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# Conceptual Difficulties Experienced by Trained Engineers Learning Educational Research Methods

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## ABSTRACT

This paper describes conceptual difficulties that may be experienced by engineering faculty as they become engineering education researchers. Observation, survey, and assessment data collected at the 2005 NSF-funded Rigorous Research in Engineering Education workshop were systematically analyzed to uncover the five difficulties encountered by engineering faculty learning to design rigorous education studies: (1) framing research questions with broad appeal, (2) grounding research in a theoretical framework, (3) fully considering operationalization and measurement of constructs, (4) appreciating qualitative or mixed-methods approaches, and (5) pursuing interdisciplinary collaboration. The first four can be understood in terms of disciplinary consensus; they represent explicit steps in education research that are implicit in technical engineering research because there is greater consensus of methods and standards. This work better frames the issue of rigor in engineering education research by clarifying the fundamental differences that prevent application of traditional engineering standards of rigor directly to engineering education research.

**Keywords:** education research, graduate programs, rigorous research

## I. INTRODUCTION

As part of the natural development of any new field, engineering education has recently experienced a sharp increase in calls for rigor [1–5]. For example, the *Journal of Engineering Education* has repositioned itself as a research journal [6, 7]. Both Lee Schulman of the Carnegie Foundation for the Advancement of Teaching [4] and Gary Gabriele while at the National Science Foundation (NSF) [8] chose this venue to argue in editorials that the same standards of rigor applied to technical engineering research need now be applied to engineering education. Gabriele also explained that the Engineering Education and Centers Division of the National Science Foundation has “moved its engineering education programs from a focus on reform to an emphasis on research” [8]. As Ruth Strevler and Karl Smith suggest in a *Journal of Engineering Education* editorial, the important question in engineering education is now, “What can be done to prepare engineering education researchers to

shift their focus from teaching and curriculum development to exploring fundamental questions about engineering learning?” [9]. Since many of these engineering education researchers are engineering faculty trained in technical disciplines, the purpose of this research is to map the developmental process that trained engineers undergo to become rigorous engineering education researchers. The following questions guided this research:

1. What intellectual difficulties might be experienced by an engineering faculty member becoming a rigorous engineering education researcher?
2. What distinct stages or discrete processes are there to overcoming the difficulties?
3. What activities are likely to help engineering faculty overcome these difficulties, or avoid experiencing them altogether?

“Rigorous engineering education researcher” is defined in this study as one who is successful at attracting research-focused external funding and publishing in archived research journals such as *Journal of Engineering Education*, since both of these employ peer review to enforce rigorous standards. Rigorous research in engineering education is defined as adherence to the National Research Council’s six guiding principles for scientific inquiry [1], enumerated in the literature review section of this paper. The results of this research will be increasingly important as doctoral programs in engineering education flourish [3, 10]. The available data suggest that most people attracted to engineering education have a technical background [11], so one might expect that the difficulties these graduate students experience in learning educational research methods will be similar to those of engineering faculty from traditional engineering disciplines.

The following section presents a literature review of theory describing the differences between engineering and engineering education research as potential sources of difficulties and frustration for engineers embarking on education research. The methods section begins with a description of the research setting and participants, followed by an explanation of the data gathering and analysis methods. The results section describes each of the five conceptual difficulties in turn. The discussion section considers alternative interpretations and aspects of the workshop that have contributed to helping the participants overcome the difficulties, concluding with recommendations for similar programs targeted to engineering faculty and other trained engineers.

## II. LITERATURE REVIEW

One of the most useful formal characterizations of the differences between and among disciplinary fields is level of consensus.

Disciplines with Higher Levels of Consensus	Disciplines with Lower Levels of Consensus
Civil Engineering	Educational Administration
Mechanical Engineering	Secondary Education
Nuclear Engineering	Special Education
Ceramic Engineering	Psychology
Chemistry	Political Science
Physics	Communication
Mathematics	English

*Table 1. Examples from Biglan's classification of academic disciplines [12]. Traditional engineering disciplines have more uniform methods than education disciplines, making it easier to evaluate rigor in engineering research. The more neutral language of Lodahl and Gordon is used to describe the categories [15].*

The original data characterizing the disciplines was presented by Anthony Biglan [12], who elaborated on a concept originally presented in an editorial by Norman Storer a few years earlier [13]. Storer described fields with higher consensus as having a tighter integration of knowledge that makes it more risky to attempt a contribution because errors and sloppiness can be more easily detected by others. In fields with less consensus, standards of rigor are not as clearly defined and enforced. (However, this actually makes it more difficult to publish in these areas [14].) Biglan's study found the disciplines with the highest levels of consensus to be the physical sciences and engineering; civil, mechanical, nuclear, and ceramic engineering were included in the study. Fields with less consensus were education, social sciences, and humanities [12]. Some examples are presented in Table 1.

