Educating Responsible Innovators-to-Be: Hands-on Participation with Biotechnology

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1 Introduction

The emerging popularity of the term "Responsible Research and Innovation" (RRI) marks an increased awareness towards innovation products and processes that respect the needs and values of contemporary societies. Leaving aside the question why isn't all innovation responsible to begin with, one can no longer dismiss the fact that the ethical and societal implications of technological innovations must be carefully considered for any technological innovation to succeed. Given also environmental, economic and humanitarian challenges all around the globe, it is urgent that our technological innovations are conceived, developed and deployed with an eye to the future. RRI emphasizes our "collective commitment of care for the future" [1], both in terms of reducing negative consequences and in terms of promoting positive change. Obviously, if all of our innovations are to be implemented responsibly, then all of our innovation *education* is to be replaced by an education on responsible innovation [2]. But how does one go about educating responsible innovators? This paper recommends a humanities-informed education for responsible innovation and proposes novel forms of pedagogy that go beyond existing models of ethics instruction.

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According to Von Schomberg's [3] frequently cited definition, RRI is *"a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society"*. An overview of recent definitions of RRI is provided in [4]. Noticeably, most of these definitions emphasize the acceptability of innovation products and/or enforce a collective accountability for both the processes and the outcomes of innovation. Ethical acceptability and social desirability constitute a reasonable response to concerns about the negative consequences of technological innovations while democratic and inclusive processes constitute a legitimate way to achieve this acceptability. For the purposes of this paper, we define responsible innovation as an innovation process that presupposes shared responsibility regarding the societal needs and values that drive a technological intervention. As such, responsible innovation would account for both of the (closely related but not interchangeable) concepts of science *for* society and science *with* society [5]. It should be clear that core to our understanding of responsible innovation is the articulation and negotiation of ethical and social values.

Our work starts with the assumption that higher education institutions can contribute to responsible innovation. Universities are, after all, acknowledged as one of the essential structures in the triple helix of innovation [6] and it is only reasonable to assume that they maintain a similar role also in the case of responsive innovation. Nevertheless, our work focuses on the (somewhat traditional) function of higher education institutions to train capable and well-equipped professionals or, in this case, ethically capable and socially responsible innovators. The role of higher education institutions as a source of ground-breaking knowledge or as responsible entrepreneurial entities themselves is beyond the scope of this paper. Furthermore, our educational objectives and derived interventions share more with the existing landscape of applied ethics education (particularly engineering ethics education) than with innovation education per se; educational practices aiming to enhance the creative capacities of future innovators, such as creativity training techniques for ideation, innovation education, or design thinking, to name a few, will not be further discussed.

Since the Hastings Centre report on teaching engineering ethics, the importance of ethics education in science and engineering curricula has been steadily established.[1] While there is plenty to be done before ethics education is compulsory to all science and technology programs [8], its relevance is undisputed and a number of high-quality educational initiatives are implemented worldwide. Note that the normalization of ethics in science and technology education precedes the discourse on RRI. The disciplines of philosophy and engineering appear to have found a perfect match in the domain of applied ethics, where a large number of the examined cases are directly derived or, at least, intensified by scientific and technological

[1] For a brief history of the major developments in engineering ethics education, see [7].

developments. Such tendencies suggest that the humanities (as the study of ethics and philosophy) are, by now, a respected partner in educational initiatives regarding (socially responsible) technological innovation. At the same time, educators urge for a broader understanding of engineering ethics [9] while others highlight the limitations of the predominant modes of instruction, such as the case method or codes of ethics induction [10]. Emphasis on macro-ethics [11], attention to meta-ethics and calls to better incorporate STS (science, technology and society) concepts in applied ethics curricula are some of the suggestions towards a more meaningful collaboration between the domains of engineering and philosophy in education.

We welcome the aforementioned developments in the domain of applied ethics education but further observe that the exact nature of RRI as a value-laden process amplifies the identified need for a more rigorous contribution of the humanities to science and technology education. In other words, the challenge of RRI introduces a need and an opportunity for a more pluralist integration of the discipline of the humanities. We expand on this thesis in Sect. 2 and further propose a pedagogy that would best serve our educational objectives, namely hands-on participation. Section 3 documents a case study on RRI education, namely the module "Ethics, culture and biotechnology", part of the minor Responsible Innovation, and the educational activities we implemented along the lines of hands-on participation. Our experiences and observations from three subsequent editions of the course are discussed in Sect. 4.

