ particularly appreciating the way in which this resonates with existing definitions of sustainable development.² Futures Labs are spaces that employ a wide range of approaches to develop RI competences and cultivate associated sensibilities and ethical orientations. Innovating responsibly demands an awareness of the ethical stakes involved in innovating and requires that efforts be made to ensure ‘societal desirability of the innovation process’ itself (Von Schomberg 2011, 9). It implies that innovators understand innovation and its value in ways that exceed narrow economic productivity and competitiveness models (Godin 2017; de Saille and Medvecky 2016). RI practitioners should recognize that even economically successful innovations can introduce undesirable effects such as fostering an uneven distribution of benefits and harms. They should also be open to the possibility that responsibility may entail *not* pursuing an innovation (see Douglas 2017; Williams 2020; and De Hoop, Pols, and Romijn 2016). Making this kind of choice requires an ability to anticipate and appreciate the kinds of long-term impacts that proposed innovations may have within complex and dynamic systems.

Foresight can help innovators to better align their practices with ‘with public visions and values’ (Guston 2008, 941). Additionally, innovators need to learn how to cultivate inclusivity, both with respect to their innovations and with respect to the innovation process (Lam et al. 2019). Accomplishing all this requires trainable practical skills. Futures Labs create opportunities for learners to develop Stilgoe et al.’s (2013) four key praxeological dimensions of responsible innovation: anticipation, inclusion, reflexivity, and responsiveness (AIRR). Part of the anticipatory axis of Futures Labs includes the promotion of futures literacy, ‘the skill that allows people to better understand the role of the future in what they see and do’ (UNESCO). UNESCO elaborates that ‘being futures literate empowers the imagination, enhances our ability to prepare, recover and invent as changes occur.’ Futures Labs pedagogies bring futures literacy into STEM education, cultivating moral imagination and responsibility in tandem with systems approaches to framing problems and prototyping solutions.

Futures Lab pedagogies can foster concrete RI skills, capacities, and habits of mind, via a PBL (Problem Based Learning) approach. PBL traces its lineage back to Dewey (1986), Piaget (1969) and Papert (1980) education theorists who placed a primacy on the practical. The importance of the praxiological dimension in RI and STEM ethics education is sometimes under-appreciated. As Åm (2019) has pointed out, many STEM professionals do not have the skills to actually operate within an RI framework even when they are aware that they must do so. In response to this, Pansera et al. (2020) have suggested that students need to learn upstream socialization skills which can help them to better align innovations ‘with societal challenges, expectations, values and needs.’ In other words, teaching students to be responsible innovators requires a great deal more than informing them about the details of an RI framework or asking them to analyze past cases of irresponsible innovation while prompting them to identify where the moral

decision-making processes of past actors went wrong. As Guston (2014) has argued, practice is the key to developing anticipation capacity, and the same can be said of other RI skills, particularly those associated with inclusiveness and responsiveness.

Futures Labs not only train students in a wide range of RI practices (scenario building, foresight, communication, and collaboration skills) but also cultivate a way of being an innovator, in Aristotelian terms, as a virtuous or ethical mode of being. The ethical innovator is attuned to the value of exercising care regarding inclusive design and is sensitive to the potential risks and abuses associated with innovating. They are, as Richter, Hale, and Archambault (2019) note, 'both reflexive and futures-oriented,' attuned to thinking holistically and critically about innovating, recognizing that technological innovations alone (to quote and critique Bouzou (2016)) will not 'save the world.' They exercise foresight in such a way as to 'enrich futures-in-the-making by encouraging and developing reflexivity in the system' (Barben et al. 2008, 986). Futures Labs train innovators who possess creative or forward-oriented practical wisdom (*phronesis*) for RI (Owen and Pansera 2019; Steen, Sand, and Van de Poel 2021; Flyvbjerg 2004).

Our approach differs from traditional approaches to engineering ethics education. These approaches tend to be more theoretical and less praxiological and they tend to focus on what might be called professional ethics as opposed to innovation ethics. Professional ethics are concerned with perennial issues implied in the practice of engineering such as the honest reporting of data and the need to respect industry-standard best practices in the face of demands to lower costs. Professional ethicists tend to pay less attention to the broader risks associated with innovation and their ethical implications for engineering practice, such that Stephen Unger's classic text on engineering ethics, *Controlling Technology: Ethics and The Responsible Engineer* does not even have a sustained discussion of anticipating and avoiding unintended consequences, value sensitivity, and forward-looking responsibility. In consequence of their focus on well-established professional norms as opposed to as opposed to more complex and uncertain broader societal risks, training programs in professional ethics tend to focus on the analysis of past cases for malfeasance and breaches of existing codes.³ Innovation, however, poses unique challenges to responsible action that are not well subsumed under well-normed moral categories such as lying, cheating, or stealing. Drawing on a distinction made by Wolf (1980), it seems legitimate to claim that professional ethics encourages students to think about responsibility primarily in terms of blame, where irresponsibility is measured in terms of deviance from a pre-existing code. Innovation ethics, to the contrary, needs to understand responsibility in terms of praise with respect to choices made by actors in light of actions which cannot yet be measured against any pre-existing normative code. Only in this way can we differentiate between irresponsible but occasionally productive approaches to innovation – for example the fail-fast ideologies promoted by innovation gurus such Diamandis and Kotler (2015) (they argue that one must deliberately pursue failure as a method 'Fail early, fail often, fail forward!' (113)) and more measured and foresightful attempts to innovate while avoiding failure – or more specifically – to innovate without exposing the collective to excessive risks.⁴ Note that the difference between fail-fast innovation and responsible innovation is not merely to be located at the level of intention but also in terms of practice, namely the upstream and downstream efforts made by responsible innovators to avoid unanticipated social harms.

