What do Biomedical Engineering Faculty Talk About When They Talk About Ethics?

Nicholas D. Fila
Department of Electrical and Computer Engineering
Iowa State University
Ames, IA, USA
nfila@iastate.edu

Justin L. Hess
School of Engineering Education
Purdue Univeristy
West Lafayette, IN, USA
jhess@purdue.edu

Andrew O. Brightman
Weldon School of Biomedical Engineering
Purdue University
West Lafayette, IN, USA
aob@purdue.edu

***Abstract*—Faculty members are stewards of academic engineering cultures and drivers of the ethical formation of our future engineers. To develop better ethics training tools we need to understand the diversity of faculty experiences and perceptions of ethics. In this study, we seek to unpack the experiences biomedical engineering faculty members have related to ethics in engineering research. We address the research question, "What are the features of research experiences that biomedical engineering faculty members discuss in the context of ethics in engineering research?" Sixteen biomedical engineering faculty members participated in this study. Faculty participants varied with respect to type of faculty position (tenured, tenure-track, non-tenure track), rank, gender, race/ethnicity, and geographic location. We utilized content analysis of semi-structured interviews to characterize the experiences these faculty members discussed. This analysis involved iterative cycles of open and axial coding to identify relevant categories and their constituent elements Faculty members described experiences that differed in context (physical setting, research phase, their current academic rank, their role in the experience), ethical topic area, ethical challenge, and characterization of ethical action. These findings will enable us to better consider how extant approaches to developing ethical engineering researchers in biomedical engineering align with the experiences of current biomedical engineering faculty members.**

Keywords*—Engineering ethics education; ethics research; responsible conduct of research; content analysis; biomedical engineering

I. Introduction

Faculty members steward academic engineering cultures and drive future engineers' ethical formation. Yet, ethics is a complex phenomenon that faculty members will likely experience in different contexts and in different ways. This variation can lead to disparate views regarding how to train or develop ethical engineers [1]. For example, engineering ethics often is equated with acting in accordance with professional values [2, 3] but scholars have also called for centering public values in engineering ethics pedagogy [4] or attending to ethical mentoring in student-faculty relationships [5]. As we strive to develop future training that better aligns with actual experiences and expectations, we must better understand the ethical issues that faculty members experience, what they understand as important to ethics in engineering, and how they have responded to such experiences and framings.

Faculty members often research and develop innovative technologies that are imbued with novel and emergent ethics issues. As faculty members engage students in these enterprises, ethics mentoring can be critical to students' formation as future ethical engineering researchers. In this spirit, the recent CHIPS and Science act emphasizes effective mentoring [6]. However, guidelines specific to ethics training concerning engineering research and technology development are rare. Thus, engineering needs better training tools for faculty PIs in RCR and ethical engineering of technology, especially training tools that are connected with empirical research on how individuals come to experience ethics in situ.

We enter this study with a premise that understanding the variety in faculty experiences is essential for informing faculty members' ethical teaching and training. We strive to develop such empirical evidence to generate guidance for improving ethical research training efforts for future engineers. Our previous research investigated ethics experiences among engineers working in industry R&D settings to develop new medical technologies [7]. This prior work has provided us with one framework for understanding training needs, but it is unclear to what extent this work aligns with faculty members' experiences of ethical engineering R&D. This current study extends our prior work by elucidating how academicians' experiences with ethics compare with industry practitioners.

Herein, we build on prior research and unpack the experiences biomedical engineering faculty members have related to ethics in engineering research. We address the research question, "What are the features of research experiences that biomedical engineering faculty members discuss in the context of ethics in engineering research?" In the future, we aim to utilize these research findings to explore faulty conceptualizations and development and to develop coherent, effective, and evidence-based education approaches for fostering ethical researchers and ethical cultures of research.

