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ARTICLE

Empathy and ethical becoming in biomedical engineering education: a mixed methods study of an animal tissue harvesting laboratory

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ABSTRACT

Biomedical engineering presents a unique context for ethics education due to the human-centric nature of biomedical engineering coupled with the pervasiveness of animal-based practices. This study summarises the design of a pedagogical practice intended to enhance students' abilities to recognise ethical issues in biomedical engineering practice and inquire into normative aspects of the discipline. The context of the study is an introductory biomechanics course wherein students harvested animal tissue, critically reflected on this experience, and discussed the experience in class. We brought two theoretical frameworks to this investigation pertaining to empathy and ethical becoming. We employed a four-phase mixed methods research design that included quantitative comparisons of changes in empathy and related phenomena, thematic analysis of written reflections, an observation and focus group, and triangulation of these results. Quantitative data remained stable before and after the course. Thematic analysis of reflections revealed five themes: research design, treatment of animals, beneficence, worth of life, and emotional engagement. The observational and focus group results emphasise affective considerations of engineering practice. This study provides a guide for future biomedical engineering education efforts that deal with ethically sensitive, emotionally powerful, and visceral experiences, as well as for research pertaining to empathy and ethical becoming.

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1. Introduction

The biomedical engineering profession aims to improve medicine through design. Hence, the vision of the Biomedical Engineering Society (BMES 2020) is 'developing and using engineering and technology to advance human health and well-being.' Consequently, as educators in the field, we should aim to equip our students with not only the technical ability to solve biomedical design problems, but also the knowledge to make ethical decisions. While we recognise that cultural systems (e.g. institutional, organisational) can inhibit individual agency and action, we should strive to instil in our students the courage and confidence to see such ethical decisions to fruition when faced with ethical challenges in their future practice. Numerous instructional resources exist that pertain to specific evidence-based pedagogical frameworks in engineering education to these ends, as evident from the abundant resources available on the Online Ethics Centre (a repository of case studies for science and engineering ethics study).

Historically, codes and case studies have been the most prominent way of teaching ethics (Haws 2001; Herkert 2000). This trend continues today, but notably, these two instructional approaches are usually coupled with myriad other instructional techniques, such as discussion, writing or reflection assignments, and ethical theory (Hess and Fore 2018). The expansive set of instructional practices, including variation in specific modalities for enacting these practices, makes it challenging to identify transferability of strategies (and strategy pairings) from engineering ethics, broadly, to the specific biomedical engineering context. Moreover, biomedical engineers encounter a unique set of ethical issues when compared to other engineering disciplines, as they may work with human patients and medical records, develop treatments involving stem cells or genetic modification, and perform testing on animals. The strong connection to medicine and bioethics (Beauchamp and Childress 2013) provides a rich source of potential case studies and theories to draw from.

This is not to suggest that no specific biomedical engineering ethics education studies exist: many do (e.g. Hess et al. 2019; Lewis, Van Hout, and Huang-Saad 2010; Martin et al. 2005; Merryman 2008; Monzon and Monzon-Wyngaard 2008; Vallero 2007). In addition, a review of the Online Ethics Centre reveals multiple cases specific to biomedical engineering, including animal ethics. Yet, a concerted focus on human and non-human relationality remains an expansive context for empirical investigation. Furthermore, ethical becoming (Fore and

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Hess 2020) presents a novel framework for studying such development. Thus, this study seeks to help advance the space of engineering ethics in biomedical contexts by applying the lenses of empathy and ethical becoming to students' experiences in an introductory biomedical engineering ethics course wherein students grapple with lab practices involving animals, namely, mice.

2. Materials and methods

In this section we (1) define research questions, (2) unpack how we operationalise and aim to study ethical formation, (3) describe the instructional strategies utilised in the course which serves as the context for this investigation, and (4) describe the mixed methods research design and the associated methods for each phase.

2.1. Research question

The primary objective of this study was to assess the impact of embedded ethical reflection in biomedical engineering students' first course within a biomedical engineering programme at a large public urban university in the Midwest United States. Specifically, students in a 200-level Introductory Biomechanics course completed an assignment that combined a rodent tissue harvesting laboratory, a series of individual ethical reflection prompts, and class discussion. Within this context, the primary research question for this study was, '**How and to what extent does participation in this embedded ethics assignment affect ethics-related skills, including dimensions of empathy and ethical becoming, among biomedical engineering students?**'

2.2. Theoretical framework

This study brings two primary theoretical framings to the instructional and research design: (1) empathy in engineering ethics and (2) ethical becoming. We conceive of empathy as instrumental in prosocial moral development and the 'spark of human concern for others' (Hoffman, 2000, 3). Moreover, ethical becoming provides a lens to study relational considerations of ethical formation in situ. This framework seeks to account for the ever-unfolding (i.e. becoming) self and its indebtedness to others (human and non-human) with whom the individual has and will interact. In the following sections, we further unpack these framings.