2 A Humanities-Informed, Hands-on Pedagogy for RRI

The contribution of the humanities to RRI and to RRI education can and should span beyond ethical analysis of (already implemented) technological innovations. Consider as an example the successful synergies between science, technology and humanities in the domain of sustainability. The well-established field of environmental humanities is acknowledged as an essential resource in coping with our present environmental crisis [12, 13], while transdisciplinary approaches are urged with regards to sustainable development. The urgency of tackling RRI problems from a multiplicity of perspectives is not missed by several theorists of RRI who suggest that multidisciplinary teams are crucial in implementing RRI. We believe that a valuable component of RRI education programs is to be found in humanities-related content. Successful RRI education programs should strive to integrate a humanities-attentive consideration of RRI, e.g. one that recognizes the socially constructed nature of the values that guide responsible innovation.

Secondly, and in order to fully prepare responsible innovators-to-be for the negotiation of values that characterizes RRI, successful RRI education programs should strive to sharpen and sensitize the anticipatory, reflective and inclusive capacities of their students. As implied in Stilgoe et al.'s [14] framework of RRI, RRI can only be truly responsible if it is performed in an anticipatory, reflective, inclusive and responsive manner. These attributes imply a capacity to productively converse with different stakeholders and a readiness to consider critically one's own role and position, qualities that are hard to find in mature professionals, let alone young professionals in training. Similar elements can be traced in the practical skills that are considered core but non-trivial to integrate in RRI education. Pavie et al. [2] observe that one of the difficulties in educating responsible innovators (particularly engineers) lies in familiarizing them with the multiplexity and fluidity of the design space as well as with the complex dynamics of including multiple stakeholders. Hollander et al.'s [15] list of required practical skills highlights the need to comprehend various stakeholder perspectives and to identify value conflicts. Successful RRI education should, thus, prepare students to actually cope with multiple perspectives (as opposed to only understanding them) and to continually reflect upon their own perspective.

To facilitate the aforementioned objectives, we propose and implement a form of pedagogy that is highly interactive, experiential and embodied, i.e. one that requires students to participate hands-on in practical exercises with a tangible character and a moral edge. Our rationale behind this approach is two-fold. Firstly, active learning is a more engaging and more effective way of learning that should better support our students in comprehending the ethical and societal issues at stake. Secondly, we expect that inviting our students to go beyond their comfort zone should enhance their appreciation of the complexity of RRI and promote a more considerate and open attitude towards the perspectives of different stakeholders.

For the remainder of this paper, we focus on the domain of biotechnology as a case study that typifies the complexities of RRI as well as the challenges of RRI education. Biotechnology, as the use of living things to make useful products for human use, is a booming industry distinguished by rapid scientific developments and rapid commercialization. It is also an industry that unavoidably touches upon fundamental questions surrounding human values, from the definition of life to the definition of human nature. The values that drive the acceptability of biotechnological innovations are often influenced by emotions and unarticulated assumptions and further problematized by the inaccessibility of the subject matter to the general public. To support and implement a hands-on participation with the issues in an educational context, we introduce two practices distinguished by a unique level of interactivity with and exposure to the materials and methods of biotechnology, namely DIY (do-it-yourself) biology and bioart.

2.1 Tactic 1: DIY Biology

DIY biology is an emergent practice that advocates, promotes and facilitates informal experimentation with biotechnology [16–18]. As specified in [19], DIY biology is "the pursuit of biology outside of scientific institutions by amateurs, students, 'hobbyists' ". Amateur DIY biologists all around the world, often organized in informal local groups or maker spaces, experiment with the materials and methods of biotechnology, actively performing a variety of biotechnological protocols such as DNA extraction or DNA sequencing [20].

The DIY biology movement is, arguably, an interesting model for innovation in the life sciences and one worth introducing to future innovators-to-be. For example, DIY biologists are routinely praised for developing innovative, sometimes ingenious but always cheaper, alternatives to standard laboratory technologies. Furthermore, it is expected that wide and pluralistic access to biotechnology will allow for novel biotechnological solutions to emerge and/or stimulate viable and competitive start-ups in an industry that is largely dominated by big players.