In contrast, Futures Labs build on a range of more recent approaches to engineering ethics education that do take seriously the need for understanding responsibility in broader terms, including Joyce et al. (2018), Riley (2003), Selin and Boradkar (2010), Walling (2015), Tomblin and Mogul (2020); Pansera et al. (2020), and Nieuwsma and Malazita (2016). Futures Labs offer a practical approach to the ethics of innovation and a reflective approach to learning creative foresight skills in part through critical making practices in which ethics, creativity, and innovation together stimulate auto-poetic reflexivity regarding the creative act and the creative actor. In order to clarify how Futures Labs can help to foster AIRR and RI skills, and to give context to the theorizations that follow, the next section of this paper illustrates the practices that go on in the Futures Labs at the authors' respective institutions: the JMU in the United States and the ENSTA-Bretagne in France.

Two futures labs

Authors York and Conley established the JMU STS Futures Lab in 2017. It is located within an applied science undergraduate degree program in the College of Integrated Science and Engineering at James Madison University, a public institution in Virginia, in the United States. Tabas established the ENSTA-Bretagne Futures Lab in 2019. It is located within a *grande école* in Brest, France, an elite engineering school financed by the French Minister of Defense with a student body consisting of masters and Ph.D.-level students earning either the masters-level generalist *diplôme d'ingénieur* or specialized advanced technical degrees.

The JMU STS futures lab

The STS Futures Lab began as a small undergraduate capstone research project that soon evolved into a larger experimental module within the confines of a required Science, Technology, and Society (STS) class in an applied science curriculum. From there, it became an informal laboratory experience in a borrowed and shared space, and in 2018–2019 finally graduated into a permanent undergraduate program with a dedicated lab space in the Engineering-Geosciences Building. In 2020–2021, York and Conley received several grants, including two National Science Foundation (NSF) awards, further solidifying the Lab's standing and creating additional opportunities for the lab. In 2021, another faculty member – Dr. Tolu Odumosu – joined the lab.

York and Conley originally conceptualized the Lab as a site of critical participation at the intersection of research and pedagogy, which would engage undergraduate students in STS-inflected research (York 2018, York and Conley 2019). Participating in the Futures Lab is technically considered a class by the institution, however in practice it is an ongoing experiment with formal weekly lab meetings and significant and ongoing non-scheduled student and teacher presence and engagement. Many students enroll in the Futures Lab for multiple semesters. The students engage in independent STS-inflected research and they participate in the research led by the Lab faculty that engages studies of expertise and interdisciplinarity, responsible innovation, and the societal dimensions of emerging technologies. A key methodology used in this Futures Lab is Creative Anticipatory Ethical Reasoning (CAER) – a blend of scenario analysis,

design fiction, and ethical reasoning designed to cultivate students' capacities for responsible innovation (York and Conley 2020).⁵ Design fiction is a blend of narrative and material making that facilitates visualizing and collective thinking about potential future forms of life related to a selected scenario (Bleecker 2009). CAER is likewise a research methodology used in an ongoing workshop series, 'Co-Imagining Futures.' As part of this series experts from different disciplines are invited to critically imagine and interrogate plausible future trajectories connected to their own research (see York et al. 2019). It is also incorporated into a new NSF research project in the Lab called 'Collaborative Research and Education Architecture for Transformative Engagement with STS (CREATE/STS)'.⁶ The space of the Futures Lab is an important component in supporting the lab's objectives of cultivating community, exploring the intersections between pedagogy and research, and facilitating 'serious play' as a means to develop what Johnson calls moral imagination (1994, 2014).

The ENSTA-Bretagne futures lab

The ENSTA Bretagne Futures Lab does not yet have a dedicated lab space, but has emerged out of a long-running class employing creative expression as a tool for developing a greater sense of ethical responsibility among engineering students.⁷ Its core pedagogical practices, including the idea of 'monstering' – making things to help us better imagine future scenarios – have also been exported and conducted virtually as part of A-STEP 2030, an EU Erasmus + funded project's Summer School's Futures program.

