Qualitative Methods Used in the Assessment of Engineering Education

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ABSTRACT

This article clarifies key concepts that undergird qualitative research, which is being used increasingly as engineering educators improve classrooms, programs, and institutions. The paper compares quantitative and qualitative research, describes some qualitative data collection strategies used in engineering education, addresses methods for establishing trustworthiness, and discusses strategies for analyzing qualitative data. Also included are illustrative examples of recent engineering education research that features qualitative data analysis and mixed-method (quantitative and qualitative) approaches.

I. INTRODUCTION

Engineering educators are increasingly using qualitative research tools to improve our classrooms, programs, and institutions. In such an atmosphere, the need has emerged for a resource that clarifies some of the primary concepts that undergird qualitative research. Since the majority of engineering educators have quantitative research backgrounds, we begin with an example that illustrates important differences between qualitative and quantitative research.

Several years ago the Kalamazoo, Michigan School Board asked teachers for feedback on newly implemented accountability procedures. They used a closed-response questionnaire that also included two open-ended questions. When the questionnaire results indicated a strongly negative view of the accountability procedures, the school board members dismissed the results, indicating that they did not expect teachers to like the system, to want to be accountable, or to stray from the position of the teachers’ unions. However, when the board members read the responses to the open-ended questions, their reaction to these qualitative data was strikingly different, partly because the data helped them understand why teachers opposed the procedures and how vehement teachers were in their opposition. Soon after, accountability procedures were designed that were mutually acceptable to teachers and administrators [1–3].

This example underscores one of the most important differences between qualitative and quantitative data: they are used for different purposes and provide different types of information. In general, qualitative methods are designed to provide summaries of data that support generalizations about the phenomenon under study. To do this, quantitative research often involves few variables and many cases, and uses prescribed procedures to ensure validity and reliability [4]. Common examples of quantitative research techniques in engineering education include the administration of tests and closed-response questionnaires to students. Such techniques result in numerical data that may be statistically analyzed [5]. Qualitative results are limited in that they provide numerical descriptions rather than detailed accounts and generally provide less elaborate accounts of human perceptions or motivations than do qualitative findings.

By contrast, the broad purpose of qualitative research is to understand more about human perspectives and provide a detailed description of a given event or phenomenon. Qualitative researchers seek to better understand social or human problems that can be examined in their natural settings [6]. Qualitative research is not meant to provide fodder for cross-case generalization. Rather, this research provides thick description of the uniqueness of particular cases and contexts [2], and such description features rich, detailed, and concrete depictions of people, events, and places [7]. Criticisms of qualitative research methods as unsystematic or lacking in rigor may stem from a misunderstanding of the aforementioned purposes. Since such research often entails many variables and few cases [8], its procedures for establishing trustworthiness are fundamentally different than those used to establish rigor in quantitative research, an issue explored below. From a quantitative perspective, qualitative findings are limited in that they provide detailed accounts that are often based on small sample sizes. As engineering educators, many of us feel more comfortable with quantitative research methods because they result in numerical data, a concept with which most of us are quite familiar. However, rather than the investigator’s level of comfort, the purpose of the investigation should primarily guide the decision to use qualitative, quantitative, or mixed methods.

Patton has noted that qualitative research highlights and builds on ten key characteristics [2], which are presented along with their approximate quantitative equivalents in Table 1. As Table 1 indicates, broad distinctions between qualitative and quantitative research involve settings, perspectives, analysis methods, and case orientations, among others. Specifically, qualitative research generally
occurs in an uncontrolled naturalistic setting whereas quantitative research often occurs in a lab or other setting with precise, intentional controls and manipulations. Whereas qualitative research features a holistic perspective, quantitative research takes an analytic one, dividing the phenomenon into analyzable parts. In qualitative research, researchers often shuttle iteratively between data collection and analysis using inductive methods, whereas quantitative researchers generally conduct analysis after data collection, working deductively. Qualitative research yields rich data that require diverse data analysis techniques. Several qualitative terms used in Table 1 are explained in the Glossary below, along with their quantitative counterparts (e.g., the concept of external validity is reconceptualized as transferability, internal validity as credibility, reliability as dependability, etc.).