First, we operationalise empathy as a four-part phenomenon that varies between affect/cognition and self/other orientation (Hess & Fila, 2016). Affective constructs include *empathic concern* or the tendency to become concerned for others and *empathic distress* or the tendency to internalise other-oriented concerns. Cognitive constructs include *imagine-self* and *imagine-other perspective-taking*. This cognitive distinction, while subtle, involves the difference between me imagining myself in your shoes versus me imagining you in your shoes. When we discuss empathy as a holistic phenomenon, we are considering some level of manifestation of each of these discrete types. In short, to accurately understand another's stance requires some level of emotive/affective considerations and, potentially, alignment. Furthermore, empathy's affective elements are the most influential drivers of prosocial action (Hoffman, 2000). Hence, instruction featuring empathy must consider learning across the cognitive/affective and self/other continua.

Second, ethical becoming (Fore and Hess 2020) includes five core components: (1) relationality and indebtedness, (2) harmony and potency, (3) care, (4) freedom and reflective thought, and (5) ethical inquiry. Taken together, these components call for explicit engagement with diverse ways of knowing and valuing, as well as a critical consideration of how the others with whom one engages have contributed to the formation of one's current self, as well as other co-created products of the encounter (e.g. designs, prototypes, datasets). Awareness of this relational process challenges one to consider their obligations to others. While each component of ethical becoming plays a role in student experience, the components of relationality, indebtedness, and ethical inquiry are the most relevant here. First, relationality and indebtedness signify that one is constituted through interactions with difference and thereby indebted to all that contributes to that constitution. The becoming of one's self, others, and that which is co-created between them is each indebted to the other. This credit/debt relationship creates the need for obligations. Second, stemming from John Dewey, ethical inquiry details a heuristic process, infused by one's moral excellencies or virtues, through which (1) awareness of the situation or problem is developed, (2) a judgement about what to do is made, (3) an experiment is carried out on that judgement, and (4) iteration occurs following the outcome of the experiment that will feed back into one's awareness and possibly transform one's judgement.

Taken together, this theoretical framing emphasizes empathy's situativity in relational processes and, thus, empathy's salience for recognising one's indebtedness and openness to others' values. For example, it is difficult to imagine a situation in which one assigns a fair value to something for which one has no genuine concern. Empathy, as a result, contributes to the modes of valuation – particularly in relation to rodent bodies – demonstrated by students in this study. This framing lends us to ask multiple relational-oriented questions which are guided (and constrained) by the

data. With that said, a priori questions include: How, if at all, do students' empathic tendencies shift as a result of their participation in this project? How do students empathise with rodents in laboratory contexts? How, if at all, does such empathising contribute to how students inquire into ethical situations regarding animal subjects? How do students become aware of relationships of credit/debt, if at all? How do students make judgements, assign value, and assess obligation in relation to animal subjects?

2.3. Course overview

2.3.1. Programmatic context

The course that serves as the testbed for this study is, typically, the first course that students take in our biomedical engineering curriculum. The course is a 16-week Introductory Biomechanics course that features a lab component. The following programmatic student outcome guided development of student learning objectives at the course level: '**Students will recognize their professional responsibilities and apply ethical inquiry when developing, refining, and communicating the solution to a biomedical engineering situation**.' While this programmatic objective details an ultimate student outcome, five learning objectives were interspersed throughout multiple courses in the program.[1] Two ethics-related learning objectives guided the design of the embedded ethics assignment (described in the next section): (1) **Recognise own values and morals** and (2) **Reflect on contemporary ethical issues in engineering design for biological and medical applications**. In this first iteration, we refrained from introducing any explicit affective-oriented goals (i.e. courage, commitment), but we are considering potentially including explicit learning goals in these domains in future iterations (see discussion).

The course which serves as the context of this study, Introductory Biomechanics, is the first course that most students take in the program. Thus, it serves as the first time that students grapple with ethical issues in the biomedical engineering disciplinary context. The course's ethics focus is on animal practices, a frequent ethical consideration in biomedical engineering. During the course, students harvest animal tissue, learn proper tissue storage techniques, and mechanically test various tissues throughout the semester. These experiences prepare students for ethical decisions later in the curriculum, wherein they will face a wider range of ethical concerns, such as human non-invasive measures, life cycle analysis of medical devices, and device recalls.

2.3.2. Course ethics instruction

Figure 1 provides an overview of the 16-week course, highlighting ethics-related instruction as well as research-related data collection efforts. As Figure 1 shows, the course includes six explicit ethics experiences and assignments. Taken together, these activities prompted students to critically reflect on their personal values, share and consider the perspectives of their peers and teacher, and identify the normative disciplinary values and how those align with one's personal values. We designed the critical reflection activities by utilising the Describe, Examine, and Articulate Learning (DEAL) model (Ash and Clayton 2009), wherein students **D**escribe the experience on a personal level, **E**xamine nuances associated with the learning objectives, and **A**rticulate **L**earning, thus promoting meta-cognition. Reflections were continuous, spanning across the semester. Specifically, of the six touchpoints embedded in Introductory Biomechanics, three explicitly required written reflection assignments.

