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Multi-cellular engineered living systems: building a community around responsible research on emergence

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Abstract

Ranging from miniaturized biological robots to organoids, multi-cellular engineered living systems (M-CELS) pose complex ethical and societal challenges. Some of these challenges, such as how to best distribute risks and benefits, are likely to arise in the development of any new technology. Other challenges arise specifically because of the particular characteristics of M-CELS. For example, as an engineered living system becomes increasingly complex, it may provoke societal debate about its moral considerability, perhaps necessitating protection from harm or recognition of positive moral and legal rights, particularly if derived from cells of human origin. The use of emergence-based principles in M-CELS development may also create unique challenges, making the technology difficult to fully control or predict in the laboratory as well as in applied medical or environmental settings. In response to these challenges, we argue that the M-CELS community has an obligation to systematically address the ethical and societal aspects of research and to seek input from and accountability to a broad range of stakeholders and publics. As a newly developing field, M-CELS has a significant opportunity to integrate ethically responsible norms and standards into its research and development practices from the start. With the aim of seizing this opportunity, we identify two general kinds of salient ethical issues arising from M-CELS research, and then present a set of commitments to and strategies for addressing these issues. If adopted, these commitments and strategies would help define M-CELS as not only an innovative field, but also as a model for responsible research and engineering.

1. Introduction: designing for biological emergence

Researchers working at the intersection of biology and engineering are now able to design and build an array of unprecedented artificial living creations: stem cell-derived 3D structures that emulate organ-level functions (organoids) (Domansky *et al* 2010, Quadrato *et al* 2017) or model early embryo development (Rivron *et al* 2018); motile 'biobots' (i.e. robots developed from biological materials) that are propelled by the action of muscle tissues on a hydrogel frame (Cvetkovic *et al* 2014, Raman *et al* 2016); and even genetically programmed species and subpopulations (Moreno 2012). These provocative capabilities form part of a rapidly developing field of research, recently dubbed 'multi-cellular engineered living systems' (M-CELS) (Kamm and Bashir 2014, Raman and Bashir 2017, Kamm *et al* 2018). The primary goal of this field is the investigation and development of systems 'composed of living cells and tissues organized in a way that produces novel functionalities by design' (Kamm *et al* 2018, 1).

M-CELS researchers achieve this goal by working across disciplines and subfields, bringing together synthetic biology (Endy 2005), tissue engineering (Huh *et al* 2010), stem cell research (Girgin *et al* 2018), developmental biology (Lancaster *et al* 2013), and cell-based bio-robotics (Cvetkovic *et al* 2014, Raman *et al* 2016). Researchers also depend on a shared set of diverse methodologies, including computational modeling and analysis (Morris *et al* 2014, Glen *et al* 2018), micro-fabrication (Madou 2011), cell cultures (Spence *et al* 2011, Sachs *et al* 2018), reverse-engineering of complex systems (Csete and Doyle 2002, Ingber *et al* 2006, Narciso and Zartman 2018), and genetically-encoded control systems (Basu *et al* 2005, Tamsir *et al* 2011).

Taken as a whole, M-CELS research is often characterized by its focus on understanding and harnessing *emergent* phenomena, loosely understood to mean macroscopic, system-level phenomena that arise from interactions between individual cells and between cells and their environment (Kamm *et al* 2018). Although the precise definition of 'emergence' is not always clear —the term sometimes denotes any properties that arise from complex systems, and other times refers only to those properties that are inherently unpredictable[14]—it features heavily in researchers' definitions of M-CELS research (e.g. see Kamm *et al* 2018).