Although relevant, a discussion of the epistemological and paradigmatic foundations of qualitative and quantitative research is outside the scope of this paper. Instead, this paper focuses on three qualitative data collection strategies—observations, interviews/focus groups, and documents—explains methods for establishing trustworthiness, discusses strategies for analyzing qualitative data, and explores mixed-method strategies that productively combine qualitative and quantitative approaches in engineering education.

II. QUALITATIVE DATA COLLECTION STRATEGIES

Engineering educators already collect a broad range of qualitative data, particularly via observations, interviews/focus groups, and documents. Here we focus on these qualitative strategies rather than broader methodologies such as biography [e.g., 9], case study [e.g., 10], ethnography [e.g., 11], and phenomenology [e.g., 12] because these four methodologies can involve their own particular sets of inquiry procedures. However, observations, interviews/focus groups, and documents are commonly used in all four methodologies.

A. Observations

Observations provide the researcher with first-hand information concerning the performances or behaviors of groups or individuals, and observations are commonly used to gather data about oral presentations, team activities, workshops and seminars. The purpose of an observation is to focus on key components of the activities that are of research interest. For example, an observation of a seminar on “active learning” given to college faculty might focus on determining whether the speaker discussed appropriate active learning techniques and whether the speaker modeled these techniques during the presentation. Observations could also be completed in the classrooms of...
III. METHODS FOR ESTABLISHING TRUSTWORTHINESS

Because of the volume of data produced in qualitative research, qualitative analysis can be a daunting task, and knowledge of data analysis processes can save considerable time and energy. Qualitative researchers aim to complete the data analysis phase with data and interpretations of data that are trustworthy. Called rigor in quantitative research, trustworthiness refers to how we determine whether we have accurately described the settings and events, participants' perspectives, or content of documents (for other quantitative terms and their qualitative counterparts, see the Glossary). Trustworthiness is generally established by using various data collection and/or data analysis methods.

A study by Winsor [13], which tracked engineering students' writing and conceptions of writing across a five-year span, beginning with their first year as undergraduates, illustrates three methods that may be used to establish trustworthiness—triangulation, member checking, and thick description. Triangulation refers to the process of contrasting conclusions drawn from multiple investigators, theories, data collection strategies, and data sources to inform a study's findings [6]. In this study, Winsor juxtaposed findings from transcribed interviews with other transcribed interviews and with student-authored documents. The students were then asked to respond to the data and interpretations of the data (which can include documents such as summarized interview transcripts, field notes, or reflective memos) to verify the appropriateness of the data and the resulting interpretations; this feedback process is one form of member checking. Through member checking, participants' responses, and sometimes researchers' replies to them, can become part of the emerging dialogue and conceptual framework of the study. In Winsor's study, the participants' responses to the researcher's data interpretations were published with the final study to substantiate its findings, thereby augmenting the trustworthiness of the research. As noted above, rich, thick, and detailed descriptions of participants' perspectives and/or settings allow readers to make decisions regarding whether findings can transfer to other people and contexts. Both verbatim and via summary, Winsor recounted students' descriptions of their co-op workplace writing samples as well as their reflections on the samples' audiences, purposes, and peer or supervisor inputs, among other aspects. In addition to providing information on transferability, detailed descriptions narrow the potential gap between the raw data and any subsequent findings and interpretations by providing readers with detailed background on the fodder for such findings and interpretations.

Triangulation, member checking, and thick description represent only three ways to establish trustworthiness. Twelve other methods are also described in Table 2. We concur with Creswell's recommendation that any qualitative study should use a minimum of two methods of establishing trustworthiness [6]. In the alphabetically ordered list in Table 2, of perhaps greatest importance in establishing trustworthiness are methods 2, 6–8, 10–11, and 14–15. Which of the listed methods one uses will depend primarily on one's research purposes as well as logistic and resource constraints.