The ENSTA Futures Lab emerged via a combination of factors. First and foremost, the ENSTA as an institution is very open to pedagogical experimentation and innovation. Tabas and the other members of the SHS (Social and Human Sciences) department are part of a research group on engineering pedagogy (EA 7529) whose recent projects have included EU-funded studies on the training of engineers for innovation and sustainable development (INNOV'Ing2020, RIIME, A-STEP 2030).⁸ This work revealed that it was possible and necessary to train innovators who were sensitive to the sociotechnical impacts of their innovations, but that current pedagogies were frequently poorly aligned with this task. Inspiration was also drawn from Gerard K. O'Neill's early 1970s attempts to re-invigorate engineering education and to solve the problems of sustainable development by pursuing radical and outside of the box future thinking with his students.⁹ Ongoing dialogue with York and Conley has also been a major factor in the development of the ENSTA Futures Lab.

Currently, the ENSTA lab exists as a third-year elective module, though elements of RI pedagogy are found throughout the curriculum. ENSTA Futures Lab students are first introduced to key notions of responsible innovation followed by a training session devoted to developing futures literacy, a self-critical awareness of the limits and biases of our anticipatory capacities (Miller 2018). The students then learn the basics of scenario thinking, employing methods developed by Schwartz (1991), and progress from generating possible futures in words to generating objects and models – monsters – which will themselves serve as supports for further investigations and practical engagements with the consequences of innovations. Past futures that have been investigated are the future in outer space, the future of everyday life, the future of engineering education and the future of food. Past monsters have employed wood, motors, cardboard, plastics,

blocks and computer simulations which have allowed students to reflect deeply on the desirability the modes of technological innovation informed daily life in a sustainable (or unsustainable) future. In addition to making monsters, ENSTA students role play dialogs and debates bearing on questions linked to innovation-enabled futures and questions of epistemic injustice (Fricker 2007).

Theoretical underpinnings

In this section we offer a preliminary theorization of Futures Lab pedagogies that undergird the JMU and ENSTA Futures Labs. Our aim here is not to pin down how Futures Labs work but rather to help other educators better understand the potential of Futures Lab learning so that they may adopt and adapt it for other geographical, institutional and disciplinary contexts. Not only has each of these Futures Labs emerged in its own specific set of contexts, as previously described, but our respective attempts to theorize it are grounded in our different trajectories toward this pedagogical formation. This section therefore identifies different, albeit complementary, theoretical lineages that have guided each of these Futures Labs toward highly similar practices.

The ENSTA Futures Lab came to critical making (or ‘monstering’) as a form of problem-based learning (PBL) that shares characteristics of what Seymour Papert has referred to as ‘learning machines’ (1993). Papert is the founder of the ‘constructionist’ approach to pedagogy, which is rooted in a theory of learning by construction, whereby playing and building things is understood as a means towards the development (‘construction’) of students’ cognitive competences. Papert contrasted this with ‘instructionist’ or ‘broadcast’ (138) theories of education that conceive of learning as a process in which students memorize and reproduce information that has been pre-digested by their teachers.¹⁰ In moving to constructionism, Papert emphasized the importance of the classroom and the material or virtual objects within that space for learning. On his account, students learn through playing, with the affordances provided by the things that one plays with informing what one learns. As he explained, even if the construction of ideas takes place ‘in the head,’ learning happens ‘especially felicitously’ when it is supported by a ‘construction’ of a ‘more public sort’ such as ‘a sand castle or a cake, a Lego house or a corporation, a computer program, a poem, or a theory of the universe’ (142). Note that different objects offer different affordances, with some toys enabling what Carse (1986) has called ‘finite games’ while others enable the far wider degree of creativity and learning associated with ‘infinite games.’

Papert sometimes suggested that what learners acquire via such constructions is a skill akin to ‘*bricolage*’ (152). *Bricolage* can be roughly translated as a capacity to tinker, an ability to flexibly and creatively solve problems with a limited and less than ideal set of tools and procedures. Rather than aiming to inculcate a single specific and well-defined lesson, these making – and play-based practices teach a more holistic set of flexible sub-skills that allow students to deal creatively with novel situations. In distinction to traditional maker-based pedagogies however, the critical making that goes on in Futures Labs is primarily subjectively and socially oriented: students learn not skills associated with fabricating new technologies but rather skills associated with the invention of the novel forms of self-reflexivity and innovative approaches to social engagement that are required for the critical assessment of proposed innovations. In consequence, the

toys – the monsters that are made in the lab – are primarily rich and multi-level representations of innovations or prototypes that show (*montrer*) the potentialities inherent in innovations that could be made, rather than types of innovations which practically function in the real world.

The JMU STS Futures Lab came to critical making through a focus on situated learning (Lave and Wenger 1991) and the role of mediated artifacts and activity in cognition, identity, and learning, as highlighted in the notion of figured worlds (Holland et al. 1998). As Holland et al. explain, a figured world is a ‘socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others’ (Holland et al. 1998, 51). Like Papert’s constructionism, there is an emphasis on environment and on the material things through which one engages in the environment. In situated learning approaches to learning, the sociality of such learning is emphasized:

Learning viewed as situated activity has as its central defining characteristics a process that we call *legitimate peripheral participation* . . . [which] provides a way to speak about the relations between newcomers and old-timers, and about activities, identities, artifacts, and communities of knowledge and practice. It concerns the process by which newcomers become part of a community of practice. A person’s intentions to learn are engaged and the meaning of learning is configured through the process of becoming a full participant in a sociocultural practice. (Lave and Wenger 1991, 29)