Its economic potential aside, DIY biology can be a relevant educational activity for responsible innovators, thanks to both its embodied nature and its collective character. Obviously, DIY activities are distinguished by a high degree of active learning: students touch, use, handle and experiment with the materials and methods of biotechnology; they perform experiments and get directly exposed to the concepts they would normally only theorize about. Furthermore, the sheer availability of these protocols outside of an institutional context raises questions about self-regulation: how far are we willing to go with the technologies at our disposal when we are the ones responsible for their use? Notably, DIY biology groups are self-regulating groups that tend to operate non-hierarchically and to adhere to the ethics of community, access and collaboration. As such, DIY biology communities can become spaces where values and ethical frameworks are negotiated in an equalitarian manner. In effect, staging or enabling a DIY biology initiative becomes a direct invitation to question, challenge and negotiate how far we are willing to go with the technologies at our disposal.

2.2 Tactic 2: Bioart

Bioart refers to artistic practice that engages with the methods of the life sciences and/or employs living material as its medium [21–23]. Much of bioart literally comes out of the laboratory for it is “created in test tubes, using the laboratory as the art studio” [24]. By definition, bioartists are directly implicated with the materials and methods normally ascribed to science, from organisms such as genes, cells and bacteria to apparatuses such as electrophoresis gels, microscopes and incubators.

Bioart is typical of the ongoing interest of artists in emerging technologies and exemplary of the potentials of art–science collaboration programs [25]. Art–science collaborations are frequently hailed as spaces of cross-contamination that can be beneficial for both research and innovation. For example, interdisciplinary collaborations involving artistic capacities and expertise can be valuable for creativity and innovation. In the case of art that engages with sciences, art can often assume a mediator role between the sciences and the public. More importantly, however, bioart works can become spaces for valuable encounters with the ethical issues surrounding biotechnology, particularly due to the material dimension of these works [26].

3 Case Study: "Ethics, Culture and Biotechnology"

3.1 The Minor Responsible Innovation

The minor Responsible Innovation is a joint initiative of three Dutch Universities (Leiden University, Delft University of Technology and Erasmus University Rotterdam). Within the (Dutch) bachelor degree organization, minor programs are coherent units of education (30 ECTS) available as an elective to bachelor students in their third year. Minors are, in principle, open to students from a wide range of backgrounds. In our case, a multidisciplinary body of students is bound to be the case as students are admitted in equal proportions from all three participating universities. In fact, a defining aspect of the program is the combination of expertise and the merging of academic traditions from three different universities.

The aims and organization of the minor are further described in [27]. The program is interdisciplinary by nature and characterized by a problem-based approach to education, with students assigned real-life cases to work with. Parallel to their project work, students attend a number of standalone modules delivered by instructors from all three participating universities. The minor Responsible Innovation is an innovative and valuable experiment on how to structure an educational program for responsible innovation in its entirety. However, our discussion here is limited to the module "Ethics, culture and biotechnology" (organized by Leiden University), i.e. the module in which we explicitly implement our hands-on pedagogy.

3.2 Ethics, Culture and Biotechnology

"Ethics, culture and biotechnology" is a 6-session long module, scheduled at the second half of the minor Responsible Innovation. As discussed in Sect. 2, the course focuses on biotechnology as a relevant and challenging case study for RRI: Contemporary biotechnology is testing accepted ethical and aesthetic values and, as such, challenges us to seek new approaches to the ethical, cultural, juridical and economic issues relating to biotechnological practices. Table 1 summarizes the learning objectives of the course, while Table 2 provides a generalized course schedule.

"Ethics, culture and biotechnology" builds upon the instructors' expertise in teaching and coordinating educational projects at the intersections of art, science and the humanities. The Leiden University Honours class "Who Owns Life? Ethical, Juridical, and Artistic Encounters with Biotechnology" [28], organized since 2007, is one of the signature courses of the instructors distinguished by both a hands-on perspective and a devotion to the voice and agency of artists. Often under the supervision of invited artists, students from a multiplicity of backgrounds explore the ethical, legal and societal implications of biotechnology by engaging with the materials and methods of the life sciences inside the biology laboratory.