IV. DATA ANALYSIS TECHNIQUES

As mentioned previously, qualitative and quantitative research differ in their respective purposes, so it follows that their processes, although both systematic, also differ. In qualitative research, data collection and analysis are highly iterative and interrelated rather than discrete phases; categories and concepts emerging from incoming data can redirect the investigation and stimulate new data collection sources and new types of analysis during any given study. Although this can also occur in quantitative studies, it is commonplace in qualitative research. Generally, the iterative data analysis phase draws to an end at the point of saturation, when newly analyzed data yield only redundant categories or findings [6]. Specific data analysis methods for observations, interviews/focus groups, and documents are explained below.

A. Observational Protocols

The trustworthiness of observational data can be examined in multiple ways. Observations of individuals or groups are sometimes guided through the use of an "observational protocol," which provides a framework of the behaviors that an observer is expected to
record. For example, in a study completed by Laeser et al. [14], two researchers were trained to use Eberhardt's team functions to record the interactions that took place between males and females during the engineering design team process. Whenever the researchers witnessed a student displaying one of Eberhardt's functions, they checked a box that corresponded to that function. To augment dependability ("reliability" in quantitative research), a sample of the observations was coded by two independent raters and compared for consistency. These data were then analyzed quantitatively, which illustrates a mixed-method approach involving qualitative data collection and quantitative data analysis.

In the aforementioned study, the researchers could have used field notes rather than a checklist of categories for data collection purposes. This approach would utilize both qualitative data collection and analysis techniques. The collection of their field notes may still be guided by specific, pre-selected categories identified through an observational protocol. One method for collecting field notes is the "three column" method. Factual observations are recorded in the first column, analyses or interpretations of those observations are recorded in the second column, and post-observational reflections are recorded in the last column. After completing the observation process, the two observers could then compare, contrast, and compile their observations. This approach would result in detailed descriptions with respect to each category, and may yield unexpected descriptive detail concerning the behaviors under observation and concerning the appropriateness of the observational protocol—a key benefit.

Another approach that may be used in observational investigations is "domain analysis." A domain is any meaningful category within a particular social context. The goal of domain analysis is to identify patterns and categories that help decipher the meanings associated with objects, activities, and places within a given social situation [15]. In part because of its structured, sequential process, domain analysis is one of the most systematic approaches for analyzing observational data. This process provides specific tools to determine how domains are organized, to decipher the attributes of particular domains, and to identify the relationships among different domains as well as the implications of such relationships [15].

### B. Interview/Focus Group Notes and Transcriptions

There are two primary methods of recording the results of an interview or a focus group. The interviewer may take detailed field notes as the interview progresses and update these notes immediately following the interview process. When used for focus groups, this method requires two individuals, one leading the focus group discussion and the other observing and taking notes. Another technique is to use an audiotape or videotape to record the interview or focus group discussion and later have the interview or focus group discussion transcribed. Deciding which is the appropriate method in a given situation generally depends on the interview purposes and available resources. For more information on interviews, see [1, 16–17] and for focus groups, see [18–21].

Various techniques assist researchers in examining the trustworthiness of interview and focus group data. One common technique for analyzing interview and focus group notes or transcriptions is to seek to categorize these responses. For example, Bjorklund and Colbeck completed a "semi-structured interview" with 27 leaders in engineering education [22]. Like structured interviews, semi-structured interviews have a standard set of questions, and the interviewer is permitted to probe responses when interesting.