In the Futures Lab, students enter into a space that includes faculty, first-time students, and returning students. Their learning and becoming in this world occur in relation to their improvisations in this environment, and their interactions with each other and with the objects and material-discursive practices within the lab. In other words, the social world of the lab and the students’ sense of themselves and relation to practices of responsible innovation emerge in a dynamic and mutually constitutive way. This occurs not only with the things they make and do but with what has already been made and done in the lab that is now figured into the space: art supplies, previous design fiction installations, posters, rolling whiteboards, virtual reality headsets, couches and different kinds of spaces within the lab (e.g. seminar space, lounge space, crafting space, virtual reality space) to think and reflect. Repetition of material-discursive practices and engagement with returning students are key. For example, students come to see that certain forms of questioning such as asking ‘who might not benefit from this innovation’ and ‘which publics are you referring to’ are valued as part of what it means to think responsibly about innovation when they hear these questions repeated by returning students and faculty. Students come to relish doing ‘juicy quote’ reflections when they see that they will engage with this many times throughout the semester and returning students enthusiastically share their own juicy quote reflections that sometimes involve sharing images, poetry, and even short stories as part of the reflection process (all followed by collective encouragement and positive feedback). Making sense of themselves as actors in this context forces them to simultaneously question many dominant practices of learning about technology and dominant images of high tech innovation. The ongoing figuring of the world of the lab is done through shared practices of material creation, reflection, negotiation, and interpretation concerning ideals related to science, technological progress, ethics and justice.

The agency of students as learners in a figured world resonates with a critical pedagogy lens as well. One of the tensions that often comes to the foreground within the culture of the Futures Labs is the relationship between innovation and domination. Futures Lab exercises encourage students to reflexively interrogate assumptions regarding the ‘universality’ of progress, considering ways in which innovations can exclude and cause harm. Students do not necessarily engage in these reflections in response to a top-down injunction from the teacher, but rather, these ideas emerge as co-creations through the active role taken by students in the learning experience. Additionally, it is the students’ perspectives, insights, and creations that help constitute the figured world. Futures Labs resonate with Freire’s ideas about critical pedagogy in two senses: on the one hand, by cultivating a reflective and critical attitude towards questionable normative ideas and power structures, and on the other hand by rejecting a ‘banking’ model of pedagogy, whereby students are imagined as ‘containers’ needing to be stocked with knowledge (including, perversely, a capacity for criticism) (2000).

In sum, these diverse theoretical lineages have led each of the Futures Labs toward anticipatory, reflexive critical making practices in ways that engage students in a dynamic space in which learners teach themselves about innovating responsibly. A Futures Lab is not a machine for conditioning students to memorize a normative code of conduct, but a space for serious play that allows students to use their creativity to develop a new, and more responsible sense of themselves and the world that they, as innovators, co-create.

Futures labs and the four praxeological dimensions of responsible innovation

As flexible and open as Futures Lab methods are, they are nevertheless collectively oriented towards the development of certain key RI skills. In this section we discuss how the JMU and ENSTA Futures Labs reinforce skills relevant to the four praxeological dimensions of RI: anticipation, inclusion, reflexivity, and responsiveness.

Anticipation

As soon as students step into a Futures Lab they are surrounded by artifacts – past monsters – calling to their attention the future as it is anticipated in the present. Anticipation is distinct from prediction in that it stands in a critical relationship to the tools and results yielded by predictive methodologies. At the same time, anticipations are more than mere conjectures: they performatively condition present courses of action (Urry 2016). Virtually every skill and practice that takes place within the Futures Lab space serves to bring student attention towards these horizons of anticipation, both to develop these horizons and to criticize them. One practice that plays a key role in this critical anticipatory thinking is scenario planning (see, for example, Selin (2011), MacKay and McKiernan (2018), Wade (2012)). Stilgoe et al. celebrate scenario thinking for calling attention to ‘the complexities and uncertainties of science and society’s co-evolution’ (Stilgoe et al. 2013, 1571), and Gaston highlights anticipation as one of the capacities that encourages and supports scientists and engineers to reflect on their roles within a technological society (2013)). The reframing practices involved in the best approaches to foresight

(for example the OSPA approach (Ramirez and Wilkinson 2016) help students to recognize and question assumptions about technology, innovation, the public good, universalism, and progress; and to reflect on power dynamics, standpoint (Harding 2004), and interpretive flexibility (Bijker 2017). Other critical foresight techniques that find their way into Futures Labs are creating design fiction and reading and writing science fiction.¹¹