Level of consensus has been shown to affect many diverse aspects of research communication in academic fields, among them publication length [16] and journal acceptance rates [17]. Creswell and Bean found that while journal articles dominate research publication in high consensus fields, books and longer publications are more common in lower consensus fields. The authors interpreted the results as evidence that far more background and detailed description is necessary in low consensus fields to motivate and in some cases legitimize the work. In higher consensus fields, precise terminology and established standards allow for more efficient communication of results [16]. Zuckerman and Merton [17] quantified the substantial differences in journal acceptance rates across various disciplines. Fields with the lowest acceptance rates included history, literature, philosophy, and political science; fields with the highest rates were geology, physics, and biological sciences. The researchers concluded that acceptance rates were far higher in fields with a high level of "agreement on standards of scholarship in the various disciplines" including well-articulated standards of rigor. In reproducing this work in 1988, Hargens also found that it can be more challenging to publish in a social science field than in a more technical discipline. Acceptance rates averaging 60 percent for the physical and biological sciences lay in sharp contrast to 20 percent and lower acceptance rates in anthropology, sociology, psychology, and political science, even after controlling for available publication space [14]. (See [18] for an extensive review of these and other disciplinary differences.)

More recently, Jeffrey Pfeffer [19] suggested that a new discipline can actively seek to advance itself through the development of consensus. He cites the cases of economics and political science, both of which have developed significantly in terms of consensus and perceived rigor since the original studies of disciplinary field development in the early 1970s. Engineering education was not included in the 1970s categorizations, but one can argue that it possesses less consensus than more traditional engineering disciplines [20]. As Wankat, Felder, Smith, and Oreovicz explain, "Educational research is generally much less precisely defined than is engineering research" [21].

A number of recent initiatives are aimed at developing consensus in engineering education. Formal efforts are underway to summarize progress and define new directions, most notably the January 2005 special issue of *Journal of Engineering Education* (Vol. 94, No. 1), John Heywood's compendium of engineering education results [22], and Purdue University's colloquies focused on defining the most important engineering education research questions [23]. Similarly, to encourage agreement as to rigorous research standards, the 2002 National Research Council (NRC) report *Scientific Research in Education* [1] identifies six "guiding principles for scientific inquiry," referred to hereafter as the NRC 6:

1. Pose significant questions that can be investigated empirically.
2. Link research to relevant theory.
3. Use methods that permit direct investigation of the question.
4. Provide explicit, coherent chain of reasoning.
5. Replicate and generalize across studies.
6. Disclose research to encourage professional scrutiny and critique.

In lower consensus fields, it is more important for researchers to name and reference rigorous research criteria like these to aid readers and reviewers. Consider, for example, principle 2 above, which addresses the need for theoretical grounding. The theoretical framework in engineering research is often the traditional scientific paradigm based on the scientific method. This framework holds that universal relationships between variables can be uncovered through objective observation [24]. If other variables can be held constant, then the effect of those manipulated can be discovered. The framework might also be a specific theory such as the universal law of gravitation. Scientific and engineering theories are so universal, they need never be mentioned among adherents. This is abundantly clear in the case of gravitation, which, as the full name suggests, is universally accepted as a law, not just a theory.

The need for a theoretical framework to guide inquiry becomes clearer when one considers working with students. In a classroom setting, most variables cannot be tightly controlled. As Wankat, Felder, Smith, and Oreovicz explain, "It is almost impossible to construct an educational research study in which potentially confounding factors can be clearly identified and their influence eliminated. Students are far more difficult to categorize than I-beams or transistors or even fruit flies" [21]. An explicit, often previously tested, theoretical framework is necessary to focus the research on the factors most likely to have an effect. However, identifying and applying a theoretical framework adds an additional step to the research process with which technical engineering faculty members are largely unfamiliar. These differences in the research process can be a source of frustration for faculty embarking on engineering education research, particularly if they expect the research process to remain essentially the same.