II. Background

A. Engineering Ethics

One typology for depicting ethics in engineering distinguishes between micro- and macro-ethics [8, 9]. This typology focuses on differences between (1) individual or interpersonal actions and effects and (2) collective actions and their effects on society [10]. Herkert [10] described "ethics in

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engineering" as prominently a micro-ethical concern due to its focus on "actions of individual engineers." This contrasts with the "ethics of engineering," which draws attention to one's professional obligations based on one's participation in "industry and other organizations, professional engineering societies, and responsibilities of the profession" (p. 405). Others have equated engineering ethics to professional ethics [2], which Herkert [10] considers a connector between individual (micro) and social (macro) considerations. Other scholars have emphasized values beyond the profession in engineering education discourses [11, 12] as a key factor in ethical decision-making in engineering. Thus, there are competing views regarding what constitutes engineering ethics, which inevitably influences approaches to engineering ethics education [1].

B. *Engineering Ethics Education*

As views regarding engineering ethics differ, so do views regarding the goals, approaches, and instructional strategies for teaching ethics to engineering students [11, 13]. Davis and Feinerman [3] suggested that standards and expectations of engineering practice ought to be the primary vehicle of engineering ethics instruction. Thus, one's view of engineering ethics education may be constrained to a focus on rules of engineering practice. However, others have emphasized attending to public values [4, 14], principles [4, 15], and other philosophical frames [13]. Katz [1] explored engineering faculty members' mental models of engineering ethics education across various disciplines of engineering. He identified ten areas of mental models that highlight the widespread variation in such views. The initial area Katz [1] identified included "definitions of engineering ethics," which varied from academic issues and research ethics (e.g., responsible conduct of research), professional responsibilities, and black boxes (e.g. uncertainty or "unawareness" of engineering ethics). Other areas included "topics of engineering ethics education," "where do students learn engineering ethics," and "who makes curricular and pedagogical decisions" (note: each area included several distinct mental models). Katz [1] did not explore the interplay between the mental models, but this framework provides one key source for understanding how faculty members view ethics in their work, be it ethical engineering practice, ethical engineering research, or related phenomena.

C. *Ethical Engineering Practice*

Our research team previously explored how engineers in the health products industry experienced ethical engineering practice [7]. We found six distinct ways of experiencing ethical engineering practice ranging from doing right (Category 1), upholding professional responsibility (Category 3), to stewarding culture (Category 6). Later categories generally incorporated elements of their predecessors; for example, upholding professional responsibility (key to Category 3) continued to manifest as a critical element of Category 6, where engineers also focused on developing an inclusive organizational culture. While this prior work serves as important background for this study, our current study features a fundamental shift in participants (from engineering practitioners in industry to engineering faculty in academia), contexts, and phenomenon (from ethical engineering practice to ethical engineering research). Based on these shifts, we postulate that this study will uncover additional elements that will be important to ethics training in biomedical engineering, based on differences between academic research and industrial practice.

D. *Ethical Engineering Research*

While much engineering ethics education has focused on engineering curricula (including many mental models in Katz's [1] work), other ethics education strategies focus beyond the curriculum. For example, the Collaborative Institutional Training Initiative (CITI) serves as baseline training for ethical and responsible conduct of research. Yet, some engineering disciplines have created ethical research training strategies beyond such compliance-oriented training. For example, in the context of engineering education research, Sochacka et al. [16] identified ethical validation strategies, such as critically reflecting on personal approaches to research in light of cultural norms or values. Another example comes from Villanueva Alarcón [5], who has promoted ethical mentoring strategies guided by ethics principles and "three themes" for improving mentoring relationships. These examples illustrate how ethics educators can triangulate extant frameworks to generate actionable strategies for ethics training in the domain of engineering research.

E. *Factors that Influence Ethical Experiences*

Katz [1] explored the literature and identified the "factors affecting faculty decision-making" (p. 74) which included factors like prior research, education, or work experiences. In short, the experiences that faculty bring forth influence their mental model, including how one defines engineering ethics or educates future engineers. While instructional strategies for training engineers can promote ethical experiences, so can myriad factors of one's environment. For example, in our prior study, organizational culture was a critical factor in the way engineers experienced ethical engineering practice [17]. Separately, scholars have emphasized how the culture of a discipline can influence individual values or perceptions [11, 18, 19]. Thus, organizational elements serve as a prominent factor in ethical practice in industry [20] and have the potential to do so in academia.