This interest in emergence is about more than the pursuit of abstract scientific knowledge about systems-level phenomena; it also arises from the field's focus on creating technology with specific societal applications. The purposeful similarity of organoids to human organs, for example, presents more than just an opportunity to understand organogenesis; organoids are being developed with the aim of modeling and treating disease (Raman *et al* 2017, Osaki *et al* 2018), reducing the use of animals in research (Bredenoord *et al* 2017), and even creating much-needed transplantable human tissues (Huch *et al* 2015). Additionally, researchers have suggested that micro-scale biobots, due to their small size and customizable form, could one day be used to conduct medical interventions in humans or assist in environmental clean-up (Williams *et al* 2014, Raman *et al* 2017, Pagan-Diaz *et al* 2018).

Although many of these applications are still highly speculative, the transformative aspirations motivating M-CELS research demand careful, collective reflection. This was the purpose of a National Science Foundation-funded interdisciplinary workshop held in August 2018, in which 72 M-CELS researchers gathered to discuss and formulate ethical principles to guide this new field. The workshop participants, hailing from 38 universities and institutes, 7 countries (Canada, China, France, Japan, South Korea, Spain, the United States), and a range of disciplines (STEM, bioethics, and history), discussed how research on organoids, embryoids, gastruloids, and biobots is provoking difficult societal and ethical questions, some of which arise from the field's focus on emergence. In this paper, we draw on discussions from this workshop, as well as on literature in philosophy, sociology, and public policy, to report key societal and ethical issues that could arise in the development and use of M-CELS. More practically, we then propose a set of commitments and strategies by which these issues can be addressed. These recommendations are tailored for an academic audience, but are designed to foster a conversation among diverse *publics*, referring here to not only the general public but also researchers, university and funding administrators, journal staff, industry representatives, policy makers, patients, and other key stakeholders.

In short, we claim that the M-CELS community must be committed to: (1) facilitating inclusive deliberation about the moral considerability of M-CELS, (2) choosing and developing responsible applications of M-CELS in consultation with diverse publics, and (3) developing institutional mechanisms to address ethical and societal challenges. If realized, these commitments would define M-CELS not only as an innovative field, but also as a model for responsible research and engineering.

2. Ethical and societal challenges

Some M-CELS researchers have already emphasized that their work raises significant societal and ethical concerns (Kamm and Bashir 2014, Kamm *et al* 2018). In discussions among workshop participants, we revisited and explored these concerns, grouping them into two categories: (1) questions of moral considerability (defined below) and (2) questions of responsible development and application. We collect them here (see table 1) not as an exhaustive or final classification of all possible ethical concerns[15], but as evidence for the need for inclusive deliberation and responsible

[14] The latter definition evokes an interesting tension within emergence-based engineering: how can we design for the inherently unpredictable?

[15] Sorting these questions into the two groups in table 1 is helpful for efficiently presenting a range of societal and ethical concerns, but also elides complex inter-connections. Answers to questions about moral considerability will undoubtedly impact ethical issues concerning M-CELS development and use, and judgments about desirable applications may generate new questions and concerns about moral considerability.

Table 1. Two groups of societal and ethical questions relevant to M-CELS.

1. Questions of moral considerability	2. Questions of responsible development and application
In which circumstances and to what degree are M-CELS creations morally considerable?	Which uses of M-CELS technology are ethical, equitable, and/or socially responsible?
How should we understand and talk about M-CELS? Are M-CELS tools or agents, objects or persons, property or nature, matter or life?	What level of control over M-CELS creations (in the lab and beyond) is necessary, and how should we prevent and/or respond to problematic loss of control?
What does the moral considerability of M-CELS require of us?	How should we deal with dual-use research of concern (DURC) or the potential for misuse of M-CELS?
What steps should be taken by regulatory bodies and by researchers when a moral boundary is crossed?	What guidelines and norms from existing research ethics are relevant for work on M-CELS?

action in M-CELS research and development (see section 3).