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<thead>
<tr>
<th>Descriptive Term</th>
<th>Method of Establishing Trustworthiness</th>
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<tr>
<td>1) Audit trail</td>
<td>Allowing for tracking back from the findings to the data to establish dependability (see Glossary).</td>
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<tr>
<td>2) Clarifying researcher bias</td>
<td>Commenting on past experiences, biases, prejudices, and orientations that are likely to shape the interpretation and approach of the study; this serves as a check on confirmability.</td>
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<tr>
<td>3) Code-recode</td>
<td>Coding, waiting a period of time, and then recoding to augment dependability.</td>
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<tr>
<td>4) Compare sample to demo</td>
<td>Comparing participants to demographic data.</td>
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<tr>
<td>5) Dense sample description</td>
<td>Describing participants in depth.</td>
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<tr>
<td>6) External audit</td>
<td>Using external consultants to examine the credibility of the research process and product.</td>
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<tr>
<td>7) Member checking</td>
<td>Asking participants to review and give feedback on transcripts, notes, drafts, and/or interpretations of data to augment credibility.</td>
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<tr>
<td>8) Negative case analysis</td>
<td>Challenging working hypotheses with disconfirming evidence and revising the hypotheses when appropriate.</td>
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<td>9) Nominated sample</td>
<td>Using a panel of judges to help in participant selection.</td>
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<td>10) Peer examination</td>
<td>Allowing peers to examine methods, meanings, and interpretations.</td>
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<td>11) Prolonged field experience</td>
<td>Spending a significant amount of time in the study setting to increase credibility.</td>
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<td>12) Purposeful sampling</td>
<td>Seeking participants who are knowledgeable about the processes or phenomena under study; also seeking settings where these occur.</td>
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<tr>
<td>13) Reflexivity</td>
<td>Tracking one’s emerging thoughts over the course of the study, by keeping a field journal of personal reflections.</td>
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<tr>
<td>14) Rich, thick description</td>
<td>Providing such description of participants’ perspectives and/or settings to allow readers to make decisions regarding transferability.</td>
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<tr>
<td>15) Triangulation</td>
<td>Triangulating multiple data collection strategies, data sources, investigators, and/or theories to augment confirmability.</td>
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**Table 2. Methods of establishing trustworthiness in qualitative research (Adapted from [6]).**
information emerges, as with unstructured interviews. The primary purpose of their interviews was to determine what the leaders perceived to be the recent changes in engineering education and how the leaders thought that faculty could be best motivated to get involved in these changes. All of the interviews were audio taped and later transcribed, and field notes were also maintained during the interview process.

Bjorklund and Colbeck examined the transcripts and field notes in an effort to identify common themes that emerged from the interview process. Nine ideas surfaced: Design, Emphasis on Effective Teaching, Computer Technology, Broad-Based Curriculum, Accreditation/Assessment, Funding, Engineering as Professional Stepping Stone, Industry Interest in Engineering Education, and Incorporating Science in Engineering. Using these categories, Bjorklund and Colbeck reported the number of leaders who commented on each of these areas and provided examples of various types of responses within these categories.

Although it may seem that providing these leaders with a checklist that contained the appropriate categories would have accomplished the same goal, Bjorklund and Colbeck did not know what categories should be used prior to the interviews. Additionally, their open-ended approach ensured that their beliefs or expectations did not limit or significantly influence the responses of the interviewed leaders. Furthermore, the interview not only resulted in a detailed description of leaders’ perceptions of the important changes in engineering education, but also information was acquired concerning the perceived influences on these changes and the reasons these changes were considered important.

Natishan, Schmidt and Mead used a slightly different method to examine the results of focus group activities [23]. They wanted to better understand the problems that were faced during the engineering design team process when teams differed in gender and ethnicity. Focus groups were conducted with three configurations of students, including 1) mixed gender and ethnicity, 2) women only and 3) minority only, to address team training, team formation, impact of diversity on the team process, and typical teaming problems. Engineering faculty had previously identified these design team issues as areas of concern. These two studies feature emergent and a priori elements; whereas Bjorklund and Colbeck’s categories emerged from the study itself, Natishan, Schmidt, and Mead used pre-established categories from engineering faculty to provide the framework that guided the analysis of the student focus group responses.