Table 1 Learning objectives as published in the e-guide

Learning objectives
Describe key ethical issues in biotechnology and its products
Identify individual and social barriers that play a role in the application of biotechnological innovations
Identify various perspectives and values in the public debate surrounding biotechnology
Demonstrate debating skills and critical reading skills

Table 2 Course overview (some variations across editions apply)

Course overview
Introduction and DIY DNA extraction workshop
Lecture "Why Art?"
Debate 1: human enhancement
Debate 2: patents
Artist workshop in the lab
Roleplay CRISPR and human germline modification technologies
Skill lab: board game design

It should be noted that our partnering university Delft University of Technology has a substantial tradition in engineering ethics education. Core material on responsible innovation, applied ethics and value-sensitive design is introduced to the students during the module "Introduction to RI" (organized by Delft University of Technology). Our efforts towards a hands-on RRI education should be understood as complementary to this module.

4 Our Approach: Hands-on Participation

Across the three editions of the module "Ethics, culture and biotechnology" (academic years 2014–2015, 2015–2016 and 2016–2017), we implemented several educational activities along the lines of hands-on participation, namely DIY biology workshops and bioartist workshops. Note that the boundaries between bioart and DIY biology are not always clear-cut, as several bioartists make use of DIY biology practices and/or relate to a DIY biology ethic.

4.1 DIY Biology Workshops

DIY DNA Extraction DIY DNA extraction is a simple activity widely used for both science communication and DIY biology workshops. It is a straightforward, inexpensive exercise with concrete results: DNA is extracted from organic matter

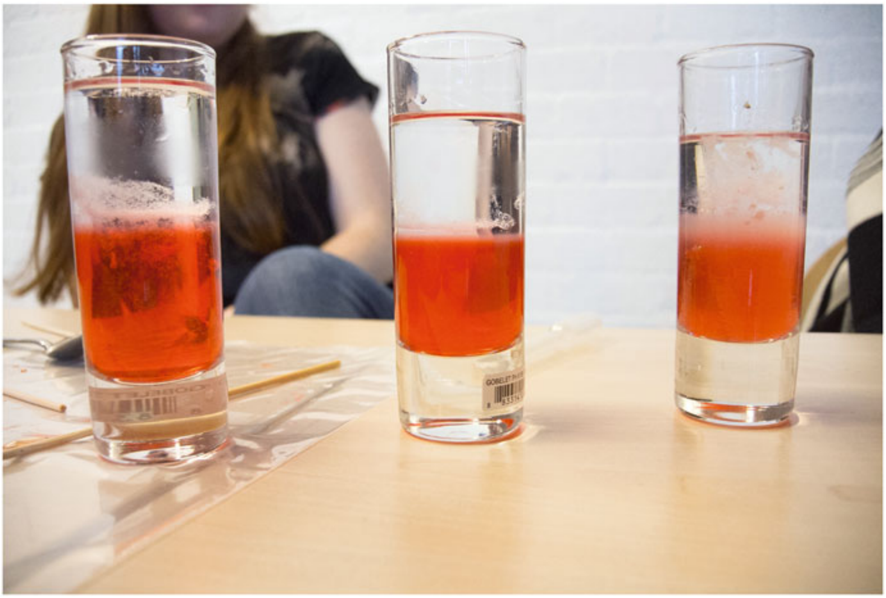

Fig. 1 Results of the strawberry DIY DNA extraction as performed by the students of "Ethics, culture and biotechnology" (academic year 2015–2016). Image credits: A. Kallergi

and is visualized in a clear layer of alcohol (cf. Fig. 1). The protocol can be performed using only household supplies and items available in one's kitchen or local supermarket.

We conducted DIY DNA extractions using strawberries in two subsequent editions of the course, as both an opening exercise and an introduction to biotechnology, in general, and genetic research, in particular. These extractions took place in a regular classroom and were led by the course instructors (both non-life scientists). Generally speaking, our protocol yields clear results without much need for guidance or accuracy. Regarding the visceral experience of a strawberry DIY DNA extraction, the process is messy but harmless. Plastic bags and coffee filters are likely to break during the process but strawberries are a very friendly and forgiving material: they smell nice and are not disgusting to clean.