The arguments presented above are based on the assumption that engineering faculty approach their teaching and educational research as they do their technical work. There is direct evidence that engineering faculty are attempting to apply engineering methods to their educational problems. In a Carnegie volume on the scholarship of teaching and learning in various disciplines, editor Mary Taylor Huber states that

One of the things we are finding is that scholars usually begin by following disciplinary models developed for other purposes when faced with the new task of exploring teaching and learning in their field...Most people inquiring into teaching and learning try to use the normal procedures in their discipline [25].

This aligns with findings from Lattuca and Stark [26] that disciplinary character strongly influences teaching and curricular innovation. Thus, we can expect engineering faculty to approach education work with the expectation of applying engineering methods, and that this can be a potential source of frustration to them [21, 25]. Testing the degree to which these theories apply to the major conceptual difficulties of engineering educators embarking on educational research will be a valuable step toward informing theory-based activities to increase rigor and consensus in engineering education.

### III. METHODS

#### A. Background and Setting

Consistent with good practice in qualitative research, this detailed description of the setting is given to aid readers in judging whether the findings developed from a faculty workshop transfer to other specific settings [27, 28]. The setting for this study is the 2005 offering of the five-day Conducting Rigorous Research in Engineering Education (RREE) workshop offered in Golden, Colorado, by facilitators from three professional societies: ASEE, the American Educational Research Association (AERA) Division I<sup>1</sup>, and the Professional and Organizational Development Network in Higher Education (POD)<sup>2</sup>. Other publications describe the project and initial assessment results in greater detail [5, 29]. In the initial (2004) workshop offering, introductory framing activities (presented prior to rigorous research content) compared standards of rigor in engineering and education fields to help participants see similarities between the two. In looking back on the 2004 experience, the facilitators felt that although the participants understood this material, they were focusing on teaching much more than research during the workshop. An example of this was when conceptual frameworks for research were being presented. The facilitators noted that participant questions and comments focused on classroom activities, e.g., writing test questions, rather than applying the theories to planning research. It was clear to many of the facilitators that additional comparisons between engineering and education research were needed. This led to a discussion of practitioner-researcher issues at the 2005 planning meeting to help refocus the workshop participants on rigorous research [30].

An article by RREE coordinators Ruth Streveler and Karl Smith describes the discussion and conclusions from the 2005 planning meeting [29]. At this meeting, the executive committee spent considerable time discussing the paradigm shifts needed for engineering faculty to conduct engineering education research. The committee agreed upon two important changes in thinking to guide participants through:

1. Engineering faculty participants are unlikely to be aware of important considerations of theoretical frameworks, measurement techniques, and research methods in educational research [5, 9].
2. Participants were most interested in assessing a teaching method they were already using to prove that this method “worked” [5, 9]. These participants needed to learn to reframe their questions for broader appeal.

In working to understand item 2, the executive committee developed a continuum representing various levels of rigor in education-related inquiry. This continuum is reproduced in Table 2. Level 2, scholarly teaching, is distinguished from level 1, excellent teaching, by the act of gathering assessment data supported by knowledge of best practices and collaboration and review by colleagues. Scholarship of teaching (level 3) makes the work public, often by publishing results in a form others can use, thereby inviting public critique. The first three levels were originally presented by Hutchings and Shulman [31], although not in the form of levels. The fourth level, rigorous research, was added by the executive committee as a natural extension of inquiry in engineering education [30]. The description in Table 2 highlights several aspects of the NRC 6 [1]: open-ended, significant questions; grounding in a theoretical framework; and rigorous methods. Arranging the various approaches in this way highlights the journey many engineering faculty take in embarking on engineering education work. Initial interest may be in localized problems, but as assessments are formalized and the work is made more public, opportunities for increased rigor present themselves.

#### B. Study Participants

Participants of the 2005 RREE workshop served as study participants. Participants were funded through one of two separate grants with different selection criteria and different mechanisms for ongoing support. *Individual participants*<sup>3</sup> completed an application which was evaluated for experience and interest in engineering education [5]. The workshop kicked off a year-long research experience for which these participants could earn a mini-grant by refining their workshop product and submitting it as a brief proposal. *Institutional team member participants*<sup>4</sup> were members of a three-person institutional team selected by the HBCU institution’s dean of engineering (one team from each of 12 HBCUs with engineering programs). It was recommended that one member of the institutional team be an education or other social science faculty member. The workshop also kicked-off a year-long experience for institutional teams, who also attend the Project Kaleidoscope Annual Meeting and the Center for the Advancement of Scholarship in Engineering Education annual symposium [33]. The combined group of attending participants was composed of 47 total participants, broken