Throughout the 16-week semester, there were six primary touchpoints pertaining to ethics. **First**, on Day 1 of class, students were introduced to an ethical inquiry heuristic that aligns with Sternberg (2010). **Second**, during Week 2, students attended an annual user's meeting for the local Science Animal Resource Centre (this activity was optional). At this time, all students completed a pre-reflection question that asked, 'In 2–3 sentences, please answer the following question: Without any additional information, what are your current feelings toward the use of animals and animal testing in biomedical research?' **Third**, students participated in a tissue harvesting laboratory. **Fourth**, students watched an animal euthanasia video and then completed an ethics assignment with five reflection prompts.[2] After watching the video, students reflected on the following items (note: we have mapped questions back to the DEAL framework, but students did not see the DEAL prefaces):

- **Describe**: Describe what you were doing when you watched the video. Where were you? Who were you with? How do you think this impacted the way you feel about what you observed?
- **Examine**: Do you feel differently about what you did with the animals in the laboratory after watching the video? In what ways does the video make you question the activity? Can you

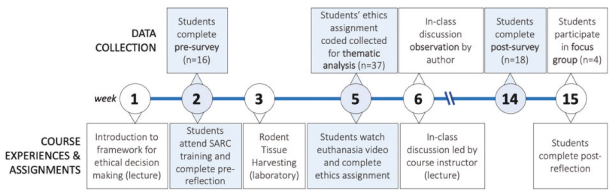

Figure 1. 200-level Introductory Biomechanics course timeline showing course experiences and assignments (below) and data collection (above) throughout a 16-week course.

elaborate on which of your core values/beliefs are most in conflict about what you saw and why?

- **Articulate Learning**: The Pew Research Centre now shows that 52% of Americans oppose animal-based scientific research (only 36% with high scientific knowledge background oppose, seeStrauss 2018). Does watching the video change your opinion about animal-based research? If so (or if not), why? Knowing that animal research is a cornerstone for research related to human health, and this is the basis of much of what we do in biomedical engineering, did this video make you question anything about your choice of major? If so (or if not), why?

Fifth, the instructor facilitated a 40-minute discussion, which included inviting various student perspectives and further prompting critical reflection on the case. **Sixth**, students completed a post-reflection in Week 15 of the course. The post-reflection provided students with the following prompt: 'In 2–3 sentences, please answer the following question: How does one (or you) balance support or opposition to animal research while studying human health/disease?' For this final prompt, because it was at the very end of the course, reflections tended to be very short and many students did not complete the reflection. Thus, this final set of reflections was relatively incomplete when compared to the first two. Hence, in Phase 2 of this study, we only thematically analyse the first two prompts.

2.4. Mixed methods research design

This study utilises a convergent parallel mixed methods research design (Creswell and Plano Clark 2011) wherein we conducted each research phase in parallel. Figure 2 provides an overview of the four research phases, including data collection and analysis strategies. We present the methods and results of Phase 1 (Quantitative Comparisons), Phase 2 (Written Reflections) and Phase 3 (Observations and Focus Group) separately in the following sections. The discussion serves as Phase 4 and provides a concerted effort at triangulating findings across studies.

2.4.1. Phase 1: quantitative comparisons

We used four constructs to measure student gains in interpersonal-related phenomena. Two empathy constructs, **empathic concern** and **perspective-taking,** were taken from the Interpersonal Reactivity Index (Davis 1983). In alignment with the theoretical framework, these constructs represent an individual's affective tendency to become concerned for others (empathic concern) and cognitive tendency to consider others' perspectives (perspective-taking). Afew items were omitted from construct computations based on confirmatory factor analytic tests reported

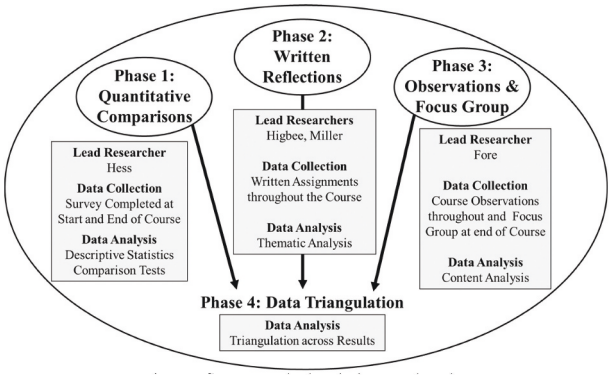

Figure 2. Concurrent mixed methods research design.

by Hess et al. (2018). In addition, we measured changes in **emotion regulation** and **interpersonal self-efficacy**. Emotion regulation represents one's ability to manage their emotions in stressful encounters. In our framing, this ability is key to conducting complex tasks, such as design or ethical inquiry. Interpersonal self-efficacy represents one's confidence in engaging with others.