The DIY DNA extraction was popular among our students. It is a surprising and fun activity and one not readily associated with a university classroom setting. Looking at strings of DNA for the first time is a rewarding experience and students happily take (and post) photos of their results. Obviously, the protocol succeeds in turning an abstract concept into something visible and tangible. As a conversation starter, it raises discussions mostly on the potential of DIY biology. What can one do with the extracted DNA? And is this a credible scientific procedure? Such discussions are often stimulated by the presence of science students who tend to reject the activity as relevant for educational or illustration purposes only.

Building a DIY Sterile Hood For the third edition of the course (2016–2017), bioart pioneer Oron Catts introduced out students to the technique of tissue culture.[2] Tissue culture (or cell culture) is the practice of growing living cells outside of an organism. The students first visited the tissue culture facilities of the Faculty of Science, Leiden University, where they were introduced by the lab responsible to the techniques, laboratory equipment and biological agents, i.e. living cells, involved in tissue culture. Oron introduced the students to his artistic use of the technique and guided them to the making of a DIY sterile hood (a component that allows growing cells in sterile conditions). A DIY hood should allow one to perform tissue culture outside of the laboratory, as Oron and his colleagues have successfully demonstrated at various settings.

The exercise of building a sterile hood was presented to the students as an engineering problem. Students worked in groups, were given a list of materials and a schematic diagram of a sterile hood and were asked to devise their own designs/ solutions. As such, the exercise was rather appealing to our students, particularly the ones with an engineering background, who took to the task and competed on their designs; one group took their construction home with them. Oron contextualized this exercise as not only a means to perform DIY tissue culture but also as an activity that requires one to think carefully about conditions of sterility and the artificial environment of the laboratory. Yet, it remains unclear whether this critical message was evident to the students, who seemed to struggle with connecting the wetware, living part of tissue culture to the hardware part of it.

4.2 Artist Workshops

General Setup For each edition of the course, we invited a practicing bioartist to lead a 1-day session with our students inside the biology lab. Invited artists were encouraged to draw from their own artistic practice and develop practical exercises that relate to the topics of the course (Fig. 2). Other than a couple of consultations with the instructors, the artists were free in the type of activities they wished to perform with the students. The workshops were hosted at the Faculty of Science, Leiden University, with the kind support of the Junior Science Lab.

Adam Zaretsky: Do-It-Yourself Biolistics For the first edition of the course (2014–2015), internationally renowned bioartist Adam Zaretsky invited our students to participate in his DIY biolistics protocol/art performance. A biolistic particle delivery system or gene gun is a device used to introduce foreign genes in the genome of an organism by "shooting" DNA-coated micro-particles to the target cells [29]. Adam's workshop attempted to replicate the functionality of a gene

[2] While strictly speaking an artist workshop (cf Sect. 4.2), we classify this activity as a DIY exercise due to the staging of the workshop, the form of participation assumed by the students and the straightforward nature of the activity.

(a) (b) (c)

Fig. 2 Student activities inside the biology laboratory (**a**) Building a DIY sterile hood (**b**) DIY DNA extraction the Adam Zaretsky way (**c**) Making breast milk butter. Image credits: A. Kallergi

gun using gold nanoparticles—a substance typically used in commercially available gene guns (cf. Helios gene gun [30])—and a powerful jackhammer. The workshop entailed the extraction of DNA from various food sources (an exercise frequently performed by Adam Zaretsky in public and art spaces) and Adam's subsequent attempt to use his makeshift gene gun with the extracted DNA. For the record, a variation of this performance was delivered a few days later in Kapelica Gallery, Ljubljana [31].

Much can be said about Adam's artistic practice in general (often described as "bioethics in action" [32]) and his DIY mechanical genetic engineering experiments in particular. Here, it should suffice to say that Adam's practice problematizes the discussion surrounding genetic engineering by, among others, amplifying the grotesque in the existing scientific methods and techniques. In that respect, Adam's workshop was a staged performance intended to merge scientific terminology, laboratory equipment, biological agents and oddity. The quirkiness of his procedures was not missed by the students who played along with Adam's instructions but would readily admit that Adam is mocking or circumventing scientific procedures rather than enacting them.