<sup>3</sup>Funded by Rigorous Research in Engineering Education: Creating a Community of Practice (NSF DUE-0341127 and NSF HRD-041194)

<sup>4</sup>Funded by Strengthening HBCU Engineering Education Research Capacity (NSF HRD-0411994)

<sup>1</sup>www.aera.net

<sup>2</sup>www.podnetwork.org

Level of inquiry	Attributes of that level
Level 1: Excellent Teaching	Involves the use of good content and teaching methods.
Level 2: Scholarly Teaching	Good content and methods <i>and</i> classroom assessment and evidence gathering, informed by best practice and best knowledge, inviting of collaboration and review.
Level 3: Scholarship of Teaching	Is public and open to critique and evaluation, is in a form that others can build on, involves question-asking, inquiry and investigation, particularly about student learning.
Level 4: Rigorous Research in Engineering Education	Also is public, open to critique, and involves asking questions about student learning, but it includes a few unique components. (1) Begin with a <i>research</i> question not an <i>assessment</i> question. Assessment questions often deal with the “what” or “how much” of learning, while research questions more often focus on the “why” or “how” of learning [32]. (2) Tying the question to learning, pedagogical, or social theory and interpreting the results of the research in light of theory. This will allow for the research to build theory and can increase the significance of the findings. For example, studies about teaching thermodynamics can be redesigned to become studies based on cognitive theory, which can help explain why certain concepts in thermodynamics are so difficult to learn. (3) Paying careful attention to design of the study and the methods used. This will enable the study to hold up to scrutiny by a broad audience, again creating a potential for greater impact of results.

*Table 2. Levels of rigor in inquiry developed by RREE executive committee. Reproduced from [30]. The authors credit [31] for levels 1–3.*

down as 19 selected as individuals, 28 as engineer-institutional team members, and five as social scientist-institutional team members. The group represented 36 different U.S. institutions which offer engineering undergraduate degrees. The breakdown was as follows: 25 percent of participants from doctoral extensive institutions, 21 percent from doctoral intensive institutions, 47 percent from master’s institutions, and 6 percent from others (based on year 2000 Carnegie classifications).

### C. Data Collection

All aspects of the study were approved through human subjects (IRB) review, and participants signed informed consent forms as the first activity of the workshop. To ensure anonymity, each participant was assigned a randomly-generated ID number that is the only identifier in the archived data. Only the external evaluators have access to the list that matches identities with ID numbers. Data sources include:

1. Workshop handouts and presentation slides.
2. Observational field notes from the formal and unstructured work sessions of the workshop.
3. Participant pre-tests and post-tests dealing with workshop content.
4. Participant workshop evaluations.
5. Photographs of the progression of each participant poster prepared to make the evolving research design process public.
6. Workshop journals of 10 participants who volunteered to participate in this portion of the research. (All participants were asked.)

Item number 5 refers to posters prepared by participants throughout the course of the workshop. The workshop was structured around helping participants to develop a plan to research a question of personal interest with plenty of feedback from facilitators and fellow participants, and in 2005 the principal place to record and share evolving ideas was a participant poster. Robin Adams and coworkers [34] brought this idea to engineering education, where participants develop a project poster by adding a new

section each day. Borrego, Streveler, Chism, Smith, and Miller describe the RREE workshop posters in greater detail elsewhere [29]. Changes that participants made to specific sections of the poster (crossing out old content and replacing it) were taken as evidence of learning to triangulate findings from other sources.

Observations at the workshop were used to develop the initial findings, which were triangulated using the other sources. In this setting, observation of participant behavior was an important complement to participants’ reflective journals, their work products, and the facilitators’ interpretations. One observer (the author) attended the workshop for the sole purpose of collecting observation data about the participants’ learning of the workshop content. As part of the informed consent (IRB) process, participants were told their professional behavior would be observed (unless they elected not to participate), and the observer was introduced as such. During structured workshop sessions, the observer took handwritten notes (to be less obtrusive) which were then typed with additional detail during breaks and after dinner each day. During informal sessions such as meals, the observer participated in informal conversations with participants and facilitators to gain insight into how participants were developing understanding throughout the course of the week [27]. Notes from these discussions were written or typed immediately following the exchanges, usually as the next formal session was starting.