Futures Labs students learn to explore, assess, and anticipate technologies as forms of life (Winner 1986), opening up broader questions about ethics and progress than might occur with a focus on technology as merely a tool or object. Drawing on Wittgenstein, Winner explains that forms of life are ‘distinctive worlds’ and ways of being in the world engendered by technical devices through ‘significant alterations in patterns of human activity and human institutions’ (Winner 1986, 11). To think about a technology as a form of life is to recognize that innovations can deeply shape norms of thinking, communicating, interacting, understanding the human condition and going about everyday aspects of life. By learning to anticipate technologies as forms of life, Futures Lab practices help students to shift their attention from an often-hyped and uncritical focus on a technology as such to imagining it as something already deeply integrated into society in a particular form, and, as Ludwig and Macnaghten argue, this concept shifts ‘... the focus from narrowly defined effects and risks of innovations towards their wider and often highly complex roles in adopting communities’ (2020). For example, with respect to autonomous vehicles, students might consider how specific versions and implementations of the technology might undergird norms and practices for different stakeholders: Will middle income people still be able drive if they want to? If only completely autonomous (i.e. ‘level 5’) vehicles are allowed on the road, where will the pedestrians go? Will certain communities, for instance, rural communities, be effaced – or alternately invaded – by new infrastructures? What does accessibility look like, and for whom? (York and Conley 2020). Such questions refigure risk in ways that go beyond simplistic cause-and-effect, cost–benefit calculations. Together, these practices encourage students to delve into, discuss, and even virtually and critically inhabit a multiplicity of possible futures.

In this learning context, the most important outcome of a scenario analysis isn’t a particular quota of plausible futures or a strategic justification for policymaking, but rather an enriched moral imagination endowed with heightened anticipatory reasoning capacities. In other words, it is the development of futures literacy as applied to innovation. Within the Futures Lab the means to this awareness often include critical making practices that generate supports for efforts to imagine the transformative potential of technical novelties. Engaging in critical making is a form of play through which learners can develop reflexive anticipatory capacities, including understanding the deeply contingent and political nature of the technologically-informed making of the social world. These learning games likewise catalyze awareness of how even ‘minor’ innovations can raise major questions of social justice (see Ludwig and Macnaghten 2020).

Futures Lab students employ multi-modal strategies to produce objects that support and encourage collective investigation of different scenarios. For example, rather than making a new home appliance, students might make a simulacrum of an imagined appliance juxtaposed with a verbal or visual slice of life to help better understand what it would be like to live in a home, or to walk into a kitchen, in which such an appliance

was installed. In so doing they would be called to reflect on their assumptions about *home*, *walking*, and the socially differentiated values of appliances. Different anticipatory media offer different avenues for thinking about and even experiencing how real innovations translate into forms of life, with each medium opening specific horizons of insight into the affordances that condition how actual innovations might inform future social ontologies. Encouraging students to develop innovative techniques to deepen their awareness of future modes of existence helps them to explore the ethical implications of an innovation without actually implementing it upon a population (Rosen 2013).

Inclusion

An inclusive innovator must learn to include others in the innovation process in ways that do not homogenize their diverse perspectives. As diversity and inclusion scholars emphasize, including others *only* gets one to diversity, not to inclusion (Robertson 2013). The value of cultivating inclusiveness, as well as a student-innovator's ability to foster inclusion in practice is vital. Inclusiveness is a social good, insofar as it avoids the 'epistemic injustice' (Fricker 2007) that ensues when the perspectives of members of marginalized or excluded groups are ignored. Inclusion likewise contributes to 'stronger objectivity' (Harding 2004) with respect to value-laden truth claims, offering clarity when answering questions such as: 'Who might not benefit and/or who might be harmed from this?' Meaningfully including social groups and communities in the innovation process contributes to 'legitimizing' 'science and innovation' driven solutions to collective problems (Stilgoe et al. 2013).

Futures Labs attempt to hone inclusiveness skills in many ways, focusing both on practicing inclusiveness within organizations and with community partners. That is, inclusiveness skills encompass facilitating and participating in deliberative fora that include not only immediate stakeholders but members of the broader public, or 'mini-publics' (Stilgoe et al. 2013, Goodin and Dryzek 2006). Labs can seek to invite and involve scholars and activists/advocates from a variety of disciplinary domains in questions about responsible innovation. For example, at JMU a disability studies scholar and a construction architect led a university-wide workshop on imagining futures of college campus accessibility. The collaborative nature of these co-imagining sessions prompted an interrogation of assumptions and values in different domains, and enabled all participants to collaboratively reflect on justice, fairness, equity, and responsibility. Reading selections and research guidance can ask students to envision and model practices of antiracism in the context of responsible innovation, or to speculate on how inclusion will have been fostered in the engineering classrooms of tomorrow. Pedagogically-engaged research can also cultivate an inclusive and diverse environment. For example, York and Conley recently began implementing their 'Collaborative Research and Education Architecture for Transformative Engagement with STS (CREATE/STS)' National Science Foundation project in the JMU Futures Lab that engages students and faculty from STEM and humanities fields to collectively imagine just futures through new pedagogy development. Futures Labs can be places where students from diverse majors congregate to participate in creative games reflecting and exploring values like diversity, equity, and inclusion.