We conducted a series of paired t-tests to identify potential significance of pre/post changes on survey constructs. We utilised a one-tailed t-test in each instance, wherein the hypothesis was, 'Students will exhibit increases after completing the course when compared to before.' Prior to conducting t-tests, we assessed data for normality. Based on Shapiro-Wilks coefficients (Shapiro and Wilk 1965) all data was approximately normal, thus supporting the use of paired t-tests. Given the relatively small sample size, we acknowledge potential concerns of statistical power. In addition to ascertaining statistical significance, we computed Cohen's (1992) effect sizes (d) to ascertain the practical significance of changes, wherein d >.80 suggests a large effect, d > .50 suggests a moderate effect, and d > .20 suggests a small effect.

2.4.2. Phase 2: written reflections

The reflection assignments prompted students to participate in cognisant recognition of ethical knowledge and to use intentional reflection to improve their ethical reasoning. While 38 students enrolled in the course, only 37 completed these assignments. We applied thematic analysis (Braun and Clarke 2006) to two artefacts: (1) the pre-reflection and (2) the ethics assignment (see Figure 1 for the course timeline). In this process, we inductively generated codes via a close review of the student responses. Two of the authors collaborated to develop and refine codes after reading the pre-reflections. Afterwards, each of the two authors independently coded data from both student pre-reflections (week 2) and student ethics assignments (week 5). The authors compared their thematic coding in an iterative process until they reached full agreement.

2.4.3. Phase 3: observations and focus group

Phase 3 is comprised of two additional qualitative methods conducted during the Fall 2019 semester of the Introductory Biomechanics course. First, one of the authors of this paper – Fore, a trained anthropologist – conducted an observation of the in-class discussion occurring in Week 6 (see Figure 1). According to the course instructor, the discussion was originally planned for the first 15–20 minutes; however, due to high student engagement with the topic of the discussion, this class activity – and, as a result, the observation – lasted 35–40 minutes. The observer took detailed notes throughout the observation, compiling a broad representation of student perspectives. Second, Fore conducted a 45-minute post-semester focus group with four students from the class (12 students expressed interest in attending the focus group but, unfortunately, only four students attended). The focus group prompted students to reflect further on their experiences harvesting tissues from the recently euthanised rodents and previously watching footage of one rodent's death. Questions on the focus group protocol were crafted after, and in consideration of, the class observation. Thus, the focus group further unpacked observations pertaining to student thoughts and emotions around the use of animal subjects, the comparative value of animal life, and 'humane' euthanasia.

3. Results

3.1. Phase 1: quantitative comparisons

Figure 3 highlights student responses on the four survey constructs pre (i.e. before) and post (i.e. after) the course. Responses were on a 9-point Likert-type scale where 1 represented strong disagreement, 9 represented strong agreement, and all items in-between represented a continuum between these two ends. As Figure 3 shows, Perspective-Taking (PT) very slightly increased as did Emotion Regulation (ER). Both Interpersonal Self-Efficacy (ISE) and Empathic Concern (EC) decreased slightly.

Next, the difference scores (i.e. post minus pre responses) were checked for normality by computing the Shapiro-Wilks coefficient (Shapiro and Wilk 1965). All difference scores were approximately normal. Hence, we conducted a series of paired t-tests to ascertain if any changes were significant. As Table 1 shows, no changes were significant. Effect sizes (Cohen's d) were also found to be below the 'small' threshold of $d = .20$ (Cohen 1992) in all instances, with interpersonal self-efficacy exhibiting the greatest magnitude of change ($d = -.17$). Thus, these findings suggest that the class had no effect on students' empathic tendencies, emotion regulation skills, or interpersonal self-efficacy.

3.2. Phase 2: written reflections

We generated five themes based on the two student reflection prompts: (1) research design, (2) treatment of animals, (3) benefit to humans, (4) worth of life, and (5) emotion. We summarise the pre-reflection and ethics assignment themes in separate tables (Tables 2 and 3, respectively). These tables also feature example codes and exemplary student quotes, with our emphases added.

Table 1. Comparison tests on survey constructs.

Factor	Factor Description	*n*	*M*	*SD*	*t-stat*	*p (1-tailed)*	d
PT	Perspective-Taking	18	.01	1.12	.04	.49	.01
EC	Empathic Concern	18	−.04	1.44	−.12	.45	−.03
ISE	Interpersonal Self-Efficacy	18	−.22	1.31	−.72	.24	−.17
ER	Emotion Regulation	18	.01	1.26	.05	.48	.01