F. *Summary of Background*

The multiplicity of ways of defining engineering ethics has led to various mental models regarding how best to incorporate ethics into engineering education [1]. Previously, we explored how engineers experience ethical engineering in industry practice and the factors that influenced individuals' experiences with ethics in their industry practice. That work did not capture how faculty members view and understand a related but distinct phenomenon: ethical engineering research.

III. METHODS

A. *Overview*

We utilized content analysis to address the research question, "What are the features of the research experiences that biomedical engineering faculty members discuss in the context of ethics in engineering research?"

B. *Positionality*

Our study team included two engineering education researchers with engineering backgrounds (electrical &

computer and civil engineering) as well as a biomedical engineering faculty member with experiences in industry and with ethics education. Demographically, our team included three white males, and we were cognizant of the privilege that we each bring to the study design and implementation. We purposefully pursued validation strategies to combat our biases and we sought a diverse sample of participants.

C. Participant Overview

We interviewed 12 faculty members who conduct research in biomedical engineering. Table 1 summarizes participants' self-reported tenure status, academic rank, gender, and race/ethnicity. Half of the participants (n = 6) had managed a biomedical engineering lab for 10 or more years while the other half each had less than five years of lab management experience. With respect to years teaching or training others in ethics, three participants had 10 or more years, three participants had 6–10 years, four participants had 1–5 years, and one participant had less than one year, and one participant reported no experience.

TABLE I. PARTICIPANT OVERVIEW

Tenure Status	
Not Tenure-Track	5
Tenure-Track	2
Tenured	5
Academic Rank	
Assistant	4
Associate	3
Full	4
Emeritus	1
Gender	
Female	6
Male	6
Race/Ethnicity	
Asian	4
Black or African American	1
Hispanic or Latino	1
White or Caucasian	10

D. Data Collection

Each participant completed a semi-structured interview between 90 and 120 minutes in length. Author 1 conducted each interview using a virtual platform (Zoom). The interview included four sections: background, experiential, conceptual, and summative. The experiential portion featured a thorough discussion of 1–3 experiences participants had related to ethics in engineering research. The experiential portion was the bulk of the interview and generally lasted about an hour. The conceptual portion asked participants to share their conceptions of the phenomenon (i.e., ethical engineering research). We asked follow-up questions to add clarifying details, explore topics in greater depth, and investigate connections between ideas. The conversations were open-ended with regards to how participants framed ethics and the types of experiences and conceptions they discussed throughout the interviews.

E. Data Analysis

We utilized conventional content analysis [21] to identify categories related to the types of experiences faculty participants discussed. This analysis involved iterative cycles of open and axial coding to identify relevant categories and the elements thereof. This analysis was informed by a non-dualist ontology [22], which suggests that (1) ways of experiencing a phenomenon vary and (2) are the result of a complex interplay between the individual and the context(s) in which they experience the phenomenon. Thus, in this analysis, we remained open to the variety of ways participants may have experienced ethics in engineering research and the contexts in which they have experienced it rather than relying on extant ethics theories to inform an a priori coding framework.

We utilized a five-stage approach to content analysis:

1. **Review Data** - Read and re-read transcripts to gain an overarching understanding of the data.
2. **Parse Data** - Identify sections of transcripts relevant to experiences with ethics in engineering research.
3. **Open Coding** - Generate codes related to features of experiences with ethics in engineering research.
4. **Categorization** - Review codes and organize them into categories, which represent types of features relevant to participants collectively. Refine both as applicable.
5. **Axial Coding** - Code transcripts using the current categories and underlying codes.

While this approach presents as linear, we iterated within and between stages as applicable. For example, codes were often adjusted after a round of categorization. Further, discussions between researchers during axial coding led to code and category refinements, as well as data review. In the Results section, we present both the categories and their constituent codes, with frequency counts based on axial coding of 12 participants' transcripts (27 total experiences). The categories represent noteworthy features of participants' experiences with ethics in engineering research. The constituent codes represent the elements comprising these features, which varied by participant and experience.

F. Validation

We employed a quality framework prominent in engineering education comprised of six validation types: theoretical, procedural, communicative, ethical, pragmatic, and process reliability [16, 23]. This framework calls attention to how decisions and actions in making versus handling data influence our ability to (1) understand participants' social realities and (2) create trustworthy insights and extensions of extant theory. In the context of this study, we aim to accurately capture and represent how a diverse group of faculty members experience and understand ethical engineering research.