Alice Vandeleur-Boorer and Heath Bunting: Survival Food Tech For the second edition of the course (2015–2016), Alice Vandeleur-Boorer and Heath Bunting organized an artist talk and a number of short indoor and outdoor exercises motivated by the notion of food and food technologies. During the laboratory exercise, the students produced butter from human breast milk[3]; the practicum was inspired by Alice's interest in food politics and her latest project Vaghurt (2013–2015) [34]. In the public space nearing the laboratory facilities, Alice and Heath demonstrated a number of survival techniques such as making fire and producing ice in the wild. These outdoor activities related to Heath's long-lasting practice of public space, cross-border, activist interventions as well as the duo's recent joint practice. In the artists' own words, "they teach domesticated artists and visionaries to nurture and protect themselves in order to release them back into the wild" [35].

Survival Food Tech triggered extreme responses by our students, at both ends of the spectrum. The artists take a clearly anti-corporate stance on issues of biotechnology and globalization and tend to take personal risks in their projects. These attributes were unexpected and outlandish to our students who, in turn, responded to the subsequent exercises, particularly the outdoor ones, either with irritation or with eagerness. When looking for a spot to make a fire, students were asked to climb walls or walk through vegetation in what was, in fact, a search for wildness and invisible borders in the public space. Students were free to withdraw any time for the activities and several of them actually did.

5 Discussion

A word of caution: our short descriptions of the artist workshops are bound to fall short to the experiences undergone by our students. To make things worse, our limited coverage fails to properly address the artistic value of the artworks directly or indirectly referenced in the workshops. While these limitations are crucial for a full appreciation of the educational activities organized, it is not our intention here to provide a fully fledged analysis of the artist portfolios; neither do we wish to assess the artistic value of the workshops as artworks themselves. Instead, we will focus on what we observe to be relevant points in understanding and evaluating these activities as hands-on participatory experiences for the sake of RRI education.

5.1 Course Evaluation

The module has consistently received very good evaluations by the students and is highly appraised for its interactive character. Unfortunately, course evaluations were organized independently to the module instructors and varied enormously across the three editions of the minor. As a result, we are particularly limited in the quantitative data at our disposal. Nevertheless, the 2016–2017 edition received

[3]For a short commentary on this activity, see [33] (in Dutch only).

the best quality rating across all modules (3.75 out of 5) and the second best overall rating (3.69 out of 5). For the 2015–2016 edition of the course, over 84.2% of the students gave a quality rating of 5 or higher in a scale of 1–7, making our module the best rated module for block 2 (no data for block 1 are available to us). Overall, students appreciate the high level of interaction ("Truly an interesting course. the small groups and interaction was very well organized", "fun outdoor activity") and, reportedly, find value "in the opportunity of learning from people outside the university or from other fields". Our own, informal in-class evaluations also testify that students do appreciate the course and approach taken[4]; some difficulties with connecting the course to RRI were reported but such comments declined progressively across editions.

We are pleased with the quality of the course and believe to have delivered a curriculum that successfully implements an active and experiential form of learning. Still, what can we say about the impact of our educational activities and their relevance for RRI education? Did our implemented activities meet our expectations and assumptions regarding the potential of DIY biology and bioart as a pedagogically relevant hands-on participation? Given our experiences and observations from the course, we suggest that the assumed potential of our hands-on pedagogy materialized in the form of two concrete contributions: (1) Hands-on encounters with the materiality of biotechnology and (2) Hands-on encounters with a vastly different knowledge system.

5.2 *Encountering the Material: Repurposing the Materials and Methods of Biotechnology*

One of the main contributions of our hands-on pedagogy is to be found in the tactile, tangible, embodied encounters with the materials and methods of biotechnology. As it was hypothesized, DIY biology activities were successful in bringing abstract or unfamiliar concepts within reach. More importantly, they allowed an equalitarian consideration of these concepts and facilitated a discussion that was not dominated by the expert (scientific) discourse. In the case of DIY DNA extraction, the subject matter became something that everyone was eligible to talk about, raising questions about sterility, purity, and the underlying quest of science to study life in isolation. Both Oron's and Adam's workshops were characterized by a clear intention to break the corresponding technologies down to their core elements, exposing the usually concealed mechanisms of controlling and manipulating life.

While successful as embodied and equalitarian experiences, the full potential of DIY biology may have been underrepresented in our current implementations. More

[4]While we have no means to specify which (out of the multiple) interactive activities are most appreciated, our informal evaluations suggest that both the DIY biology activities and the artist workshops make a lasting impression to the students.

specifically, a missed opportunity is to be found in the collective possibilities of DIY biology. Our activities lacked a practical follow-up that would allow the group to feel as part of a DIY project/community and to, consequently, take ownership of the process. As a result, the possibilities of DIY biology as a space of moral negotiation remained hypothetical.

