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A Pathway to Initiate Engineering Education Research: A First-Year Reflection on Faculty Development

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Abstract

Many engineering faculty have been involved in some form of engineering education research (EER) during their professional career. This may range from a relatively superficial participation as a collaborator on a small departmental education initiative to a larger role in a leadership position as a principal investigator on a multi-institutional research grant. Regardless of the level of involvement, each engineering educator must evolve and invest substantial time to acquire a level of EER knowledge that is commensurate with their desired degree of participation. For those educators who are motivated to fully immerse themselves into a potentially rewarding EER program with the expectation of perpetuity, their evolution is not without barriers to entry and associated risks.

The objective of this paper is to share the experiences of three established civil engineering faculty and their mentor who are within two years of receiving their first NSF grants to support EER projects at their home institution. Barriers to entry, challenges, and the lessons learned associated with their growth as emerging engineering education researchers are discussed. Strategies and resources are provided to assist new engineering educators to: lobby for institutional support, secure initial extramural funding, initiate collaborations, formulate short- and long-term career plans, build an Individual Development Plan (IDP), and develop an effective mentor-mentee relationship with an established researcher in the social sciences. It is hoped that this work will provide a holistic summary of their pathway, and to also caution and guide faculty who are contemplating either a partial or complete shift in their research paradigm to EER.

<u>Keywords</u>

Faculty development; mentoring; research initiation; engineering formation; RIEF

1. Introduction

Engineering education research (EER) is an interdisciplinary field that addresses the unique challenges associated with the teaching and learning of engineering, and the pathways leading to engineers' professional formation and growth [1-3]. EER integrates a wide range of qualitative and quantitative elements from the physical sciences, social sciences, mathematics, and engineering. The scope of EER was assessed in a study by Jesiek et al. [4] that identified 38 categories of EER studies published in journal articles and conference proceedings over a four-year period between 2005 and 2008. Among the most common categories were "instructional technologies", "assessment", and "collaborative learning". Since then, EER has been continuously evolving as an internationally recognized field of research [4].

EER and technical (or "pure") engineering research have many similarities [1] yet the two research paradigms have significant differences [5]. First, engineering research is typically grounded upon universal and reproducible laws of nature, whereas EER relies heavily on theoretical frameworks that lack uniform consensus among social science researchers. Second, engineering researchers can narrowly isolate experimental variables and follow uniform and widely-accepted laboratory testing standards. The results from engineering research are well-defined and replicable, and proposed models can be validated. Unlike engineering research, EER typically includes a broad range of uncontrollable confounding variables and a lack of specificity and guidance in the selection of appropriate theoretical frameworks and analytical methods [5,6].

Since engineering faculty are often the initiators of EER studies, it is logical that faculty who already teach engineering courses and conduct engineering research may be inclined to pursue EER opportunities. Their motivation may be to either complement their ongoing technical research, or to shift their entire research paradigm to EER. Nonetheless, prospective engineering education researchers face barriers of entry that may stymy their progress and weaken their perseverance to initiate a formal EER program. Among the most prevalent barriers are an educator's time constraints associated with their current academic position [7], and insufficient training in EER methods [5]. The latter poses the greatest challenge -- a lack of training in the methods to conduct social science are vital to safely and effectively carry out EER on human subjects such as engineering students. Without such training and acclamation to social science research methods, engineering educators are likely to encounter five conceptual difficulties identified by Borrego [5]. These include: (1) formulating research questions with broad transferability, (2) identifying a suitable theoretical framework to inform the EER study, (3) mixing both quantitative and qualitative methods, (4) defining and measuring experimental variables, and (5) establishing a multidisciplinary collaborative team with expertise in the social sciences [5].

Initiatives to assist engineering educators to carry out EER have become increasingly available over the past two decades [8]. A key proponent in the United States is the National Science Foundation. Their programs include faculty workshops [9], competitive research initiation grants [10], and national centers of higher education dedicated to advancing engineering education [11]. Despite this support, the path to formally engage in EER on a substantial level is not trivial. In this paper, the authors present challenges and lessons learned based on their own experiences, as well as specific recommendations for prospective engineering education researchers. Three of the authors are civil engineering faculty new to EER, while one author is an established social science researcher and mentor to the engineering faculty.

2. Research context

In the sections that follows, the experiences associated with initiating and undertaking EER are discussed in the context of the authors' recent grant funding in Table 1. Two of the projects are still gaining traction in Year 1, while one project has entered Year 2.