Validation strategies we implemented include aligning findings with prior ways of operationalizing ethics in engineering, particularly biomedical engineering (theoretical validation). We aimed to ensure consistent interview experiences by utilizing a single protocol and a single interviewer (process reliability). Post-interview reflection enabled us to capture uncertainties and insights from interviews (process reliability, procedural validation). We cross-checked results with a multi-member research team (ethical validation, communicative validation) and we shared emergent findings with a community of practice of biomedical engineering faculty members (communicative validation), whom we also asked to consider alignment between the results and ethics education strategies in their field (pragmatic validation). We sought to be representative of participant perspectives as we narrated and shared emergent insights with external audiences via thick description (ethical validation), and we constantly aimed to iterate on gathered input to enhance the study findings (communicative validation, process reliability).

IV. Results

Seven categories (or prominent features of ways of experiencing ethics in engineering research) emerged from our content analysis: academic rank, role, setting, research phase, ethics topic area, ethical challenge, and characterization of ethical action. Each category consisted of three to nine unique codes. We discuss each of the features below.

A. Academic Rank

Each participant described their academic rank at the time of the experience to contextualize the experience. Participants discussed ethical experiences during their time as faculty members (n = 21), as postdoctoral researchers (n = 4) and as PhD students (n = 2). While some participants had worked in industry, no participants discussed experiences in industry practice.

B. Role in Experience

In addition to academic rank, participants described their specific roles during their experiences. One third of the experiences were as principal investigator (n = 9), wherein participants were responsible for the overall success of the project and team members. Four experiences involved participants in a non-PI research role (n = 4), wherein they contributed to the research project but were not the lead investigator in the research. The remaining experiences involved participants inhabiting roles related to but not directly involved in the research enterprise. These roles included supervisor (n = 4), observer (n = 4), instructor (n = 4), and service (n = 2).

As our focus was on ethical engineering research, the instructor role was surprising to our team, but we observed that some participants expressed an interest in teaching ethical engineering research through extant courses or curriculum, and often treated these course as part of the research or research training enterprise. These results are summarized in Table 2.

TABLE II. Role in Experience

Role	n	Description
Principal Investigator	9	Was formally responsible for the research project in which the ethics experience occurred
Non-PI Researcher	4	Was actively engaged in the research in which the ethics experience occurred
Supervisor	4	Was supervising or mentoring someone conducting the research in which the ethics experience occurred
Observer	4	Was not actively participating in the research in which the ethics experience occurred but became aware of the experience
Instructor	4	Was teaching a course in which the ethics experience occurred
Service	2	Was engaged in a departmental or external service role through which ethics in engineering research became relevant

C. Setting of Experience

Participants described their experiences in three distinct settings. Academic research was the most frequent setting (n = 22), but a subset of experiences involved the classroom, with a focus on classroom research (n = 2) or classroom teaching (n = 3). This finding highlights that most participants oriented their experiential discussions within the domain of academic research. However, for some participants, the line distinguishing research from teaching, as related to ethics in engineering research, was permeable. Indeed, sometimes research experiences informed teaching experiences and vice versa.

D. Research Phase

Participants described experiences in connection with specific phases of the engineering research endeavor. These experiences spanned the entire research process, including research design (n = 1), obtaining approval (n = 2), collecting data (n = 7), analyzing data (n = 4), and eventually publishing findings (n = 8). Some experiences occurred beyond the traditional research process, including communication within one's lab or university (n = 5) or outside one's university or lab (n = 3). One participant discussed daily lab operations. Table 5 summarizes these results. The values in this table sum to more than 27 (i.e., the number of experiences participants described) because some experiences spanned more than one research phase.

TABLE III. Research Phase

Research Phase	n	Ethical research experiences manifested during…
Research design	1	The design of a research project.
Approval	2	Seeking approval for a research project.
Data collection	7	Collecting data for a research project.
Data analysis	4	Analyzing data on a research project.
Publication	8	Publishing findings from a research project.
External communication	3	Communicating with external audiences about a research project (e.g., outreach).
Lab operations	1	Managing the operation of a lab during a research project.
Advocacy/internal communication	5	Communicating with internal audiences about a research project.