Reflexivity

In a certain sense, Futures Labs students make nothing but themselves, and so a Futures Lab can be considered a reflexive pedagogical tool *par excellence*. Reflexivity has been defined as the knowledge that ‘one’s own activities, commitments, and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue might not be universally held’ (Stigloe 2013, 1571). Reflexive practices include interrogating value systems, thinking about what it means to create and be a creator, and considering big questions such as whether innovation as such is necessarily a good thing (see Williams 2020).

One of the key practices associated the development and need for reflexive thinking in the innovation process is ‘midstream modulation’ (on this, see the work of the Socio-technical Integration Research (STIR) program (Fisher et al. 2006, Fisher 2007, Conley 2011, Conley and Fisher 2019)). As a practice, midstream modulation requires that innovators learn to attend to their innovations in an ongoing way, constantly surveying, analyzing, and adjusting the innovation as needed. Such a practice is inseparable from an ongoing preoccupation with cultivating reflexivity. Modulating midstream involves coordinating and communicating with publics affected by an innovation, and thus requires that actors be skilled at publicly eliciting reflexive responses in others as well as in themselves. Stigloe et al. (2013) advocate that the collective engagement in reflexive practices be incorporated into the requirements of research funders and governance institutions that interface with scientific and technological development (see also Owen et al. 2021).

In order to foster these skills in the Futures Lab, educators can use the STIR protocol to reflect on ethical decision-making by engaging with science fiction. For example, Conley has effectively engaged STIR in Mary Shelley’s *Frankenstein* (1818), prompting students to think about the analogies between themselves as creators and Victor Frankenstein, and to describe how and why they might have acted differently, were they in his shoes. The students were then encouraged to apply a similar process of reflexive creativity to reflecting on the creation of a 1/8th scale autonomous vehicle, with the express intention of anticipating ways in which this vehicle might become a monster and they – its creators – latter-day Frankensteins.

Other practices of engaging science fiction can also cultivate reflexivity. For example, Tabas invited students to collectively write science fiction stories about technological innovations which feature engineers as their protagonists. Because these stories are written collectively, students spend significant time thinking about the destructive impacts of the innovation within the future world described in the tale. They can also be challenged to explore whether the engineer character incarnates a positive example to be imitated, or a negative prototype to be avoided. Students can also be encouraged to engage in critical role play in which they criticize innovations from the viewpoint of different sorts of actors, each of whom sees the same innovation but in a different light.

Responsiveness

One of the problems with technocratic innovation as usual is that it tends to impose new technologies on actors without taking into account their needs and desires. Cultivating

responsiveness in innovators – an ability to learn and adjust based on upstream input and feedback as well as previous experience – can help to ensure that innovations are a good fit for the communities that they are meant to serve. Learning to be responsive involves cultivating an openness and attunement to the world and a willingness to acknowledge the claims and contributions of others. Such acknowledgement may entail the ability to see reason in the demands, desires, and needs of others (Cavell 1979, 326). As Stilgoe et al. point out, responsiveness is crucial for realizing the goals of inclusion and reflexivity outlined above (2013, 1573). Erik Fisher (2006) suggests that innovators can be encouraged to be ‘more responsive’ when they ‘make their assumptions more explicit and decisions more deliberate,’ since in so doing they clarify their own reasons and demonstrate intellectual humility and openness to alternative assumptions and motives.

Practically speaking, Futures Lab stimulate responsiveness in many ways. By fostering openness in a creative lab setting, a positive feedback loop can be created in which students become motivated to respond to and acknowledge others because they see the benefit and utility that are accrued when they themselves are acknowledged through the responsiveness of others. For example, a practice of snapping and clapping after a student shares a reflection or material creation can reinforce a culture of positive response and acknowledgement. Additionally, because one of the major difficulties facing technologists, governance actors, and policy makers is a lack of responsiveness to non-specialists, one of the major objectives of the Futures Lab is to provide students with hands-on experience engaging with community actors. This can be done to solicit input on design and needs both before and during the design and build process, so long as this is done with care to avoid an extractive relationship. Such an approach is exemplified by JMU’s ‘Technology Outside the Lab’ (TOTL) program implemented in conjunction with the STS Futures Lab, which takes inspiration from the Science Outside the Lab (SOTL) program pioneered by Drs. Dan Sarewitz and Neal Woodbury (Bernstein et al. 2017). TOTL is a grant-funded collaboration with George Mason University in which science and engineering students interface with governance actors, lobbying groups, policymakers, and agency officials in order to cultivate their awareness of the broader socio-technical ecosystem in which their innovative projects are embedded.¹² Specifically, students developed a capstone project on autonomous vehicle that focused on engaging disability communities, and soliciting input on design and needs both before and during the design and build process.

Responsiveness can likewise be fostered through classroom discussions about concrete cases. For example, Callon, Lascoumes, and Barthe (2001) recount how engineers constructing a nuclear waste facility in the wine growing region of Bourgogne encountered resistance to this project by growers concerned with the impact of this facility on the perception of their grapes. The wineries were concerned that the construction of the waste facility would kill their sales regardless of whether the actual radiation contamination were real or merely imaginary. This case is brilliant, since it forces the student engineers to recognize that even a fantasized contamination of a vineyard can have very real social and economic consequences. Students can then be challenged to make, and to imagine, other cases in which competing logics clash, and they can learn to use these encounters within practical processes of creative making that aim

to better inscribe and acknowledge these opposing concerns within a single, and positively monstrous, technical object.