Several tools exist to facilitate the coding of transcribed interviews or focus groups. Constant comparative analysis is an inductive, three-step process that aids in the identification of themes and patterns in data, leaving a clear audit trail between data and any resulting interpretation [24]. Also, new software has made more efficient the task of coding transcriptions, which can become cumbersomely voluminous. Qualitative data analysis software types include text retrievers (e.g., Sonar Professional and Text Collector), text-based managers (e.g., Folio Views and InfoTree32 XT) code-and-retrieve programs (e.g., HyperQual2, Kwalit, and QUALPRO), code-based theory building programs (e.g., ATLAS/ti, HyperRESEARCH, and NVivo), and conceptual network builders (e.g., MetaDesign and Visio). Which software type and which product one uses will depend on one’s research purposes. (For a more detailed examination and evaluation of each type, see [25]).

C. Document Analysis

One common method for examining written data is the use of scoring rubrics. Scoring rubrics are descriptive scoring schemes that guide the analysis of the products or processes of student work [26–27], and are typically employed when a judgment of quality is required. There are two types of scoring rubrics: analytic and holistic. An analytic rubric uses a separate scale to rate different aspects of students’ responses whereas a holistic rubric uses a single scale to evaluate the larger process reflected through the response [27–28]. Since the application of an analytic or holistic scoring rubric results in categorical data, statistical summaries and analyses that are appropriate to categorical data can be used, assuming that all other assumptions of the statistical test are met. This provides the advantage of being able to use well-known quantitative methods in the analysis process while maintaining detailed descriptions for each level of response.

One group of researchers used an analytic scoring rubric to evaluate students’ performances at the middle (end of sophomore year) and end (end of senior year) of a students’ undergraduate education in evaluating the engineering design process [29]. Rubric categories included design process, teamwork, and communication, and each of these was further divided into subcategories that described student behaviors at seven different analytic levels. Their scoring rubric was designed to measure changes in design performances from the students’ first year of college all the way through to their initial years of professional practice.

Plumb and Scott proposed the use of a holistic scoring rubric for the evaluation of engineering writing samples at the University of Washington [30]. In order to ensure the reliability of the categorization of the student writing process, they used a three-step process. First, the raters individually categorized a common set of student papers as Not Acceptable, Competent, or Strong. Next, they discussed these papers, agreed on ratings for each paper, and developed a detailed description of the qualities of papers that fell within each category. After the categories were firmly established and understood, the raters individually scored the remaining student responses.

These two studies also provide a contrast between emergent and a priori approaches. Whereas in the Plumb and Scott study the categories emerged from reading a range of documents [30], the categories in the longitudinal design process study were pre-selected [29]. Whether one chooses an emergent or a priori approach will depend on the availability of relevant categories and on the trustworthiness of the processes by which the categories originally emerged.

V. Qualitative and Quantitative Research: Mixed-Method Approaches

Combining research that focuses on few variables and many cases (quantitative) and research that focuses on many variables and few cases (qualitative) can unite the primary advantages of each—namely, breadth and depth. Again, whether we use quantitative or qualitative research methods in engineering education should depend primarily on the underlying purpose of the assessment. Whereas qualitative research techniques are more appropriate when detailed information is needed with respect to a given subset of the population, quantitative research techniques are more appropriate
when generalizations are needed across a population. However, quite often the assessment of engineering education has both of these goals—the need for detailed information concerning a subset of individuals and for generalizations across the population. When this is the case, both types of research methods can be used in combination. This is referred to as a mixed-methods approach, as exemplified in the aforementioned examination of team and gender issues in an engineering design course [14]. Other recent engineering education examples of mixed-method approaches include program evaluation by the NSF-sponsored Foundation Coalition [31], where retention statistics were augmented by free-form interviews of students talking about their experiences in purposely-formed learning communities. At our institution, faculty are investigating student misconceptions in fluid mechanics using exams that combine multiple choice questions with prompts that ask students to explain their reasoning processes in writing [32].