Rather than taking notes on the content presented, which was captured in the form of slides, handouts, and the memory of the facilitators, observation focused on the questions or comments of participants which revealed their degree of acceptance and understanding of the material. Thus, “questions or difficulties in accepting the workshop material as presented” served as the sensitizing concept [35] that guided observation. The workshop schedule itself provided structure to the topics and the order in which they were covered, which roughly followed the order of steps in the research process. Table 3 provides a listing of the topics covered during each day of the workshop, for reference.

The field notes gathered during the formal and informal sessions emphasized factual events and exchanges over interpretation.

For example, questions asked by participants during the formal presentations and the facilitators' responses were documented. Lists generated by the assembled group were recorded. During small group activities, various groups were observed, and their conversations grappling with the workshop material were logged. Whenever possible, the exact language of the participants and facilitators was included in the field notes.

The observer prepared for workshop observation by attending the executive committee planning meeting at which the facilitators discussed the 2004 workshop and updates for 2005 and reading *Scientific Research in Education* and other materials to be presented as workshop content. The educational background of the observer was similar to that of both the participants being observed and the audience for this research (e.g., Ph.D. in engineering, experience teaching at the college level, and interest in engineering education). While this background can facilitate understanding of what the participants are experiencing, it is also a potential source of bias. To balance any potential biases, results arising from the observation were triangulated with data from participant journals, posters, surveys, and evaluations. The final analysis, interpretations, and this manuscript were reviewed by the workshop facilitators (both engineers and education researchers) as a validity check of the results and interpretation.

#### D. Data Analysis Methods

The constant comparative method [36] was employed to thoroughly and systematically analyze the observation field notes to arrive at the conclusions. First, a simple set of codes was established and applied to categorize brief passages in the data. An open coding approach was used in which codes were developed based on the concepts emphasized by participants through their comments and questions. The terminology employed by the facilitators was used, since the workshop involved many new terms for the participants. Naturally, many of these codes aligned with the workshop topics listed in Table 3. An important difference was that each was further subdivided into accepting and rejecting incidents and comments (e.g., theory-accept, theory-grapple, and theory-reject). The patterns and pace of participant understanding were uncovered when the frequency of each type of comment was plotted over time and compared to when the topics were formally presented. (The plot is not included here due to small n, but the result is discussed in section IV.B.) Once this initial framework was developed, it was

refined and expanded using data from participant journals, posters, surveys, and evaluations. As a final validity check, all six workshop facilitators, both engineers and educational researchers, reviewed the findings. It is this rigor in analyzing data that distinguishes qualitative research from anecdotal information [37].

## IV. RESULTS

Analysis of the observation field notes revealed participant difficulties in accepting the workshop material as presented, specifically the following five items:

1. Rigorous research questions are open-form "why" or "how" questions as opposed to closed-form "yes or no" questions; rigorous research is characterized by transferable results applying to a wide range of settings.
2. A theoretical framework is needed to guide educational research.
3. Qualitative or mixed research methods can provide valuable insight into educational problems as a complement to quantitative approaches.
4. Measurement and definition of constructs or variables are not trivial research tasks.
5. In the absence of individuals trained in both engineering and social science methods, a team of collaborators with diverse disciplinary backgrounds is required to provide the necessary expertise for rigorous engineering education research.

However, by the end of the workshop, most participants accepted the above statements as true. Using these items as the categories for analyzing participant research journals and poster updates, three major themes describing the changes in participant attitude and knowledge during the workshop were developed:

1. Some participants entered the workshop with interest in local and/or closed-form research questions before arriving at more generalizable questions by the end of the workshop. A few others remained localized in their approach.
2. All participants were aware of the ambiguity inherent in education work. Through exploration of measurement issues, most participants came to appreciate the need for a theoretical framework and the value of qualitative research methods as a complement to quantitative approaches.

Day One Monday	Day Two Tuesday	Day Three Wednesday	Day Four Thursday	Day Five Friday
<ul style="list-style-type: none"> <li>• Pre-tests, Informed Consent, and Overview</li> <li>• Engineering and Education Research</li> <li>• Scholarly Teaching, Scholarship of Teaching and Learning, Rigorous Research</li> <li>• Assessment versus Research</li> </ul>	<ul style="list-style-type: none"> <li>• Research Questions</li> <li>• Conceptual Frameworks</li> <li>• Reading Educational Literature</li> </ul>	<ul style="list-style-type: none"> <li>• Measurement</li> <li>• Unstructured time to work on posters</li> </ul>	<ul style="list-style-type: none"> <li>• Research Methods (presentation and consultation)</li> <li>• Finding Collaborators</li> <li>• Working with Human Subjects</li> <li>• Post-workshop Community and Activities</li> </ul>	<ul style="list-style-type: none"> <li>• Final Poster Presentations</li> <li>• Post-tests and Evaluations</li> <li>• Adjourn at 12:00 p.m.</li> </ul>

Table 3. Listing of the daily topics/activities at the 2005 RREE workshop.