Discussion

Futures Labs are one approach to developing and implementing RI pedagogies. They can be run in such a way as to expressly facilitate the acquisition of anticipation, inclusion, reflexivity, and responsiveness skills. Futures Labs help train students to be capable of practically working within RI frameworks and guidelines, and they contribute to forming students' moral characters and their awareness of the broad social, political, ethical, and environmental consequences of innovation. By acknowledging the similarities and differences between the JMU and ENSTA approaches, we hope to show that there are different ways to approach this, and to encourage readers to 'locate and engage RI in *local contexts, cultures and practices*' (Macnaghten et al. 2014, 194) as here applied to Futures Lab pedagogies. With creativity and attunement to local needs, as well as affordances and constraints, the Futures Lab concept can be adapted to different institutional settings.

At this juncture it is pertinent to consider the effectiveness of the Futures Lab as a model for training responsible innovators. This is an important but extremely difficult question to answer. Giving an adequate response implies being able to respond to both responsible innovation skeptics such as Nordmann (2014) who question the overall efficacy of foresight practices as a component of yielding better adapted innovations, as well as to specific questions regarding the efficacy of the Futures Lab approach. To only focus on the effectiveness of the Futures Lab, let us note that while it is possible to evaluate whether students have acquired the RI skills that we aim to teach over the course of Futures Lab modules, the real and ultimate test of the effectiveness of this pedagogy occurs when our students show themselves able to translate what they have practiced in the Futures Lab into actual professional settings. As a recent survey on sustainable development awareness and competences carried out among work-study apprentice engineers at the ENSTA highlighted (Tabas, Paisley, and Faure 2022), students who have followed courses which emphasize the acquisition of sustainable development and RI related skills tend to feel that they have learned a great deal from these courses, but they do highlight the difficulty of putting what they have learned into practice in their professional lives. As the respondents explained, their currently low status within their organizations combined with a strong counter-current of entrenched company culture makes it difficult for them to put more socially responsive approaches to innovation into practice. Hearteningly, however, many respondents expressed the desire to put into place more responsible practices at their company once they had attained to positions of greater authority.¹³ That said, we have also received positive anecdotes from graduates who have reached out to us to share stories about how they have integrated design thinking and ethics into their work, and a preliminary study of the Creative Anticipatory Ethical Reasoning process suggested shifts in students' ability to anticipate and reflect on broader ethical dimensions of technology (York and Conley 2020). Even if present Futures Lab pedagogies involve little summative assessment at present, the students' projects, self-reports, and willingness to engage in repeated Futures Lab experiences suggests that such an assessment is possible.

Challenges

A key challenge for implementing Futures Labs is obtaining a dedicated lab space and materials. While it is possible to teach a Futures Lab without a dedicated space – and even without a classroom at all (both JMU and ENSTA Futures Labs took place fully virtually during the 2020–2021 school year) – this is clearly not the ideal case. At JMU, the Futures Lab is not just a classroom but also a community space in which both students and colleagues meet even outside of scheduled class hours and formal lab meetings. The perpetual availability of the space encourages and supports student efforts at larger and more complex projects. Moreover, and as we have noted above, the relics of past projects contribute directly to the figuring of the world of the Lab. This effect is clearly heightened when traditional desks are replaced with mobile square and round tables, a lounging area with comfortable chairs, soft lights, and a couch, posters connecting the lab to STS and design fiction on the walls; a virtual reality corner and cabinets full of traditional art supplies; multiple rolling whiteboards and corkboards, as well as personal-sized whiteboards that can be used while sitting at a table; and a projector and a full video camera. But all of this takes money, which is why a recent ENSTA project (Project RIIME) aimed at developing sustainable development pedagogies for engineering schools in the Maghreb barely touched on the applicability and usefulness of Futures Labs. Two additional finance-related challenges confronting educators hoping to found Futures Labs are time and labor. At the JMU Futures Lab, faculty run lab meetings, run projects with students, and mentor them. These engagements are very time- and labor-intensive. Likewise, because a Futures Lab module is not a two-hundred student lecture course, scaling up access to Futures Labs can be challenging. While it may be desirable for all students at a given institution to participate in a Futures Lab over the course of their studies, this may not ever be feasible at larger schools.

Considerations such as the above make obtaining institutional support a challenge. The JMU Futures Lab, because it is a pioneering effort, has benefitted from broad support from both its home institution and generous support from external funding sources. However, there is little reason to believe that external support agencies will fund the creation of new Labs once they have ceased to be terrains of pedagogical innovation and have established themselves as expected features of any STEM institution. The difficulty of obtaining support may be aggravated by situations such as the one noted by Owen et al. (2021), where ‘competing institutional logics, responsibility norms and epistemic practices’ have hindered the widespread institutionalization of RI training in a number of UK universities. Nevertheless, even without significant institutional financial support the basic principles of the Futures Lab method can be employed in any real or virtual classroom by motivated teachers working in institutions open to pedagogical experimentation.