Table 1. Summary of the authors' recent NSF awards related to EER

No.	Area of Research	Objective	Current Progress
1	Research Initiation in Engineering Formation (RIEF)	Establish links between students' state of mind with course rigor and psychological stressors; professional development of faculty	Year 1
2	Research Experience for Undergraduates Site (REU)	Provide summer research opportunities in coastal infrastructure resilience	Year 1
3	Improving Undergraduate STEM Education (IUSE)	Investigate the effects of augmented reality on student learning in engineering mechanics	Year 2

Prior to receiving these competitive grants, the engineering authors had a combined total of 2 journal papers and one conference paper related to EER. Their mentor had 36 journal publications and 50 conference presentations related to the social sciences.

3. Barriers to Entry

The authors identified specific barriers to entry on their pathway to initiate engineering education research, as shown in Figure 1. Some barriers are consistent with those reported in other studies [5,7]. The authors classify the barriers as either *intrinsic* or *extrinsic*. Intrinsic barriers are personal to oneself, while extrinsic barriers stem from factors outside the researcher. The term *barrier* implies an unyielding obstacle that cannot be overcome. In reality, many obstacles could be considered "permeable" if opportunities (or "inlets") are carefully sought by the motivated engineering education researcher.

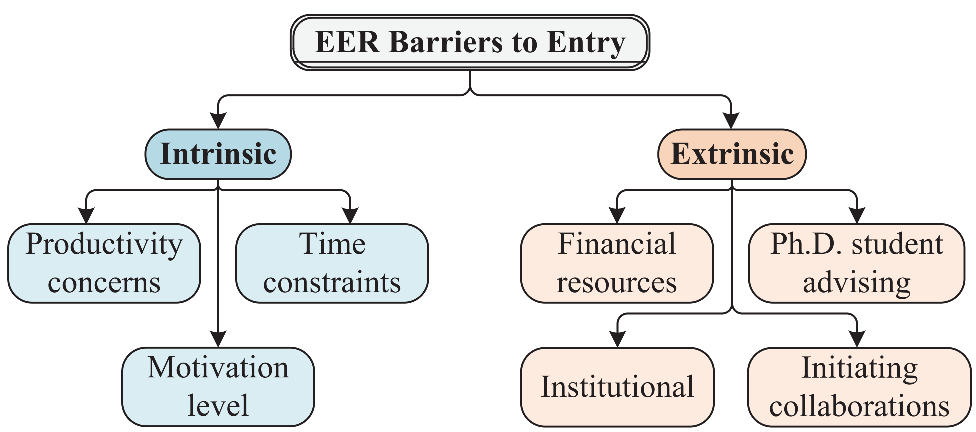

Figure 1. Summary of authors' barriers to enter EER

Among the researcher's intrinsic barriers include: (a) level of motivation, (b) time constraints to acquire sufficient knowledge to submit competitive grant proposals, and (c) lack of interim research productivity while learning EER. Even if engineering faculty can overcome their intrinsic barriers, they may face extrinsic impediments. These include: (a) limitations imposed by financial resources, (b) difficulty initiating social science collaborations, (c) insufficient EER experience to advise graduate students in the social sciences, and (d) institutional culture and support. As described later, the authors were able to overcome many of the aforementioned barriers.

The sections that follow highlight several significant elements of the authors' experiences on their pathway to initiate substantial EER. These elements are:

- Initiating collaborative relationships
- EER Knowledge acquisition
- Institutional environment
- Research ethics

Many experiences pertain to the NSF RIEF project that involves formal mentorship and structured learning. Each section describes the associated challenges with barriers to entry, lessons learned, recommendations, and potential resources to better inform prospective engineering education researchers.

4. Initiating collaborative relationships

Challenges: The prominent challenges associated with the initiation and growth of meaningful social science collaborations included: (a) identifying collaborators and a mentor; (b) creating a mentoring framework; and (c) evaluating the health of the mentoring program.