3. Some participants began and ended the workshop desiring only engineering-specific examples, methods, and collaborators. Others gradually saw the value of educational resources, while still others already entered the workshop with this attitude.

Analysis of participant journals also supports the hypothesis (testable through future work spanning time periods much longer than one week) that trained engineers who become engineering education researchers do so by *moving through* the levels listed in Table 2. In other words, it is unusual for an engineer to develop an interest in engineering education research without teaching and classroom improvement experience. At first, instructors may focus on solving local problems. Over time and through exposure to the scholarship of others, instructors may be encouraged to share their results. Seeing the additional power of transferable results, an instructor may seek to employ increasingly rigorous research methods. Selection criteria for RREE workshop cohorts shifted in 2005 to require experience in engineering education, attesting to a developmental process in which increasing exposure facilitates movement to the next stage. Each of the five conceptual categories not readily accepted by workshop participants is discussed individually in the following sections.

#### A. Transferability of Results

Transferability refers to exploring a problem of broad appeal. An engineering faculty member might initially be concerned about an issue or problem specific to her own classroom or department. As rigorous research methods are pursued, the problem is expanded beyond its original context and broadened to a question with wider appeal. One simple example of this was found on the poster of an institutional team that began with, "What contributes to the low retention rate of students at [specific institution]?" but had ultimately changed their question to, "What factors affect the retention of engineering students at [historically black colleges and universities]?"

A second example captures not only the issues of setting but also deeper questions about the learning process that can ultimately be used to design a variety of learning activities. One participant began his poster with, "Can I develop useful inquiry-based activities to correct important student misconceptions in heat transfer & thermodynamics?" Strictly speaking, this is a closed-form question requiring only a yes or no answer. Later in the week, this participant had expanded the question to consider learning processes with broad appeal to science and engineering educators:

What kind of inquiry-based activities lead to increased conceptual understanding and how does this work (what elements are key in the activities)? How does student thinking about important concepts change as a result of engaging in these activities?

By seeing the research questions and concerns of others listed on their posters, participants began to see that the same concerns are present on many campuses. Not only does the potential for a broad audience serve as motivation for completing and publishing one's own study, but it also suggests that there may be some prior work relevant to a particular widespread problem of interest. The clearest example of this was in the clusters of institutional teams that combined to form multi-institution teams exploring the same research questions. This was the case of the retention team mentioned

above. Another multi-institution team decided to pair institutions to compare two instructional methods. (Two institutions would test one method, the other two would test the second method, and the data from all would be pooled.) At the final presentations, an education faculty team member from one of the institutions explained,

See, the folks at [institution] have such a small class size, they know they can't really say anything about any kind of intervention they might do, so they are teaming up with [other institution] to do the same kind of intervention, to increase the generalizability. Now, there are all kinds of limitations with different instructors and different schools, but you just have to be up-front about it and acknowledge [the limitations]. That's all you can do.

Although it is likely that this education team member already understood the power of a multi-institution study, the fact that so many engineering faculty planned to participate in this study by the end of the workshop is an important one.

This was not the case of all participants, however. Another final presentation was given by a participant who had not substantially altered the scope of his research question. Although the question was broadened to eliminate mention of specific strategies, the final version on his poster was very localized: "Are my current efforts in teaching [topic] effective?" The presentation focused on the specific details of this person's program and course, including a listing of each time the course was taught and the numbers of students involved. The audience (of fellow participants) perceived that the presenter wanted to prove that his existing program works. When they suggested a research design that compares students exposed to the program with an unexposed control group, the presenter paused briefly, ignoring the comment, then continued describing the details of his program as before.

However, it was possible for other participants with limited interest in rigorous research to locate themselves within the scholarship of teaching-research spectrum (Table 2) and answer questions about the contribution of their work with confidence. A different group was observed in which the presenter described an exploratory data-gathering study related to student retention in engineering at his institution. He was asked by other participants planning more ambitious studies what variables he would change and whether there would be interviews. The presenter was able to answer with confidence, "I'm just information gathering at this point," and "At this point I've contacted an education department person about interviews. But if it's just me I would do surveys, time wise. Plus I have no experience with interviewing." Thus, some participants expanded the scope of their research questions to appeal to a broader audience, while others did not, due to limitations of interest or time.