E. Ethics Topic Area

We identified nine topic areas in participants' ethics experiences. These topic areas represented the types of issues participants experienced and, more broadly, the aspects of their research within which their experiences of engineering ethics were most situated. We observed widespread variation across topics. The most common topic areas were compliance (e.g., following internal or external procedures), professional integrity (e.g., honesty and respect for others), research integrity (e.g., maintaining high process standards), and the "right" or proper treatment of subjects and their data. Table 3 summarizes the topic areas and includes the frequency of each topic area based on the experiences we synthesized.

TABLE IV. ETHICS TOPIC AREA

Topic Area	n	Ethical issues pertained to...
Compliance	4	...following federal or university guidelines.
Professional integrity	4	...professional considerations, such as honesty and conduct.
Research integrity	4	...the "right" way to conduct one's research.
Subject treatment	4	...the "right" way to treat subjects or handle subject data and samples.
Peer relations	3	...the proper treatment of colleagues in the research enterprise.
Social responsibility	3	...the implications of research findings for select societal populations.
Community relations	2	...differences in beliefs between researchers and select community members.
Publication ethics	2	...acting with integrity in publishing work.
Lab safety	1	...the safety and security of the laboratory.

F. Ethics Challenges

In addition to the ethics topical areas, participants expressed nine challenges they experienced amidst the ethics encounters. These challenges presented as either uncertainty toward ethical decisions during research or obstacles to the act of ethical research. In many instances (n = 8), participants struggled with colleagues' behaviors they observed, which they personally found as misaligned with how they perceived others ought to act while conducting ethical engineering research. The second most prominent challenge involved engaging in research on a controversial topic (n = 4), wherein there was not a clear "right" way to proceed. In a similar vein, participants sometimes found guidelines to be limiting for conducting the best, most ethical, or highest quality research (n = 3). Other challenges included outcome-oriented challenges (i.e., societal implications, injustice, negative outcomes) or related but distinct system-imposed challenges (i.e., publication pressure, unclear guidelines). Table 4 summarizes these results.

TABLE V. CHALLENGE RELATED TO ETHICAL ISSUE

Challenge	n	Ethical engineering research challenge involved…
Colleague's ethics	8	…a colleague behaving in a way that conflicted with the participant's ethical beliefs.
Controversial topic	4	…research being conducted in an area with disputed ethics among different groups.
Publication pressure	3	…a drive to publish results and further one's career as conflicting with proper research conduct.
Challenging guidelines	3	…the participant being committed to complying with guidelines, but viewing this such guidelines as interfering with conducting quality research.
Societal implications	2	…a potential conflict between proper research conduct and positive/non-negative implications for society.
Injustice	2	…research is being conducted in a setting where systemic injustice exists.
Unclear guidelines	2	…guidelines did that do not present the participant with a clear ethical decision or approach.
Negative outcome	2	…an adverse outcome despite perceived ethical behavior among interested parties.
Uncertainty	1	…the participant being unsure of what constituted proper research conduct during the experience.

G. Characterization of Ethical Action

Participants predominantly described themselves as behaving in ways that aligned with their ethical beliefs and values or working towards ensuring ethical outcomes. We identified seven distinct types of ethical action/behavior. The most common type was acting ethically despite challenges in doing so (n = 6), followed by promoting ethical behavior in others (n = 5) and working toward systemic ethics (n = 4). Only one experience was predominantly about a participant questioning their own ethics. Table 6 summarizes these results.