Qualitative and quantitative methods can be mixed in a single study or a sequence of studies in multiple, often complementary ways, four of which are briefly mentioned here. First, qualitative studies can precede and/or motivate the need for quantitative studies, especially when researchers need to first explore the research terrain before they can understand how to approach a research topic. For example, in the Bjorklund and Colbeck study, nine categories emerged concerning faculty perceptions of recent changes in engineering education and ideas on how faculty could be motivated to become involved in these changes [22]. A quantitative follow-up to this study could involve a large-scale questionnaire that examines these specific categories and is administered to a larger sample of engineering leaders. Analysis of the results of this effort would suggest whether the categories identified as important by Bjorklund and Colbeck generalize to a broader population.

Second, quantitative research can also lead to qualitative investigations. For example, a large number of studies have raised the concern that women are underrepresented in engineering [e.g., 33–35]. Many of these studies point to statistical data, such as the finding that women only comprise 22 percent of those who are employed in science and engineering [35]. These statistics have stimulated qualitative researchers to probe the reasons that women either choose not to enter or choose to leave engineering [e.g., 36].

Third, a few in-depth studies or interviews can be embedded in a large-scale quantitative study to provide context and/or checks on validity of the quantitative results. In other words, qualitative methods can be used as a form of triangulation for quantitative studies and vice versa. Finally, a research project may be primarily qualitative but draw from quantitative data for background, demographics, etc.

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<thead>
<tr>
<th>Quantitative Term</th>
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<th>Definition of Qualitative Term</th>
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<tr>
<td>External Validity</td>
<td>Transferability</td>
<td>The degree to which aspects of research findings can apply to contexts other than the study context from which the findings emerged [37].</td>
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<tr>
<td>Internal Validity</td>
<td>Credibility</td>
<td>The relative truth value of qualitative findings and interpretations [37-38].</td>
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<tr>
<td>Objectivity</td>
<td>Confirmability</td>
<td>Checks designed to detect any effects of researcher bias (which is not the same as researcher perspective) [38].</td>
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<tr>
<td>Random Sampling</td>
<td>Purposeful Sampling</td>
<td>A process of selecting information-rich cases to maximize the depth of information that can be obtained regarding the phenomenon under study [2].</td>
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<tr>
<td>Reliability</td>
<td>Dependability</td>
<td>Refers to the consistency of research findings [38].</td>
</tr>
<tr>
<td>Results</td>
<td>Findings</td>
<td>Findings that emerge from systematic data analysis.</td>
</tr>
<tr>
<td>Rigor</td>
<td>Trustworthiness</td>
<td>Trustworthy research yields findings readers can trust due to the use of various procedures (described in Table 2); procedures and other details provide information on a study’s confirmability, credibility, dependability, and transferability [37-38].</td>
</tr>
<tr>
<td>Subjects</td>
<td>Participants</td>
<td>People involved in providing detailed information that is pertinent to the purpose of the research. Sometimes called respondents.</td>
</tr>
<tr>
<td>Validity</td>
<td>Verification</td>
<td>A process that verifies the quality of procedures and findings and that occurs throughout the interspersed phases of data collection, analysis, and writing. [6] Verification is sometimes used as a synonym for trustworthiness.</td>
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Glossary. Terminology distinctions in quantitative and qualitative research.
VI. CONCLUDING REMARKS

As the examples presented in this article illustrate, qualitative research already has an important role in engineering education. Researchers in this field are currently using qualitative techniques either in combination with quantitative techniques or as standalone methods. Again, the selection of quantitative, qualitative, or mixed approaches should depend primarily on the purpose of the research. We suggest seeking the counsel of experienced qualitative researchers when embarking on one’s initial foray into qualitative research; this can have the added benefit of expanding discourse on research between engineering educators and educators in other disciplines.

REFERENCES


AUTHORS’ BIOGRAPHIES

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