The question of why transferability is such a difficult concept for engineering faculty may be answered by comments made by the participants midweek. One participant had particular difficulty understanding the distinction between local and transferable studies, asking nearby participants, "If you do something in your classroom, isn't it automatically generalizable?" Scientists and engineers are trained to expect that once a fact is proven or discovered, it is universally true. A conclusion drawn in one engineering laboratory is fully expected to be the same if the experiment is repeated under identical conditions elsewhere. Reproducing the exact same experimental conditions in another classroom, however, is impossible.

Transferability is assumed to be built into the research processes of most engineering disciplines, so many think that it does not need to be discussed or illustrated. Thus, the data suggest that *engineering faculty have difficulty understanding the importance of educational questions with broad appeal because considerations of transferability are implicit in engineering research.*

## B. Theoretical Frameworks

After the sessions on day one focused on comparing engineering and education research, the presentation of workshop topics followed the order of steps in the research process: research questions, theoretical frameworks, measurement, and research study design. Participant understanding followed this sequence but lagged in instruction by a day or more. Some participants described this in their journals as giving the material “time to sink in.” Learning may also have been facilitated by considering later stages in the research process and, as in the engineering design process, returning to earlier steps. One participant’s final journal entry summarizes this well:

I was unable to formulate a refined version [of my research question] initially. It was only *after* the Wed[nesday] morning discussion of Theory, Constructs, Operational Def’n, Measurement that I was able to iteratively think about the ability to research the question. I highly value Wed[nesday]’s cumulative effect. Incorporating the material from Thursday has not happened yet. The [Thursday morning consultation] was very helpful to crystallize the thoughts leading to a measurement plan...Measurement Plan is TBD.

Acceptance of transferability and theoretical frameworks both followed a pattern of apparent acceptance, followed by questioning, and finally, true acceptance and integration. The facilitators repeated their message often, so it was clear to the participants which concepts were important. Following the initial presentation of these concepts, it was as if participants were repeating back to the facilitators the responses they knew would be accepted (much like engineering students sometimes do). A few hours later, participants were observed in side conversations with other participants questioning the importance of these concepts. Still later (often the following day), participants were integrating the concepts into their research plans and logically defending their decisions when questioned. This pattern repeated for transferability and theoretical frameworks in an overlapping pattern over the five days of the workshop.

For example, the need for a theoretical framework to guide educational studies was presented on day one as one of the NRC’s 6 guiding principles for scientific research in education. On day two, participants were asked as groups to list the characteristics of a good research question. Participants were observed in their discussions questioning the need for a theoretical framework: “I think that happens more often than people admit, that it isn’t grounded in theory.” Participants also made similar comments at another table, but an education participant explained to the others that without a framework one doesn’t even know where to start. Immediately following this discussion, several groups reported back to the facilitator that a theory is necessary, though a third group mentioned it was a point of contention at their table. Participants knew the facilitators valued a framework and were sure to offer it as an answer. Later in

the day, when frameworks were formally presented, participants’ questions changed to be more accepting. Participants were most often confused about which to select when multiple frameworks seemed appropriate, indicating that they were concerned about selecting the correct one (e.g., “I don’t want to pick the wrong one”). Comments and questions indicated that the participants were expecting a single, correct framework to be available as an obvious choice. The analogy to an engineering design problem was made often by the facilitators: there is no single correct answer, but some are more appropriate than others. By the last day of the workshop, when participants were asked about the “best thing” they learned during the week, an overwhelming 57 percent of respondents listed the need for theoretical framework. This was by far the most popular response. It is doubtful that participants would list theoretical frameworks under these anonymous circumstances if they did not truly believe in them. (This particular feedback form did not include participant IDs.) On a different form, participants were asked to list their theoretical model if they had one in mind. Over 75 percent of the 44 respondents listed a specific theory, representing a wide variety of cognitive, motivation, student development, and critical theories.