Identifying collaborators and a mentor. Consistent with the literature [5], the engineering authors struggled to identify experts in the social sciences that (a) had similar research interests, (b) were knowledgeable in EER methods, and (c) willing to collaborate despite the engineering authors' minimal knowledge of the field. Prior to submitting EER grant proposals, the three engineering authors utilized several resources to identify potential collaborators. These included searches of recent NSF awardees, SCOPUS, the ASEE member directory, and the profiles of faculty whose institutions awarded graduate degrees in engineering education. While these avenues did identify potential collaborators, the engineering authors' were most successful by using their network of existing engineering research collaborators as well as administrators in their home institution. This close network of collaborators facilitated virtual introductions. However, it was difficult to invite social science researchers to collaborate on an EER project given that the engineering authors' existing knowledge of such research methods was minimal. This was overcome by pursuing seed funding at the authors' home institution. Such funding is typically less competitive than proposals to federal agencies like NSF and, more importantly, the proposals are substantially more concise and require a minimal investment of time. Thus, a proposal for seed funding represents a "low-cost" effort to a potential collaborator. This approach was successful in initiating collaborations with two social science researchers. A third collaboration (and formal mentorship) was accomplished via the submission of a NSF RIEF proposal.

Creating a mentoring framework. Prior to receiving substantial EER funding, the engineering authors were receiving informal mentorship from another social science researcher (not a co-author of this paper). Mentoring was typically irregular with only a modicum of structure. Due to the informal nature, the mentoring was not prioritized and, as a result, the engineering faculty did not benefit to the extent desired. Upon notification of significant EER funding from NSF, the engineering authors opted to pursue a formal mentoring arrangement to ensure longevity of the commitment from the mentees and mentor.

As part of the formal mentoring, each of the engineering authors formulated a two-year Individualized Development Plan (IDP) [12] in consultation with their social science mentor. Each IDP serves as a roadmap tailored to the unique research and career goals of the engineering faculty member. The IDP outlines personalized objectives for research and teaching, all in the context of the EER awards presented earlier in Table 1. The specificity of each objective is characterized using the following:

1. Supporting activities (educational and research) to achieve the objective
2. Relevance of the objective to the EER project
3. Metrics to assess completion
4. Timeline and target dates for completion
5. Anticipated products

Examples of the metrics to assess completion of the objectives include: (a) quantity of scholarly works, (b) quantity and scope of future proposal submissions related to EER, and (c) quantity of new collaborations initiated in the social sciences both within and outside the authors' home institution.

Since the IDP is a roadmap with quantifiable metrics, it constitutes the basis of the formal mentoring. Every year, each mentee schedules a private meeting with the mentor to revisit the IDP. The benchmarks outlined in the IDP are utilized to compare the individual intended goals with the actual outcomes achieved by the mentee. They also consider a holistic view of the overall progress of the engineering investigator on their path to become an independent social science researcher. The IDP can be revised to account for emerging research opportunities, perceived weaknesses, and changes in metrics.

Evaluating the health of the mentoring program. The quality and effectiveness of the mentoring is periodically assessed by the mentees, the mentor, as well as an external evaluator. On a triannual basis, each mentee anonymously completes the Mentorship Profile Questionnaire [13] and the Mentorship Effectiveness Scale [13]. The mentees then convene annually to review the survey results and to formulate constructive feedback to share with the mentor. Similarly, the mentor utilizes each mentee's IDP as a basis of evaluating their participation in the mentoring initiatives. Lastly, an external evaluator (independent of the EER projects, and not located at the authors' home institution) gauges the quality of the mentoring by reviewing the IDPs, and meeting individually with the mentees and mentor at the start of the project and annually thereafter. These meetings allow the evaluator to document the mentoring expectations, extent of the mentoring, perceptions of the investigators' progress to achieve their desired goals, benefits realized by the mentor and mentees, and the mentees' future EER plans, all of which are considered best mentoring practices [14].

<u>Lessons learned</u>: (a) Despite a broad range of avenues to identify potential collaborators, opportunities at the home institution can be facilitated using an existing network of colleagues; (b) establishing a formal mentor-mentee relationship implies a sense of commitment and

seriousness far beyond that of an informal relationship; and (c) assessing the health of the mentoring can be accomplished using both quantitative and qualitative methods, as well as observations from an independent evaluator.

Recommendations: (a) pursue seed funding opportunities from internal and external sources to initiate collaborations that involve minimal commitment from a potential collaborator; (b) create a formal mentorship plan that includes concise goals, metrics, and milestones; (c) incorporate quantitative and qualitative approaches on an established schedule as well as external evaluation to monitor mentoring activities

5. EER Knowledge acquisition

Challenges: Struggles related to the acquisition and conceptual understanding of the social sciences included (a) understanding the EER discipline and methods; (b) acquisition of deeper EER knowledge and skills; (c) embracing social science theories and abstract concepts.