Let us begin with Column 1. The eventual role and acceptance of M-CELS in society will depend at least partly on M-CELS' *moral considerability*, i.e. on whether M-CELS are or should be considered subjects of moral principles, moral attitudes, or rights (Goodpaster 1978). Intuitions about moral considerability are complex for researchers and publics alike, and are influenced by many factors. For example, the tendency to use machine-based metaphors in synthetic biology (e.g. expressions like 'genetically engineered machine' and 'platform organism') has been shown to decrease the likelihood that stakeholders will attribute moral considerability to complex biotechnologies (Boldt 2018). M-CELS creations are likely no different. If a biobot is produced from artificial mechanical components and a few non-human cells, and if the language used to describe the biobot draws primarily on mechanical metaphors, many in the general public might interpret it as simply an 'object' or 'tool,' deserving of little to no moral consideration. Such biobots might be seen as analogous to nanotechnologies, non-living biomedical implants or pacemakers: marvels of microscale engineering, but not intrinsically deserving of respect, care, or other forms of moral consideration.

Yet, M-CELS creations could also exhibit features that are culturally associated with existing biological lifeforms, like mobility, autonomous behaviors, response to external stimuli, or animal-like appearance (Chan *et al* 2012, Webster *et al* 2016). Eventually, they may even display elements of intelligence and adaptability (Han *et al* 2013, Nesbeth *et al* 2016). It seems plausible that, for some stakeholders, increasing similarity in form and function to complex biological life corresponds to increasing levels of moral consideration. Our duties to these creations could thus range from simple protection from harm (as with mice in the lab) to the granting of positive rights like autonomy and freedom of choice (as we grant to our fellow humans). Discussions in environmental ethics on the moral status of ecosystems and environmental resources (Brennan 1984), and on the ethics of animal research and meat consumption (Smith and Boyd 1991, Rollin 2006) provide precedents for working through such questions about moral consideration. Given that these are highly contentious ethical debates—think, for example, of the polarization present in debates about animal rights, factory farms, and climate change—we may not be able to directly export conclusions from these debates to the M-CELS context. Nonetheless, we believe that they contain relevant and thought-provoking ideas that could be mutually enriching when juxtaposed with M-CELS questions. For instance, some cases in animal and environmental ethics suggest that the moral considerability of M-CELS should not be determined solely by intrinsic features of the creations themselves (e.g. what they are made of, what they can do, how similar they are to 'natural' living creatures, etc), but must be assessed in light of the role that these creations play and could play in social contexts.

Public concerns about moral considerability are often heightened when cells of human origin are involved, as illustrated by ongoing debates about HeLa and other human cell cultures (Landecker 2007, Skloot 2011), tissue donation (Abouna 2003), embryo and stem cell research (Sagan and Singer 2007, Rivron *et al* 2018), and new reproductive technologies, especially gamete donation and freezing (Thompson 2007). Even when cells are spatially and temporally distant from the donor, their human origin and continued life outside of the body can blur the line between self and other. Chimeric M-CELS, which mix animal and human-derived components, may also unsettle the distinction between person and animal, or between person and thing, similarly to how research on artificial intelligence and machine learning has shifted conceptions of the boundary between human and machine (Garside 2014, Hyun 2018). We are thus left with the questions: when are M-CELS creations morally considerable and what language should we use to describe them? Is this considerability grounded in cellular origin (human versus non-human), structure (simple versus complex), or something else entirely (e.g. societal context)? These are more than abstract philosophical puzzles; our collective judgments about considerability will have significant implications for research ethics, regulatory practices, and technological development.

Now on to the next column of table 1. The responsible development and application of M-CELS technology is a second, albeit overlapping, source of questions. Here, equity is a primary concern; how do we select, pursue, and manage M-CELS applications, such that potential benefits are equitably distributed, and are responsibly balanced with potential risks (e.g. accidental or intentional misuse of knowledge and products)? And whose interests and values will be represented in that process? As has been noted with respect to synthetic biology (Van den Belt 2013), we should not assume that the impacts of new technology will be fairly distributed across individuals and communities. For instance, M-CELS applications that alter or enhance the human body may, especially if accessible only to a select few, exacerbate existing social inequalities (Savulescu and Bostrom 2009). Conversely, potential M-CELS-based dangers to the environment or human health may disproportionately affect socially marginalized groups, who may lack the resources to adapt or move if, for example, engineered organisms 'become invasive' and negatively affect existing ecosystems and related industries and economies (Pollack 2004, US EPA, OA 2014, Science for Environment Policy 2016, 14).