TABLE VI. TYPE OF EXPERIENCE

Type	n	Ethical engineering research experience involved…
Acting ethically	6	…acting in a way they believed was ethical despite challenges that presented to conducting quality research
Promoting ethical behavior	5	…taking action to ensure that others behave ethically or change their perspectives on ethics
Working toward systemic ethics	4	…taking action to correct an injustice inherent in the research ecosystem or topic area
Responding to other's ethical breach	4	…acting ethically or promoting an ethical outcome in response to unethical behavior by a colleague or acquaintance
Problematized research	3	…responding to others who have challenged the ethics of their work
Questioning ethics	1	…questioning whether the research approach they took was ethical
Responding to crisis	1	…responding ethically to an adverse event

V. DISCUSSION

In this study, we utilized content analysis [21] to identify the nature and types of experiences faculty members engage in as part of their ethical engineering research. We synthesized types of experiences, challenges, settings, and roles of participants. Study findings revealed a multitude of experiences with ethical engineering research across a relatively small sample of participants (n = 12). Here, we consider the questions, "What constitutes ethical engineering research?", "How does ethical engineering research compare with ethical engineering practice?", and "How do these results inform the training of ethical engineering researchers?"

A. Ethical engineering research

Ethical engineering research experiences in this study often found participants striving to be ethical amidst uncertainty, conflict, and other challenges. Experiences were often micro-ethical in nature [7] and involved acting in alignment with one's perception of what constitutes ethical behavior or extant norms. Most experiences found participants responding or behaving to an ethical issue or challenge that itself challenged individual views or extant procedures. These experiences often featured the faculty member's response to an unethical or non-ethically ideal situation, often arising from others' behaviors or values. Some experiences focused on responsible research, but even when seeking to comply with procedures or regulations, participants expressed uncertainty regarding how best to act. These findings suggest the importance of further study on ethical behaviors in engineering [24], despite its limited focus on engineering ethics education [1]. Specifically, as institutions incorporate university-specific training in response to the CHIPS act, they ought to monitor individuals' experiences incorporating such training into their research contexts. Social ethics, implications, or related macro-ethical outcomes of ethical decisions or practices were sometimes the central topic or a key challenge in one's ethical engineering research practice. These experiences featured faculty members communicating with stakeholders outside of their labs or universities. These beyond-the-institution experiences were less common, but are ostensibly key elements of ethical validation in academic research [16].

B. *Ethical engineering academic research versus industry practice*

Our prior work explored how practitioners experience ethics in industrial practice [7,17]. We observed both commonalities and differences based on the types and nature of experiences discussed across studies. In both studies, interpersonal experiences were discussed. More specifically, both academic faculty members and industry practitioners often expressed ethics experiences that involved responding to colleague's questionable behaviors and/or aspiring to promote ethical behavior among colleagues or mentees. Both academics and practitioners shared strong convictions or beliefs regarding what constitutes ethical action and steadfastness in ensuring these values manifested in their practice or research, respectively. Finally, practitioners and academics generally described experiences in the "workplace" (e.g., academic research among faculty participants) rather than during training, formal education, or other non-work-related contexts.

Regarding differences, we first observed publication ethics as a unique focus among academics. Publication ethics is ostensibly like the validation studies described by some industry practitioners (i.e., the types of studies that engineers conducted to ensure a product was itself sound and of high-quality). Academics often discussed publication ethics (focused on the norms and expectations of manuscripts), but practitioners rarely discussed publications or validation studies. Conversely, documentation of processes and procedures was a common topic among practitioners and was seldom discussed by academics as a key feature of their ethics experiences. Publications, validation studies, and documentation each are ways of sharing procedures and findings with external audiences, and future research may seek to explore how writing, documentation, and sharing norms relate and differ across these contexts.

Second, while academics often discussed micro-ethical engagements and seldom discussed macro-ethical considerations, when compared to practitioners, academics engaged with social implications to a greater degree. Terms like justice and broader impacts beyond one's work environment were the focus of roughly a quarter of these interviews, whereas practitioners did not note these as the focus or challenge of their ethics experiences. Rather, practitioners' organizational, industrial, personal, and professional norms were prominent in their ethical practice.

Third, we observed more practitioners admitting mistakes than faculty members. While practitioners shared few failures [17] such failure experiences were virtually missing in this study. Importantly, in both studies, the relatively few failure experiences shared might rather speak to the sensitive nature of such failure experiences (rather than the notion that practitioners and academics rarely experience ethical failures).