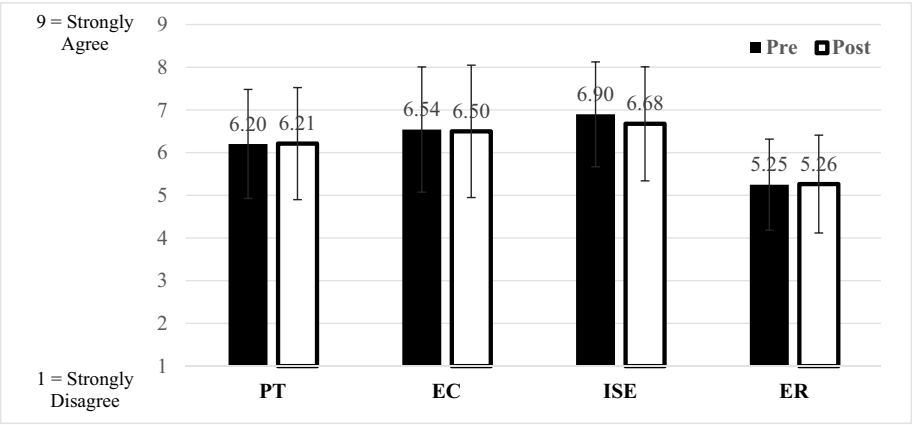

Figure 3. Pre/post descriptive statistics of interpersonal constructs ($n = 18$). Note: values represent mean responses and error bars represent standard deviations; PT = Perspective Taking; EC = Empathic Concern; ISE = Interpersonal Self-Efficacy; ER = Emotion Regulation.

Table 2 details themes from thematic analysis of students' pre-reflections which took place at the outset of the course (i.e. before attending the SARC user meeting, watching the euthanasia video, or performing the tissue harvesting lab). Student reflections included many comments on practical reflection themes (i.e. research design, treatment of animals, and benefit to humans). Considerations of human benefit were most prevelant (58%) followed by considerations of treatment of animals (53%).

After substantive ethics-related activities (i.e. user meeting, watching the video), students performed a second ethics reflection. While most responses still contained aspects of the practical reflection themes as before, there was a notable shift in distribution to worth and emotion (see Table 3). Rather than suggest that students were less concerned with technical aspects of research, we note that this potentially suggests students were engaged with a more holistic understanding of engineering beyond rule-based research processes. This

Table 2. Themes identified in student pre-reflection assignments and example codes.

Theme	Example Codes	Example Student Quotes from Pre-reflections
Research Design (42%)	Alternatives exhausted (e.g. *in vitro* options)	'I feel like the use of animal testing in research is a **necessary evil**.' ' … but in our current world we have **no other way to do tests** before doing them on humans.'
	Necessity in research design	'I am for the movement towards alternative methods when possible, but recognize**that in some circumstances, research cannot be accomplished by other means**.'
	Appropriate sample sizes used	'So, before doing any animal testing there should be a **check [to] prove the significance** of doing the test.'
Treatment of Animals (53%)	Animals are treated humanely (e.g. pain management)	'Noninvasive research that 1) **does not harm** the animal, 2) is conducted in a manner consistent with respecting the animal's dignity, and 3) the animal **continues to live a normal and happy life**, is perfectly acceptable.'
	Researchers trained in animal care and use	' … as long as ethical **rules and regulations are being followed**.'
Benefit to Humans (58%)	Provides value to humans	' … the sacrifice of those animals has the **potential to help people** … '
	Important scientific tool	' … but I think that animal testing is a **very valuable tool in research**.'
	Important to advance knowledge or experience	' … animals **greatly enhance the studies** of certain drugs, medicines, or implants … ' ' … not only a great idea, but **a fantastic opportunity for students and researchers to learn and gain experience** … '
Worth of life (32%)	Existing species hierarchy	'but at the end of the day, **we are humans and they are animals**.'
	Agency considerations	' … while animals are of course very different from humans, I cannot imagine them not **possessing their own agency** (in the same manner as I do with other humans) … '
	Justification of using animals	'In the end, the **ends must justify the means**; if the animal was used without good reason or lackadaisically, its life was just wasted.'
Emotion (11%)	Raw response (e.g. sadness)	'While it **saddens** me, I understand the necessity of using animals for testing in biomedical research … .'
	Inner conflict	'I believe that a lot of good can come from testing on animals first to ensure positive outcomes when tested on humans. However, **the other half of me thinks** that animals have a right to live just as much as humans.'

Note: n = 37; % represents instances of codes in any student reflection response

Table 3. Themes identified in student ethics assignment and example codes.