Issues of equity also arise in the context of intellectual property (IP) (Hart 2017). Can the emergent objects of biological engineering fit with traditional IP regimes, and if so, how (Calvert 2008, Torrance and Kahl 2014)? Is a strong patent system necessary to ensure innovation and progress, or should we adopt a computer science-inspired 'open-source' approach? Which approach would lead to more equitable access to and distribution of benefits from M-CELS research? Questions about ownership and IP touch not only on pragmatic concerns about promoting innovation, but also on moral, ethical and political questions about moral considerability (e.g. is it ethically permissible to patent a complex multi-cellular system?), privatization and the commons, distributive justice, and equitable access to new and emerging technologies (König *et al* 2015, Parthasarathy 2017).

Finally, beyond equity, it will also be necessary to consider biosecurity and the possibility of malevolent applications. Regarding the former, we will have to decide: what level of control is necessary for responsible development and use? Like gene drives and other 'living' biotechnologies, M-CELS creations relying on emergent properties—properties that may change over time and may be impossible to fully predict (see discussion of emergence in section 1)—will only compound these concerns (Rudenko *et al* 2018). It is also conceivable that M-CELS research and technology could be used for violent purposes, such as weapons development (Regalado 2018). Additionally, because of the purposeful similarity of some embryoids, organoids and biobots to human tissues (greater similarity than an engineered yeast cell or an animal model), M-CELS could very plausibly be categorized as dual-use research of concern (DURC)[16]. Even when the creations themselves do not constitute a material threat, the knowledge gained through their use may, as seen in recent controversies over gain of function experiments (e.g. the creation of new strains of transmissible H5N1 virus) (Duprex *et al* 2015).

3. Commitments to responsible M-CELS research

Once ethical and societal questions surface (table 1), how should we go about answering them? Broadly speaking, prominent debates in the ethics of medicine and the biological sciences have historically focused on two approaches: researchers in science and engineering should either manage ethical issues themselves (i.e. they should self-regulate), or they should submit to regulatory guidance or laws from external experts (e.g. from ethicists or policymakers). In the most famous example of the former approach, the genetic engineering research community came together in 1975 at a summit in Asilomar, California to address the ethical and societal implications of genetically engineered organisms (Berg *et al* 1975). Committed to a particular vision of scientific autonomy, the summit participants did not seek out assistance or input from external groups or individuals. The Asilomar approach has become an unfortunate blueprint for many present-day responses to emerging societal and ethical challenges (Hurlbut 2015). Without involvement of diverse publics and careful consultation of stakeholders, attempts at self-governance in science and engineering may do little to foster a societal consensus on a contentious issue. For example, despite earnest ethical and societal deliberations at Asilomar, many citizens continue to express unease about research on genetically modified food (Funk and Kennedy 2016). The lack of public involvement, among other factors, likely contributed to this continued distrust.

Meanwhile, in the same decade as the first Asilomar meeting, we find landmark cases of regulation imposed from outside, rather than from within, the research community. In 1979, a group of philosophers drafted the Belmont Report, a set of ethical guidelines for conducting research involving human subjects based on principles of beneficence, non-maleficence, justice, and respect, which ended up shaping federal and eventually international legislation ('The Belmont Report' 2010). In that same year, an ethics advisory board to the US Department of Health, Education and

[16] DURC is 'life sciences research that, based on current understanding, can be reasonably anticipated to provide knowledge, information, products, or technologies that could be directly misapplied to pose a significant threat with broad potential consequences to public health and safety, agricultural crops and other plants, animals, the environment, materiel, or national security' (NIH Office of Science Policy n.d.).