Finally, there were relatively more experiences focused on prior learning or training experiences (e.g., as a graduate student or post-doc) among academics when compared to practitioners. This may be due to the greater alignment between graduate students/post-doctoral experiences and ethical engineering research versus ethical engineering practice. However, this finding may suggest there is a greater need to cultivate curricular experiences aligned with ethical engineering practice in order to prepare students for such career pathways.

C. *Training ethical engineering researchers*

Cultural norms can dictate ethical expectations, and we suggest that faculty members are a key driver of institutional culture. Yet, faculty members possess numerous mental models regarding what should be taught to engineering students [1]. Our prior work on ethical engineering practice in industry suggested that cultural immersion and learning from others were key modalities for experiencing ethical engineering practice in more comprehensive ways [17]. Findings from this study suggest that faculty members aspire to motivate others to act ethically, with less explicit attention on shifting cultural paradigms at one's institution. Conversely, some of the most comprehensive ways of experiencing ethical engineering practice explicitly focused on stewarding an inclusive organizational culture. Nonetheless, the informal mentoring experiences among faculty members often aimed to cultivate more ethical students and set expectations for ethical behavior among students in one's labs or department. The commitment among participants in this study to promote such ethical formation is noteworthy, and the strong convictions for fostering and mentoring ethical engineering researchers among biomedical engineering faculty participants suggests an earnestness among faculty for training and mentoring ethical engineering researchers.

VI. Conclusion

This paper reported a content analysis of the experiences with ethics in engineering research among biomedical engineering faculty. This analysis identified seven key features of such experiences, including academic rank, role, setting, research phase, ethics topic area, ethical challenge, characterization of ethical action. These findings are based on the experiences of 12 faculty members engaged in biomedical engineering research, and thus may not reflect the experiences of all such faculty members.

Participants were selected to maximize variation in the types of experiences they might have related to ethics, engineering research, and the intersection between the two. Findings demonstrated variation across individual role, research setting, ethics topic area, ethical challenge, and overarching type of experience/action, showing a range of experiences potentially relevant to how biomedical engineering faculty come to engage in and understand ethics in engineering research. Participants often expressed that they lacked explicit ethics instruction while pursuing their undergraduate or graduate degrees, but during our interviews, they often unpacked their experiences introducing ethics into their current curriculum.

Future work should continue to explore the experiences of biomedical engineering faculty members to better understand how biomedical engineering faculty experience ethical engineering research. Such investigations should be conducted with members of other disciplines to understand how ethical engineering research manifests across engineering disciplines. Further, we plan to explore differences not only in features of experiences related to ethics in engineering research, but how these experiences demonstrate or contribute to differences in how faculty conceptualize and engage in ethical engineering research.

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References

[1] A. Katz, "An inquiry into the nature and causes of the state of U.S. engineering ethics education," Doctorate, Purdue University, 2019.

[2] C. E. Harris, M. Davis, M. S. Pritchard, and M. J. Rabins, "Engineering ethics: what? why? how? and when?," *Journal of Engineering Education,* vol. 85, pp. 93-96, 1996, doi: https://doi.org/10.1002/j.2168-9830.1996.tb00216.x.

[3] M. Davis and A. Feinerman, "Assessing graduate student progress in engineering ethics," *Science and Engineering Ethics,* vol. 18, no. 2, pp. 1-17, 2012.

[4] D. Riley, "Engineering principles: Restoring public values in professional life," in *Rethinking Technology and Engineering: Dialogues Across Disciplines and Geographies*, A. Fritzsche and A. Santa-María Eds. Cham: Springer International Publishing, 2023, pp. 13-23.

[5] I. Villanueva Alcaron, "Ethical practices and tips for improving engineering faculty-student research relationships," presented at the Frontiers in Education Annual Conference, Uppsala, Sweden, 2022.

[6] D. Kaushik. "CHIPS and Science highlights: Developing A scientific workforce of the future." Federation of American Scientists. https://fas.org/publication/chips-workforce-of-the-future/ (accessed 5/22/2022).

[7] C. B. Zoltowski, N. D. Fila, J. L. Hess, A. J. Kerr, D. Kim, and A. O. Brightman, "Ways of experiencing ethics in engineering practice," presented at 2020 ASEE Virtual Annual Conference, Virtual, 2020.