Theme	Example Codes	Example Student Quotes from Assignment Reflections (week 5)
Research Design (49%)	Alternatives exhausted (e.g. *in vitro* options)	' … but I believe if there are some research that can be **simulated**, that should be incorporated to research.'
	Necessity in research design	'From my point of view, testing on animals shouldn't be applied **unless for necessity** … '
	Appropriate sample sizes used	' … emphasized at the users' meeting was to **reduce the use of animals** and only use them when absolutely necessary.'
Treatment of Animals (68%)	Treat animals humanely (e.g. pain management)	'If we can find an alternative way for these animals to be sacrificed where they **feel little to no discomfort** that would be ideal.'
	Researchers appropriately trained in animal care and use	'Furthermore, I know that everyone involved in the research and that handle the animals are **required to complete courses** on the treatment of research animals.'
Benefit to Humans (86%)	Provides value to humans	'While I understand that this practice is **pertinent to the well-being of mankind**, I also know have a solid appreciation of these laboratory animals.'
	Important scientific tool	'I also made sure everything the mouse had given for my research was **properly stored** and the rest was properly disposed of.'
	Important to advance knowledge or experience	' … though it hurts to kill so many animals for simplistic research, in the end, **the advancements we make through animals is more important**.'
Worth (76%)	Existing species hierarchy	' … the animal feels no pain and have **too low of an intelligence** to understand what is happening … ' '**Human life is priority number one**, followed by animals, then plants, then microscopic life.'
	Agency considerations	'The animals **give their lives** for our benefit, so it is important to take the labs serious.'
	Justification of using animals	'To me **senseless killing** is wrong.'
Emotion (73%)	Raw response (e.g. sadness)	'I felt the animal advocate in me becoming **unsettled** and my morals being pulled into **question-a feeling similar to as if I was doing something wrong**.'
	Inner conflict	' … **I don't** want to justify killing animals, **but I do** see it as a necessary evil in order to advance scientific research.'

Note: n = 37; % represents instances of codes in any student reflection response

includes a greater consideration of (and, potentially, attunement with) one's own personal emotions. Notably, benefit to humans remained the most pervasive aspect and was even more pervasive than in the pre-response.

3.3. Phase 3: observations and focus group

Observational data collected during the in-class discussion revealed several shared themes with the reflection assignments. This is unsurprising given that the class discussion was specifically concerned with creating a dialogue about student responses on the post-video assignment reflection. Having recently had the experience of rodent tissue harvesting and witnessing a video recording of the euthanasia process (both of which were a first for many), students brought these new, visceral, and reportedly emotional experiences to their reflective group discussion.

Before we present data in this section, it is important to first identify and define an important concept: affect. Emotion and affect are often equated, but that is not how we utilise these concepts here. The tissue harvesting and euthanasia video created an encounter between students and the tiny bodies of dead mice. Though small, these mice bodies, like human bodies, have the capacity to affect and be affected. Following the work of Massumi (2015), who builds off of philosopher Giles Deleuze's reading of Spinoza, affect is a force signifying the ability to produce transitions. So, when students encountered the mouse cadavers, they were affected; when they cut into the body, they affected that body and were, in turn, affected. This affect is pre-conscious, but in its conscious capture, emotion may then be produced. Or, as this section will explore, the capturing of this affective force can also be articulated in ways that are focused on reasoning and conceptual frameworks, albeit, while not appearing overtly emotional.

In the class discussion, several students described the **emotions** produced through their encounters with the mice. One student was very disturbed by the video. By design of the assignment, she had no warning about the video content. She described being in a public place when she watched the video. She then reported being overwhelmed by the video and weeping in public. This same student went on to discuss having rats as pets growing up; she stated the she was 'raised to treat small animals kindly.' When she spoke of this in class, it appeared as if she may again start crying. Her admittedly emotional response appeared to arise from an empathy born from her personal experiences. In response, another female student reflected upon the tissue harvesting activity. She stated that she was initially upset when she looked at the dead mouse body in front of her. Though she did not elaborate on how, she reported that she managed to detach herself and remain calm, that is until she cut into the warm body and saw a trickle of blood. A third female student expressed disgust regarding the smell of the fresh rodent cadaver. Finally, a male student with military experience pondered aloud whether the taking of a life does moral damage to the person taking the life. This was an intriguing question of significant depth and noticeable feeling; however, fellow students did not respond explicitly to this inquiry.

Students also discussed the **humaneness** of the mode of euthanasia (CO_2 in this case). Several students expressed concern about how, in the video, the mouse appeared in distress as it gasped for air. To help assuage the students' empathic distresses (or, conversely, prompt emotion regulation of said distress), the course instructor described the gasping as 'an involuntary response' before going on to describe other, currently less common, euthanasia practices (e.g. cervical dislocation). When asked by a female student how the instructor came to terms with euthanising mice, the instructor confessed that when he first started euthanising mice, he would have nightmares about it. However, after having more experience with the process, he stated: 'you gain a respect for science and … you start to see the clinical relevance.' This introduces a process of rationalisation that many students also discussed.

This rationalisation took on a few forms, which correspond well with two themes developed within the analysis of the reflection assignments. First, students often negotiated the affective force of mice cadavers via cognitive processes of **valuation** or **assigning worth**. This often took the form of students (both male and female) adopting a pre-existing structure of thought that resembled a reified 'hierarchy of being' in which, they reasoned, rodent life is of lesser value than human life. In cases such as these, value was simplistically determined by students through appeals to size, whether that size be in reference to the tininess of mouse brains or the slightness of their bodies. Following the prompting of a male student, the instructor brought up the socio-cultural, and potentially normative perception of mice as 'pests.' The instructor stated that 'many people wouldn't think twice about killing a pest in their house,' before adding that the modes of euthanasia performed in those contexts were often 'cruel.'