Welfare proposed the '14 day rule' as a strict ethical constraint on how long research can be conducted on human embryos (Hyun *et al* 2016). This too had international repercussions, and was taken up in the UK by the interdisciplinary Warnock Committee (Warnock 1984). These activities set a precedent, leading to a proliferation of regulatory frameworks for research, including the formation of institutional review boards (IRBs) in the United States, the National Institute of Health report on embryo research (1994), and the Guidelines of the International Society for Stem Cell Research. In contrast to Asilomar, these activities and institutions delegate much of the ethical deliberation to individuals *outside* of research practice. What they share with Asilomar, however, is a failure to adequately engage all relevant stakeholders in deliberative processes.

When questions have broad socio-ethical implications that fall outside the realms of scientific or regulatory expertise, it is insufficient to consult only researchers, policy makers, or ethicists. As illustrated by the cases of Asilomar and the Belmont Report, expert answers to ethical or societal questions may not facilitate a wide cultural consensus on difficult topics. Because most citizens will not be included in Asilomar-style deliberation or the creation and practice of IRBs, they will not have any reason to adopt expert conclusions aside from deference to authority. Particularly in the current moment, with increasing societal worries about an erosion of public trust in experts (Czerski 2017), new ethical frameworks must be built on solid dialogical foundations. More generally, justice in democratic societies is usually understood to demand robust mechanisms in which citizens can shape social order and our shared future. This ideal is just as relevant in the biotechnological realm as it is in more straightforwardly political realms. But expert scientists, ethicists and policy-makers, especially if they are not holding government office, may not be meaningfully accountable to citizens.

A better approach is needed, one that realizes the need for robust democratic input and for effective, publicly-acceptable sociotechnical systems. For this, we look to recent work in science and engineering ethics. New strategies for fostering inclusive deliberation can be found in frameworks for 'responsible research and innovation' (RRI) (Stilgoe *et al* 2013), models for public engagement with science (Museum of Science, Boston 2017, Bandelli and Konijn 2013), technology assessment mechanisms (Banta 2009, Hennen 2012), public participation frameworks (Gehrke 2014), citizen juries (Gooberman-Hill *et al* 2008, US EPA, OITA 2014), the creation of global interdisciplinary 'observatories' (Jasanoff and Hurlbut 2018), and consensus conferences like those pioneered by the Danish Board of Technology (Rowe and Frewer 2005). Best practices can be drawn from each of these to guide M-CELS research. For example, a recent report within the RRI framework provides 36 concrete indicators for evaluating responsible research, ranging from level of citizen interest in scientific decision-making to the importance of ethics in proposal evaluation (Stilgoe 2019). Overlapping in many ways, all of the above frameworks offer resources for and approaches to responsible research. Drawing on these, we propose that the M-CELS community orient itself around three core commitments, and outline corresponding sets of strategies for the realization of each commitment (table 2).

The *first commitment*—facilitate inclusive deliberation on moral considerability—is a collective pledge to answering pressing questions of moral considerability in collaboration with other disciplines, institutions, and with diverse publics. While some M-CELS researchers may desire precise rules or fixed procedures for how to morally assess and treat M-CELS creations, such rules currently do not exist and cannot be devised without holding difficult and nuanced discussions. For this reason, we believe that the research community must bring the uncertainty and tough questions that arise in the lab into broader societal conversations. Involving publics in this way avoids mistrust or misunderstanding and fulfills the ideals of democratic representation.

This need for inclusive deliberation applies equally to the *second commitment*: choose and develop responsible applications. As with moral considerability, there is no predetermined formula for positive societal impact, and it is insufficient to simply assume, imagine or infer the attitudes of diverse publics. Thus, the question of how M-CELS technology should be developed and applied must also be answered in active consultation with publics and stakeholders. However, this second commitment goes beyond dialogue. Unlike questions of moral considerability, which are often highly abstract and for which researchers may not have special expertise, technical and scientific questions are often delegated exclusively to researchers by society. This special role requires that researchers exhibit virtues linked to it; they must exhibit modesty, openness and care when envisioning the role of M-CELS in society.