Understanding the EER discipline and relevant methods. Without fundamental knowledge in an educator's desired niche area of EER, it may be impossible to establish any meaningful relationships with potential collaborators. Thus, a prospective engineering education researcher will face an almost unsurmountable obstacle -- becoming reasonably knowledgeable in EER with minimal, if any, formal education or training. This problem is exacerbated by time constraints imposed by the obligations of a researcher's current job role. Prior to initiating any collaborations or investigating specific EER areas of interest, the authors' first critical steps were to: (1) gain an overall understanding of the developing field of EER, and (2) become acquainted with EER terminology and methods. The authors accomplished these steps over several months using independent learning. Since a comprehensive textbook on engineering education research is yet to be published, the authors utilized the Cambridge Handbook of Engineering Education Research (CHEER) [15]. CHEER provides both a macro view of EER, as well as relatively detailed discussions of the specialties within EER and their associated methods. This reference has, and continues to serve as, a critical source of knowledge for the engineering authors of this paper.

Acquisition of deeper EER knowledge and skills. Gaining deeper knowledge (a "micro view") as well as relevant experience in specific topical areas within EER can be exhaustive if a formal learning plan and schedule are not established. Specifically, two of the authors sought to conduct research related to the development and assessment of augmented reality as an instructional technology to improve student learning. Understanding the many facets of conducting research on instructional technologies was best suited to a cohesive training program. Therefore, the primary author chose to complete a 6-month continuing education program in Instructional Design and Technology at his home institution. The program consisted of four asynchronous courses that were scheduled around the authors' existing work obligations. In addition, two of the authors participated in a number of networking and faculty development workshops hosted by their institution's Department of Academic Technologies. The knowledge and experience gained was utilized in a successful grant proposal submission to the NSF Improving Undergraduate STEM Education (IUSE) division.

For the authors' RIEF project, a significant knowledge of the social sciences (specifically, psychology) was warranted. The breadth and depth of learning required was simply not conducive to independent learning. Therefore, the engineering authors' gradual acquisition of the relevant research knowledge was planned using a scaffolding approach with their social sciences mentor (psychology). Structured learning is currently ongoing (Year 1), with the expectation that the mentor's role will gradually shift to a supervisory capacity in subsequent years as the mentees mature towards research independence. The meetings currently follow an active learning format where the mentor first identifies "pre-class" reading materials (or videos) that cover project-specific social science topics and research methods. Among the topics include affective (emotional) processes [16-19] and Bayesian statistics [20]. The mentees independently study the material and prepare a list of questions for discussion or clarification. Half of each 1-hour meeting serves as an open forum to discuss the materials, while the remainder is utilized as a research briefing of the ongoing RIEF project. Meeting minutes are documented using a cloud-based, digital note-taking app that allows all collaborators to share, edit, and sync project notebooks. This documentation also serves as both a professional development journal and a formal project log for the external project evaluator to periodically assess.

Embracing social science theories and abstract concepts. The authors' disciplines (civil engineering and psychology) are so disparate that the engineering mentees are challenged to adapt to a research field in which learning theories [21] are qualitative and not supported by universally accepted constitutive equations. The authors' continue to confront this challenge, especially in their ongoing RIEF project where they solicit engineering students' emotions and state of mind using survey instruments. Survey questions use a broad range of psychological terms such as "stress" and "fatigue". In the engineering authors' opinion, terms like these are often ill-defined. For example, the World Health Organization (WHO) defines "stress" as "*any type of change that causes physical, emotional or psychological strain*" [22]. Such a construct cannot be experimentally measured with an intended level of confidence since it is ambiguous and subject to interpretation by the researcher. It is also ironic that the WHO uses the term "strain" -- another parameter used in engineering mechanics. There, both stress and strain have universal and unequivocal meanings. They are well-defined quantitative parameters that can be experimentally measured and related using Hooke's Law of elasticity [23]. In their ongoing RIEF project, the authors are attempting to quantify psychological "stress" in human subjects by formulating phenomenological (empirical) relationships. An inherent difficulty is the ability to discern the complex interrelationships of numerous independent, dependent, and confounding variables.

<u>Lessons learned</u>: (a) Familiarization with the EER discipline and methods is a prerequisite to initiate formal EER studies and collaborations; (b) substantial knowledge gain is best accomplished using a formal learning program and scaffolding by a mentor; (c) adapting to EER methods requires the researcher to concede that social science topics possess inherent ambiguities that are not founded on reproducible nor universally accepted laws of nature.

<u>Recommendations</u>: (a) Identify a comprehensive resource to gain a background understanding of the EER field and its associated methods; (b) seek formal learning opportunities and set associated milestones to maintain discipline and motivation; (c) invest substantial time to become knowledgeable in EER terminology [24], assessments [25], qualitative methods [26],

statistics [20], and human subjects research [27]; utilize online databases such as the Education Resources Information Center (ERIC) [28].