[8] J. R. Herkert, "Ways of thinking about and teaching ethical problem solving: Microethics and macroethics in engineering," *Science and Engineering Ethics,* vol. 11, pp. 373-385, 2005, doi: https://doi.org/10.1007/s11948-005-0006-3.

[9] C. Rottmann and D. Reeve, "Equity as rebar: Bridging the micro/macro divide in engineering ethics education," *Canadian Journal of Science, Mathematics and Technology Education,* vol. 20, pp. 146-165, 2020, doi: 10.1007/s42330-019-00073-7.

[10] J. R. Herkert, "Future directions in engineering ethics research: Microethics, macroethics and the role of professional societies," *Science and Engineering Ethics,* vol. 7, pp. 403-414, 2001.

[11] D. A. Martin, E. Conlon, and B. Bowe, "A multi-level review of engineering ethics education: Towards a socio-technical orientation of engineering education for ethics," *Science and Engineering Ethics,* vol. 27, no. 60, pp. 1-38, 2021, doi: 10.1007/s11948-021-00333-6.

[12] D. Riley and Y. Lambrinidou, "Canons against cannons? Social justice and the engineering ethics imaginary," presented at the American Society for Engineering Education, Seattle, WA, 2015.

[13] J. L. Hess and G. A. Fore, "A systematic literature review of US engineering ethics interventions," *Science and Engineering Ethics,* vol. 24, no. 2, pp. 551-583, 2018, doi: http://dx.doi.org/10.1007/s11948-017-9910-6.

[14] Y. Lambrinidou, W. J. Rhoads, S. Roy, E. Heaney, G. Ratajczak, and J. Ratajczak, "Ethnography in engineering ethics education: a pedagogy for transformational listening," presented at the ASEE Annual Conference & Exposition, Indianapolis, IN, 2014.

[15] J. Beever and A. O. Brightman, "Reflexive Principlism as an effective approach for developing ethical reasoning in engineering," *Science and Engineering Ethics,* vol. 22, no. 1, pp. 275-291, 2016.

[16] N. W. Sochacka, J. Walther, and A. L. Pawley, "Ethical validation: Reframing research ethics in engineering education research to improve research quality," *Journal of Engineering Education,* vol. 107, no. 3, pp. 362-379, 2018, doi: 10.1002/jee.20222.

[17] J. L. Hess, D. Kim, and N. D. Fila, "Critical incidents in ways of experiencing ethical engineering practice," *Studies in Engineering Education*, vol. 3, no. 2, pp. 1–30, 2023, doi: 10.21061/see.80

[18] E. A. Cech, "Culture of disengagement in engineering education?," *Science, Technology, & Human Values,* vol. 39, no. 1, pp. 42-72, 2014, doi: 10.1177/0162243913504305.

[19] A. L. Pawley, ""Asking questions, we walk": How should engineering education address equity, the climate crisis, and its own moral infrastructure?," *Journal of Engineering Education,* pp. 447-452, 2019.

[20] E. F. van Steenbergen, N. Ellemers, B. van Rooij, and D. D. Sokol, "The social and organizational psychology of compliance: How organizational culture impacts on (un) ethical behavior," *The Cambridge Handbook of Compliance,* p. 626, 2021.

[21] H.-F. Hsieh and S. E. Shannon, "Three approaches to qualitative content analysis," *Qualitative health research,* vol. 15, no. 9, pp. 1277-1288, 2005.

[22] F. Marton, D. Hounsell, and N. J. Entwistle, *The experience of learning : implications for teaching and studying in higher education*, 2nd ed. Edinburgh: Scottish Academic Press, 1997, pp. xi, 273 p.

[23] J. Walther, N. W. Sochacka, and N. N. Kellam, "Quality in interpretive engineering education research: Reflections on an example study," *Journal of Engineering Education,* vol. 102, no. 4, pp. 626-659, 2013, doi: 10.1002/jee.20029.

[24] R. F. Clancy and Q. Zhu, "Why should ethical behaviors be the ultimate goal of engineering ethics education? ," *Business and Professional Ethics Journal,* vol. 42, no. 1, pp. 33-53, 2023, doi: 10.5840/bpej202346136.