Conclusion

In this paper, we have introduced an innovative type of lab pedagogy that we call the Futures Lab. A Futures Lab is in some ways like a FabLab – it is a maker space – though Futures Labs are not devoted to making new things, but rather to training responsible innovators and inventing new methodologies for anticipating, including, reflecting,

and responding, in other words, new ways of creatively exercising responsibility while innovating. We have briefly theorized this innovation and we have attempted to offer some description of the pedagogical practices that occur within these RI-oriented maker spaces. We have particularly focused on ways in which Futures Labs can be run to target the acquisition of competences relative to each of the four axes of responsible innovation presented in Stilgoe et al.'s Responsible Innovation Framework. That said, the Futures Lab idea is very much an open concept and can be developed and interpreted through different ethical frameworks and disciplinary lenses and tuned to different student needs. The Futures Lab should not be seen as a single, sharply delimited object but as an open experimental framework that needs to be translated and transformed from one institutional and disciplinary context to another. Both the ENSTA and the JMU Futures Labs differ from one another in significant ways, but they are united in cultivating RI skills via critical making practices. It is our hope that readers will find sufficient inspiration in this paper to reflect on ways to incorporating Futures Lab practices into the portfolio of responsible innovation offerings at their home institutions.

Unlike some Fab Labs, Futures Labs inculcate a *go slow and create things thoughtfully* mentality. They encourage students to think deeply about the consequences of an innovation before they go out and risk people's well-being in the name of learning through failure. We do not contend that Futures Labs should *replace* Fab Labs within STEM education, but rather that both serve as necessary counterpoints to one another. Seen as a process, innovating requires both daring to think out of the box *and* daring to face down the possible negative consequences of such risk-taking. Students need to learn both how to unleash their creativity, and how to use their creativity to foresee and tame the consequences of this creativity before anyone gets hurt. Where there is a Fab Lab there should be a Futures Lab, and vice versa, with the two forming complimentary elements in the education of responsible innovators.

Notes

1. Our approach to RI is distinct from the policy-driven 'five keys' of RRI (Responsible Research and Innovation) emerging out of the European Commission. While RI and RRI are 'linked discourses,' RRI at times 'intersect[s] with, reinforce[s] or challenge[s] existing de facto narratives and norms of responsibility' as related to scientific R&D (ibid 26). The discourse of the ground-up RI framework emerging primarily from academia, however 'enlarges, reframes and challenges these extant responsibilities' (ibid 26).
2. We recognize, however, that definitions and accounts of the practice of responsible innovation remain in flux (see Stilgoe et al. (2013), Wickson and Carew (2014), Fisher (2020), Owen and Pansera (2019)), and that other approaches to RI pedagogy might place emphasis on different aspects of responsible innovation.
3. This is the approach employed in the widely used textbook, *Engineering Ethics: Concepts and Cases* (2018). For a broader- – and insightfully critical- – discussion of the role of the case study in engineering ethics see Mitcham 2019, 207–221. For a systematic review of approaches to ethics in education engineering, see Hess and Fore 2018.
4. Other advocates of the fail-fast approach to innovation include Sternberg and Lubart (1995), Seelig (2012) and Couros (2015).
5. An extended discussion of this methodology is available at: York E, Conley SN. Creative Anticipatory Ethical Reasoning with Scenario Analysis and Design Fiction. *Sci Eng*

Ethics. 2020 Dec;26(6):2985-3016. doi: 10.1007/s11948-020-00253-x. Epub 2020 Jul 23. PMID: 32705538.

6. NSF Award Number 2121207.
7. Tabas (2021) offers a fuller explanation of the rationality and the method employed in this latter course.
8. The results of INNOV'ING have been published in Lemaître 2018, the outputs and project reports associated A-STEP 2030 are currently available on the project website: <https://www.astep2030.eu/en/project-reports>
9. On this, see: O'Neill 1977.
10. Tabas' perspective on interactive learning is influenced by the interactivist theories of cognition pioneered by Andy Clark (2008) and the work of Lambros Malafouros, who in his 2013 *How Things Shape the Mind* draws on both cognitive science and archaeological evidence to illustrate precisely how interactions with different networks of technological sub-structures condition the emergence of changing worldviews over the course of early human history. York's perspective on situated learning is influenced by the work of Lave and Wenger (1991) and Holland et al. (1998).
11. Scholars such as Miller and Bennett (2008) have advocated that reading and composing science fictions can stimulate creativity and prompt reflections about just and unjust socio-technical futures. In addition to making futures in words, students are also prompted to generate both 2-D and 3-D topographies, models, and prototypes, interactive representations of future technologies and the worlds in which they will be embedded (Bleeker, 2009).
12. This is funded through the 4-VA grant program which fosters collaboration among Virginia public institutions of higher education.
13. A similar a qualitative assessment of the effectiveness of the CAER approach used in the JMU Futures Lab is to be found in York and Conley 2020.

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No potential conflict of interest was reported by the author(s).

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