These two commitments can be fulfilled in a variety of ways (Left Column, table 2). As suggested above, researchers should foster a benchside sensitivity to tough ethical and societal questions and proactively facilitate conversations outside of the lab. These activities should begin as early as possible in a research cycle, to allow for the identification and implementation of 'alternative design choices' (Hyun 2017) or even alternative projects or research questions. Researchers, especially those in senior positions, should thus advocate for and organize opportunities for inclusive deliberation among a wide variety of publics, including engineers, policymakers, patients, and others. The goal, here, is not only to represent diversity (particularly among individuals whose values may differ from those of the researchers), but also to empower

Table 2. Three commitments for responsible M-CELS research and corresponding strategies.

<table>
<tr><th>1. Facilitate inclusive deliberation on moral considerability</th><th>2. Choose and develop responsible applications</th><th>3. Develop institutional mechanisms to address ethical and societal challenges</th></tr>
<tr><td colspan="2">At the laboratory level, maintain a sensitivity to questions regarding moral considerability and a focus on actual (rather than merely assumed) societal needs.

Continuously seek to identify alternative M-CELS design choices and trade-offs, and openly discuss the values underlying these choices and trade-offs.</td><td>Foster ethical deliberation skills throughout the M-CELS training pipeline (i.e. high school-postdoc), with concrete learning objectives and in collaboration with humanities and social science departments.

Allocate time and resources for faculty and students to work on societal and ethical issues by establishing norms and structures that recognize and reward such work.

Incentivize the integration of 'ethics and society' reflections in M-CELS publications and grant applications.</td></tr>
<tr><td colspan="2">Organize events and initiatives that facilitate two-way communication between M-CELS researchers and publics about moral considerability and responsible applications.</td><td>Recruit partners with experience interacting with the public (e.g. at science museums, libraries, local government, places of worship, hospitals).

Develop and share public engagement strategies and open access educational material.</td></tr>
<tr><td colspan="2">Build on existing expertise from other disciplines (esp. social sciences and humanities), ethical review boards, and other publics.

Comply with existing norms in research ethics, while also encouraging public and stakeholder discussion of how these norms should evolve with M-CELS research.</td><td>Fund research collaborations, conferences, and networks between M-CELS researchers and social scientists, ethicists and other experts and stakeholder groups.</td></tr>
<tr><td colspan="2">Proactively seek out ethical perspectives and values that are likely to differ from those of the researchers.</td><td>Encourage and fund initiatives and interventions aimed at increasing diversity (in all forms) within the M-CELS research community.</td></tr>
</table>

those participating in the deliberations to make informed and meaningful contributions (Morrison and Dearden 2013, Museum of Science, Boston 2016). Importantly, the organization of inclusive deliberation processes and activities need not start from scratch but should build on existing deliberative expertise and experience in non-STEM disciplines, such as philosophy, anthropology and the communication fields.

Finally, to support the feasibility of commitments one and two, we propose a *third commitment*: to develop the multi-level social and institutional mechanisms and incentives that make it possible, and indeed rewarding, to address ethical and societal issues (Right Column of table 2). In terms of training, university-level M-CELS courses and pedagogical materials should be developed that include modules from humanities or social sciences and that involve humanities and social science researchers in the teaching process (either as guest lecturers or co-instructors), and should be shared across institutions. These teaching strategies should focus not just on teaching ethical content (e.g. the kinds of ethical and societal issues listed in table 1) but on teaching skills for participating (and eventually organizing and facilitating) in ethical discussions (e.g. through debates, scenario exercises, role-playing, etc). Doing so would help prepare the next generation of M-CELS researchers for participation in collaborative ethical and societal deliberation. Simultaneously, lab directors must allocate time and resources for their trainees to exercise these skills, in research or in lab meetings, as well as processes and mechanisms for valorizing the acquisition and practice of these skills.