The students and instructor also discussed value in terms of the experiment itself. In discussions around this topic, to warrant rodent death, it was as if the value of the experiment to humans had to be greater than the value of the lives of the rodents needed for the study. Simply put, to justify the loss of life, students needed to see potential **benefit to humans**. It is in this context that valuation began to take on more complex dimensions that did not explicitly exclude emotion. For example, towards the end of the discussion, one male student spoke about how many of the people in the class had been 'touched' in some profound way by

biotechnology, such as a student's cherished family member who may currently be alive due to some kind of biotechnological intervention. He added that these considerations breed 'a greater respect for the animal.' A female student built on this discourse and argued for the relevancy of 'consequentialism,' which she described as 'the ends justify the means.' She reported that we all want the 'medical benefits, the prolonging of life,' and, in order to achieve that, we may need to make some hard choices, such as the use of animal subjects. At this point, the instructor introduced the concept of '**sacrifice**.' Sacrifice is a scientific term in biomedical engineering. However, this discourse had echoes of not just the sacrificial performance of the scientist, but also the mouse's sacrifice for the betterment of human life. Here, the in-class discussion ended.

The introduction of the idea of sacrifice in the closing moments of the class discussion hints at an even deeper engagement with the idea of value that could not be sufficiently unpacked within the boundaries of the class discussion. Hence, this concept of sacrifice was explored in greater detail in the focus group. When prompted to discuss the word 'sacrifice' and its meaning, student responses introduced the idea that an exchange occurs with sacrifice. One student stated that the mice were 'giving something up to improve [human life].' A different student added that without the mice 'there would be no ability for [scientific] advancement, because what we're testing is too dangerous to test on humans.' Another participant followed up on this by stating: 'They're doing something we can't do, for us.' During the focus group, we asked students if 'gratitude' was an acceptable term to describe some of their feelings around sacrifice. One student stated in response, 'I think that is where the term "sacrifice" comes from. It's just acknowledging and being thankful that they've sacrificed their life for our advancement.' Each of the other focus group participants nodded in agreement.

4. Discussion

This study sought to identify changes in biomedical engineering students' ethics-related skills and dispositions resulting from an animal tissue harvesting lab. This lab is a part of the first course in a biomedical engineering programme that integrates ethics across the curriculum. The concerted study of this first course in the sequence allows us to identify successes in this first iteration as well as future instructional design and research considerations. This discussion serves as a fourth and final phase, wherein we seek to integrate findings across the first three phases. Specifically, we address the question, 'Looking across the three phases, to what extent were learning goals met pertaining to students' abilities to (1) recognise their own values and morals, (2) recognise their professional responsibilities, and (3) apply ethical inquiry when developing, refining, and communicating the solution to a biomedical engineering situation?'

The survey results suggested that students' empathic tendencies remained stable before and after the course. In retrospect, an unintentional bias that we brought to the study was the human-centric nature of our quantitative evaluation metrics. While the qualitative data suggested potential inter-special (i.e., between human and non-human beings) empathic changes, the constructs emphasised interpersonal tendencies. Hence, we consider this as one potential reason for the stability between pre/post survey responses.

Nonetheless, students were engaging with diverse perspectives within the disciplinary context for the first time. As the perspective-taking responses started and remained relatively high and interpersonal self-efficacy showed slight reductions, it is possible that these reductions capture students' understanding of the complexity of navigating interpersonal encounters. For example, the classroom discussion involved sharing perspectives and emotions pertaining to unique, and potentially counter-normative, ways of thinking about animal ethics.

In a prior study (Hess, Strobel, and Brightman 2017), sharing diverse perspectives was particularly influential for students' perspective-taking development. However, this prior work provided students with myriad opportunities to share perspectives (i.e., four case studies across an entire semester in a course devoted solely to ethics). In contrast, students in this biomechanics course were explicitly tasked to share perspectives with peers in one instance (or two for the four focus group attendees). Hence, it is possible that having more opportunities to engage in ethical dialogue increases the likelihood of promoting empathic formation. Moreover, different cases or experiences might have varying levels of potential criticality on students' empathic development. In future work, we will consider these possibilities as we track student changes longitudinally throughout the programme.

The qualitative data suggested students were more attuned with their emotions, yet we did not see quantitative increases in empathic concern or emotion regulation. Of course, a greater attunement with one's emotions does not necessarily translate to becoming concerned with others' emotions. Yet, we question why we did not see quantitative changes in empathic concern, as the reflection data also saw pervasive considerations (and concern) of human benefits from biomedical engineering practice. We postulate that students may have been struggling with a challenge of assigning worth and balancing assignments of worth between humans and animals. As the reflection prompts indicate, many students argued that sacrifice of the former might be a 'necessary evil'

(direct student quote) to benefit the latter. Future work might measure empathic concern for humans and non-humans and identify the relationship between these.