6. Institutional environment

Challenges: the culture of an institution brings forth a number of challenges related to (a) incentives, support, and reward systems; and (b) interdisciplinary graduate student advising.

Incentives, support, and reward systems. New engineering education researchers must overcome several extrinsic barriers of entry related to institutional buy-in. An engineering educator's institution may, or may not, duly incentivize faculty to augment or shift their research path to EER. At institutions where incentives from administrators are not explicit, prospective engineering education researchers can lobby for support by emphasizing the possible outcomes of EER that would benefit the institution. Table 2 summarizes common concerns and ways in which the authors' ongoing EER grants may mitigate them. These concerns are typical among many engineering institutions across United States.

Table 2. Typical areas of concern, relevance to the author's ongoing EER, and institutional benefits

Institutional concern	Relevance to the authors' EER	Institutional benefit
Undergraduate student retention in engineering programs	RIEF addresses undergraduate student emotion and behavior, and aims to identify potential interventions to improve retention and persistence.	Increased student retention and tuition revenue
Availability of research space and shared facilities	IUSE and RIEF projects do not occupy any space, while REU integrates students into existing research areas.	Research spaces remain intact; cost savings
Effectiveness of pedagogical delivery	Instructional technologies from IUSE may provide faculty with powerful tools to incorporate into coursework to improve student learning	Increase in student satisfaction with faculty; increased tuition revenue

Institutional support can be sought in many forms, such as reduced teaching assignments or seed funding to generate preliminary research results for use in comprehensive proposals. Administrators should be supportive and cognizant that a faculty member will likely exhibit a period of low research productivity as they invest substantial time to submit EER proposals. The faculty member and their institution should consider and agree upon alternative, yet appropriate, metrics to assess research productivity during the transition to EER.

Interdisciplinary graduate student advising. It may be difficult or impossible for an engineering educator to secure permission to formally advise social science graduate students on EER projects if the engineering educator does not possess an earned terminal degree (or equivalent experience) in a relevant social sciences field. Opponents of graduate student advising (by an engineering educator) argue that an engineering educator new to the EER field may lack the social science skill set and expertise necessary to provide graduate students with sound guidance, feedback, and mentorship. In the absence of formal education and experience, the educator may be perceived as lacking credibility, which can undermine an advisor-student relationship. Proponents advocate that an engineering educator can offer social science students a unique perspective given their first-hand experience teaching engineering students, assessing curricula, developing degree programs, and mitigating high attrition rates in early undergraduate engineering courses.

The inability to advise graduate students on EER projects will negatively impact an engineering educator in several ways. First, intrinsic motivation and scholarly productivity will likely diminish. Second, the educator's annual performance review may be harmed if the institution uses graduate student advising (especially PhD) as a chief metric to assess faculty productivity. Similarly, an educator's aspirations to increase their academic rank may be jeopardized since graduate student advising is typically a significant factor considered in the promotion review process.

A potential compromise is to permit co-advising in which the PhD student has two advisors (one in the social sciences, and the engineering educator). Each advisor can take distinct roles and responsibilities to ensure the PhD student receives consistent guidance. This collaborative advising arrangement benefits all involved:

- The graduate student can receive both the social science and engineering perspectives throughout the conduct of the research.
- The social science advisor can have a lighter workload since the engineering educator will assume some advising responsibilities, such as reviewing students' manuscript drafts and assisting with data analysis.
- The engineering educator can have a deeper involvement in the research, and grow professionally in the long-term.

<u>Lessons learned</u>: (a) identifying the broader impacts of EER can garner institutional support; (b) the inability to advise graduate students in EER may be detrimental to the long-term career goals of a new researcher in EER

<u>Recommendations</u>: (a) lobby for support by identifying institutional- or program-specific issues that the proposed EER can potentially alleviate; (b) obtain approval to participate in the advising of graduate students in the social sciences prior to submitting EER grant proposals.

7. Research ethics

<u>Challenges</u>: Although ethics are generally universal among all scientific fields, the authors faced several unexpected issues rooted in the ethical conduct and dissemination of results related to EER studies. These included (a) assigning students into control and treatment groups, (b) withholding student artifacts, and (c) publishing results in social science journals.