To take these discussions outside of academia, it is essential to recruit partners from other disciplines (e.g. social sciences, humanities, public policy) and public-oriented institutions, such as museums and funding agencies. For example, socio-ethical questions about human enhancement with respect to human genome editing were adapted for public discussion through an innovative Museum of Science initiative in Boston, which has since been used nationwide (Todd *et al* 2018). The method and deliberative content of these public events should be recorded and distributed along with other training resources (e.g. EBICS n.d.) to build a shared resource for the field while simultaneously bringing socio-ethical questions from the margins into mainstream discussion. Even outside the context of public engagement, such partnerships can jump start ethical and societal conversations by building on existing expertise. For instance, while it may seem difficult to respond to the misapplication of M-CELS by malevolent actors, some researchers are already discussing the management of risk in synthetic biology and in artificial intelligence (Palmer *et al* 2015). To the same effect, useful questions and insights regarding personhood, rights, and the possibility of non-human minds can be gained by consulting with researchers not only in bioethics but also in philosophy of mind (Nagel 1974, Dennett 1988, Lavazza and Massimini 2018) and many other overlapping fields.

To be most effective, all of these strategies require high-level attention and dedicated resources from departments, universities, and funding agencies. New university courses are not possible without institutional backing for their development and ongoing support of all contributing departments. Funding agencies must commit to sustained funding for independent work in STEM, social sciences, and humanities, in addition to enabling ambitious collaborative projects between researchers and ethicists or community groups. Grant applications should require careful discussion of the ethical and social issues in and beyond research ethics as commonly understood. Science and engineering journals, which also have tremendous power for influencing research directions and priorities, should instruct reviewers to assess authors' discussion of ethical and social impacts—and to pay attention to evidence of deliberative public engagement—when making publication decisions. We view these various forms of institutional support as analogous in structure and complementary in spirit to STEM-wide initiatives to increase diversity in all its forms (e.g. the multi-year NSF INCLUDES initiative). The purpose of inclusion is not merely to develop ethical insight but also to enable more fair and impactful scientific and engineering practices.

4. Next steps for responsible M-CELS research

At our August 2018 workshop, researchers sought answers to significant ethical and societal questions about moral considerability, about how to benefit society and avoid misuse, and about potential issues of control stemming from the field's focus on emergence-based design. In starting this discussion, M-CELS researchers play a crucial role in highlighting these questions, but they cannot and should not answer them alone. To this end, we have suggested a set of commitments and strategies that, if adopted, could facilitate collaborative and meaningful deliberation, and could lead to the development of research norms and practices based on a shared and robust understanding of what it means to conduct responsible and ethical M-CELS research.

The motivation for this work is, importantly, not grounded solely on a novel type of question or on the provocative character of biological emergence. As we have noted, the ethical challenges raised in this paper are not unique to M-CELS research. What is unique, in contrast to other fields, is the opportunity to engage with these issues as the field is just developing. Unlike more entrenched debates, such as those on the ethics of meat consumption discussed above, we have yet to form widespread social norms around and established attitudes towards M-CELS creations. Given this open-endedness, inclusive societal debates about biobots or organoids may foster alternative conceptions of moral considerability, conceptions that are perhaps harder to foster in polarized conversations such as those about factory farms or climate change. M-CELS researchers, then, have an opportunity to proactively (rather than reactively) lead a robust ethical conversation, one that goes beyond the requirements of standard ethical regulations, and beyond the conventional wisdom that the public should be educated and consulted. We maintain that the commitments and strategies proposed in this paper, if adopted, would help to fulfill this potential and establish M-CELS as an ethically responsible community, and as a model for future emerging techno-scientific fields.

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