While some students made a sacrificial argument in the reflections, during observations, some students (particularly those who seemed prone to relate to and potentially empathise with mice) seemed to be experiencing cognitive dissonance (another theme in Hess, Strobel, and Brightman 2017). Here, dissonance may have resulted from the moral intensity of the topic. We feel that this dissonance presents an untapped learning opportunity that we may more purposefully integrate into the course in the future. For example, affective considerations were not a direct learning objective or target in this course, but we are considering introducing an explicit learning objective dealing with moral commitment. In turn, this would be a more intentional component of reflections and class discussion. In addition, it would be worthwhile to explore how, if at all, students bring forth these learning experiences into their future ethical encounters in the program.

Hearkening back to the concept of ethical becoming (Fore and Hess 2020), the notion of 'relationality and indebtedness' and 'ethical inquiry' could be powerful starting points for the exploration and development of greater moral commitment to animal welfare and waste minimalization among students. There was evidence of this manifesting in this course, specifically as students participated in an ethical inquiry process. More specifically, students engaged in 'experimentation' with the rodent bodies regardless of the level of their 'awareness' of the complexity of using animal subjects and their personal 'judgments' of such practices. Through the outcomes of that experiment (e.g. harvesting rodent tissue, watching euthanasia video), students could then expand their experiential awareness and produce more informed judgements colouring future experiments (i.e. 'iteration').

Throughout their critical reflection on these two visceral experiences with euthanised mice, students interrogated emotions arising from the affective force of rodent cadavers and sought to rationally justify such laboratory practices in ways both simplistic and complex. During the class discussion and focus group, many students demonstrated abilities to not just acknowledge the affective force of mice, but also to value it in ways that subverted mere appeals to a reified hierarchy of being. Moreover, students articulated complex expressions of the circulation of debt/credit in their relationships with these rodent bodies.

We encourage engineering educators, especially in the ethics space, to more purposefully grapple with considerations of the affective force of critical and visceral experiences, such as those experienced by students in this study, and identify how such experiences might support students in their processes of empathic formation and ethical becoming. While experiences akin to tissue harvesting may be less transferrable to other contexts, experiences from the empathic design space wherein students seek to simulate stakeholder perspectives might be more broadly applicable. For example, an instructor might have students navigate public infrastructure using a wheelchair. Moreover, Fore and Hess (2020) posited that experiential learning (e.g. community-engagement) courses that demand students work through the engineering design process with a community partner could also create meaningful experiences with others who, through a dialectical dialogue, have an affective force that students must account for throughout the design process.

5. Limitations and future work

This study has a few notable limitations. First, a small subset of students in the course participated in the survey (n = 18 out of 40); thus, it is possible a greater response rate might have generated unique findings. Moreover, the focus group included only four students, thus representing only 10% of the class. We feel that the mixed methods strategy partially offsets the limitations of small participation rates in these phases, but we also recognise potential concerns associated with statistical power in Phase 1 and non-response bias in Phase 3.

These findings also present unique domains of future research. First, we will continue to monitor students' ethical development as they matriculate through the biomedical engineering programme at IUPUI, but we hope to incorporate non-human-centred considerations into our survey instrumentation, thus presenting a more holistic picture of students' ethics-related skills and dispositions. Second, the observational data suggests a potential difference in empathic engagement between male and female students. Though not exclusively, male students were more likely to voice issues in ways that we might describe as objective and cold, whereas female students were typically more vocal about emotional considerations. Thus, these findings potentially point to greater prioritisation of 'cognitive' and 'affective' empathy types between male and female students, respectively. Post-hoc, we compared post-course perspective-taking and empathic concern responses by sex; while perspective-taking scores were similar, female students evidenced greater empathic concern. While this study did not explicitly explore responses by sex, future studies exploring potential variations in affective versus cognitive empathy utilisation by biomedical engineering students would be fruitful lines of research.

6. Conclusion

There are numerous strategies for integrating ethics in engineering curricula. The limited body of

knowledge on biomedical engineering ethics education suggests a critical need for more empirical work specific to this context. Through this study, we sought to identify how and to what extent aspects of a biomedical engineering tissue engineering laboratory that featured ethical considerations coupled with critical reflection enabled students to recognise and inquire into ethical issues in biomedical engineering. We brought two primary theoretical framings pertaining to empathy and ethical becoming. The quantitative instrumentation did not reveal changes in students' empathic dispositions, but after additional analyses, we realised that we brought an unintentional human-centric bias to the design of these quantitative metrics. Thus, qualitative findings provide a more insightful picture of student learning gains, specifically suggesting that students left the course with a greater appreciation of animal concerns, how to rationalise animal practices in biomedical engineering praxis, and a concrete experience trying to grapple with one's emotions in visceral ethical encounters.

Notes

1. Miller et al. (2020) provides a more expansive overview of the curricular design.
2. The animal euthanasia video is a brief two-minute video that aims to teach a carbon dioxide overdose technique for use in animal research.

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