5.3 Encountering Another: The Artistic Perspective

While DIY biology exercises tend to be a new but comfortable territory for our students, artist workshops aren't. Surprisingly, it seems to be the case that simply bringing our students in contact with the practices, idiom and ways of working of artists is quite a striking experience. Our students seem to be affected by the vast differences in worldviews and methodologies that were revealed during their encounters with artists at work. It can be argued that encounters with (any) real stakeholders could train the anticipatory and inclusive capacities of our students. Still, their encounters with artists were unique in challenging the authority of the students' existing and assumed knowledge systems. As such, encountering the artistic perspective not only enriches the anticipatory and inclusive capacities of the students with additional viewpoints but also confronts them in a way that requires them to reflect upon their own certainties.

Of course, there is and should be much more to art than coming to terms with alternative ways of knowing. Successful bioart works are platforms where moral dilemmas are enacted and explored, a quality that may or may have not been present in our current implementations.

5.4 Limitations and Additional Recommendations

Despite our encouraging results, a limitation of our approach may be the choice of subject matter. Throughout the paper, we reasoned over the relevance of biotechnology as a case study for RRI and RRI education. Nevertheless, we are aware that RRI education spans across a variety of technological subjects. The tactics chosen as the means to implement our pedagogic stance on hands-on participation (DIY biology, bioart) may be unique to the domain of biotechnology and may not be directly applicable to other technological subjects. Furthermore, it might be the case that these activities were made possible only thanks to our long lasting involvement with the field and our existing professional network. We acknowledge these limitations but are confident that a humanities-informed approach which values active learning and respects the artistic perspective should be relevant and applicable to several technological subjects.

As a humanities-informed hands-on pedagogy finds its way in RRI education, some practical risks and recommendations must be taken into consideration. First and utmost, motivated instructors should be attentive to the fact that their students are about to embark on a challenging territory. A hands-on participation with potentially confusing and/or morally charged situations should by no means put the wellbeing of students at risk. Sufficient preparation and full disclosure on the voluntary nature of the activities are some of the ways to address this risk. Furthermore, inviting students to go beyond their comfort zone requires some good will from the participants and can only happen in a safe learning environment. To our experience, workload pressure (unrelated to our module) and stress from minor-wide related issues can be detrimental to student motivation. As it is often the case, a clear articulation of the course objectives and of the relevance of the course to RRI is essential.

On a similar tone, we insist that hands-on participatory exercises are properly contextualized. DIY biology activities can be easily reduced to science communication activities or engineering tasks while the idiom of art can be particularly confusing to students with minimum to no prior exposure to contemporary art. The experiences of students may remain unarticulated or, even worse, get dismissed if not properly contextualized, embedded, discussed and theorized. This need for contextualization is yet another reason why we believe that interactive exercises are not enough: hands-on participation requires a form of instruction that is both experiential and humanities-informed.

6 Conclusion

This paper contributed a pedagogic stance for RRI education that emphasizes a humanities-informed, hands-on participation with the complexity that defines RRI. We suggested that active and experiential learning that brings students in close contact with the material aspects of the issues at stake and exposes deep differences in stakeholder perspectives can be an engaging way to train the anticipatory and reflective capacities of future responsible innovators. We implemented such a hands-on participatory pedagogy using the tactics of DIY biology and bioart, two practices distinguished by a unique materiality and a potentially challenging moral edge. Our experiences with three subsequent editions of the module “Ethics, culture and biotechnology”, minor Responsible Innovation, are particularly encouraging and motivating. Our observations have also enabled us to separate our original notion of hands-on participation into two potentially promising dimensions, namely the encounter with the material and the encounter with vastly different knowledge systems. It remains to be seen whether hands-on participation can be implemented also according to our original motivation, i.e. as a hands-on engagement with actual moral dilemmas. And it remains to be seen whether the experiences of our students can translate to personal changes as well as to changes in the institutional and professional settings of RRI practice. Still, we hope to have encouraged RRI educators to consider and implement their own versions of hands-on participation with the fundamental aspects and challenges of RRI.

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