Control and treatment groups. The authors carried out an EER study to measure the effect of an active learning intervention on undergraduate students' knowledge retention. Students were randomly assigned into either a treatment group to receive the intervention (an instructional technology), or a control group in which the students received traditional instruction. Of course, the intervention was withheld from the control group as a means of establishing causality. After the class was completed, students in the control group reported feeling marginalized since they were not able to participate in an active learning session using the instructional technology. These feelings of exclusion may negatively affect student motivation especially in early engineering courses with high attrition rates. Implementing a crossover study [29] can mitigate this issue by allowing all students to experience the intervention. However, it may be impractical or impossible due to insufficient class time, limited equipment, lack of space, or combinations thereof. Sympathetic to the plight of the disappointed students, the authors questioned the ethics of assigning students to a control group.

Student artifacts. When a pedagogical intervention will be repeated over multiple semesters, it may be necessary to reuse the same assessment such as a quiz or exam. If the assessment becomes available to students in subsequent semesters, they will have pre-knowledge of the assessment content [30]. Accordingly, efforts must be made to maintain confidentiality of the assessment and prevent students from sharing it with peers or posting it to online repositories such as Chegg® [31]. The simplest solution is for the researcher to retain the graded assessments (student artifacts) indefinitely and not return them to students. While this approach can lessen the concern of test pre-knowledge in future semesters, it may eliminate the possibility of students viewing their work, learning from their mistakes, receiving valuable feedback, and, ultimately, mastering the content of the assessment. The authors faced a dilemma -- should graded artifacts be returned to students, or be retained to preserve a study's integrity? The authors decided to return those assessments that counted towards the students' final course grade, except for final exams. Upon request, students can view their graded final exam but are not permitted to keep nor photograph it. Assessments that do not factor into the course grade are not returned. The authors believe these arrangements constitute a reasonable compromise that allows students to learn from their mistakes while still maintaining the validity of their EER studies. This approach was formally recognized with pre-approval from an Institutional Review Board (IRB).

Publishing. Dissemination of research results is a pillar of the scientific community. In engineering research, experimental results are considered valid if a standard (or well-justified) protocol was followed. Regardless of whether the study results confirm or refute an engineering researcher's hypothesis, the results should be viable to disseminate via scientific journals. However, unbeknownst to the engineering authors of this paper, it is common for social science journals to limit the publishing of scientific studies to those in which the studies' outcomes were "favorable" or "good" (i.e. the proposed intervention was better than control). A journal's practice of restricting the publication of only these results may lead researchers to embellish or falsify their findings. This may partially explain why repetition studies often fail to replicate the "favorable" results of prior researchers [32]. In addition, other researchers who are unaware of prior "unfavorable" research findings may waste valuable time and resources to conduct a similar study that yields the same result.

<u>Lessons learned</u>: (a) Assessing a pedagogical intervention that has the potential to positively impact thousands of future students is a significant benefit that far outweighs the disadvantage of withholding the intervention from a small number of students in a control group; (b) a balance can be achieved when considering whether or not to return graded artifacts to students; (c) unlike engineering research journals, social science journals favor studies in which an intervention produces a positive outcome.

Recommendations: (a) Strive to conduct crossover studies to enable all students to experience both the traditional and experimental forms of learning; (b) seek assistance from an IRB to address concerns regarding the return or retention of student artifacts; (c) meticulously document (and, with permission, record on video) all student activity to later identify clues to help explain why an intervention did not produce desired results.

8. Conclusions and recommendations

Prospective researchers seeking to pursue substantial EER will likely face barriers of entry that may complicate or impede their successful transition. Among those experienced by the authors were intrinsic barriers, which include their level of motivation, time constraints, and concerns of research productivity. Extrinsic barriers stem from factors related to institutional culture and policy, identification of potential collaborators, and financial limitations. The authors' noteworthy experiences were summarized in four categories: (1) initiating collaborative relationships, (2) EER knowledge acquisition, (3) institutional environment, and (4) ethics. Each category had unique challenges, lessons learned, and specific recommendations for prospective researchers to increase their likelihood of succeeding on a pathway to conduct EER. In addition, the authors also provide the following general recommendations:

1. Acquire relevant EER knowledge using a combination of formal and informal learning in tandem with a structured plan for mentorship from faculty in the social sciences

2. Invest substantial time to form a solid understanding of mixed methods of research and their applicability in EER

3. Be forthright with the institution's administration to explore incentives, support, productivity metrics, graduate student advising, and long-term career goals associated with a transition into EER

4. Pursue funding opportunities geared towards new engineering education researchers who are initiating research in EER

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