## C. Operationalization and Measurement of Constructs

Questions of measurement first emerged when participants began to think seriously about selecting a theoretical framework for their own studies. As they were being presented theories of behavior, learning, and motivation, participants naturally began to question how a concept like motivation can be measured. Many of these questions were forestalled by the facilitator, who explained that it would all become clearer during the following morning’s session focusing on measurement. During the measurement session, participants were asked to read and evaluate the measurement methods used in a psychology journal article on humor. The intention of the facilitator was for the participants to focus on how well humor was defined, assessed, and triangulated in the study. Though the groups found the methods used to define and measure humor ironically humorous, the answers they offered the facilitator in reporting back focused on the presentation and interpretation of the quantitative results. In fact, much of the discussion concentrated on a single data plot. Previous research suggests that this type of focus is to be expected of engineers, who are oriented toward both quantitative approaches and the ability of plots “to render phenomena into compact, transportable and persuasive form” [38]. Participants were paying more attention to the aspects of measurement that are familiar to them from engineering than to the new considerations playing an important role in educational research. During the second half of the measurement session, the facilitators discussed existing measurement instruments (e.g., surveys), recommending that participants avoid creating their own because surveys must be properly validated through time-consuming processes that could not be covered in the workshop. Many participants were previously unaware that validated instruments relevant to their research questions had already been developed by psychologists or educational researchers. Participant questions at this point focused on locating these instruments, suggesting that they realized that measurement considerations are important to educational research. When asked at the end of the week which workshop topic they needed to learn more about, 79 percent of respondents listed a combination of measurement and data analysis issues, by far the most popular response to this question.

#### D. Qualitative and Mixed-Methods Approaches

At the beginning of the week, participants clearly identified with a quantitative research orientation. On day one, most participant groups listed among the characteristics of a good research question that it can be measured quantitatively and/or describes a causal relationship. This prompted the facilitator leading the discussion to express his concern to participants that they thought quantitative approaches were a requirement for quality research questions. By the presentation of research designs on day four, several participants were interested in qualitative methods. Approximately ten participants took detailed notes on the qualitative methods presented, while only three took notes on correlational and interventional studies presented in the next sessions. In one participant's journal this was manifested as a full page of notes on qualitative methods, accompanied by just a few lines on the other approaches.

Also, during the day four presentation of qualitative research methods, one participant noted a potential conflict between the NRC 6 recommendation of transferability and the thick description characterizing qualitative methods. If a qualitative approach does not necessarily seek to represent a larger population, she asked, "Does this mean it's not rigorous?" Although the NRC authors state that exclusion of qualitative methods was not their intent [1], the publication has been criticized by some educational researchers for favoring paradigms that focus on causal and quantitative relationships and rejecting non-positivist approaches [39]. In response to the participant's question, the facilitators summarized this controversy and explained their view that good qualitative research can meet the NRC 6 criteria by addressing research questions of broad, rather than localized, appeal. The important point illustrated by this exchange is that some participants were thinking critically and deeply about integrating qualitative methods into their rigorous research plans. Of the 22 individual and team posters with a completed measurement and methods section (titled "what will be measured"), 11 (50 percent) listed qualitative methods as part of a mixed methods research plan. Only four were strictly quantitative, and seven others were unclear with respect to quantitative or qualitative approaches.

A fascinating example of acceptance of qualitative methods comes from the journal and poster of one particular participant. On day one, this participant decided to skip a journal question about the "messiness" of educational research because, "My bias towards rigorous quantitative research is too strong. There will be a hard job convincing me that education research is as rigorous as mainstream scientific research." On day two, he notes in his journal not once but twice that one characteristic of a good research question is that it "demonstrates a causal relationship." But by the evening of day three, following both sessions on conceptual frameworks and measurement, his poster included "interviews" and a "written essay" to complement quantitative methods also listed in the measurement section. His final journal entry lists the expertise he needs to continue his research plan as "help w/qualitative research" in addition to creating surveys and understanding students' definition of the specific construct central to his research question.

Some readers may not agree that discovering and integrating qualitative methods indicates a more sophisticated approach to engineering education research. Similar debates over which approach is correct have plagued [40] and even impeded the growth of other fields [19]. However, this process of individual researchers altering their research approaches, particularly upon experience with funda-

mentally different subject material, is not without precedent. Toma [41] has uncovered evidence that academic researchers often begin as quantitative positivist thinkers only to discover other paradigms as the result of an influential personal or professional experience. In his book about the development of science education as a distinct field, Peter Fensham discusses how many of the researchers initially approached educational research with the positivist paradigm learned during their scientific training, only later to discover and integrate qualitative methods [42]. It is possible that the participants in this study alleviated discomfort arising from the "messiness" of education research by integrating complementary qualitative methods into their quantitative studies. What is most important is that these faculty members are now more open to the contribution that qualitative methods can offer to our overall understanding of complex student learning processes.

#### E. Interdisciplinary Collaboration

The fifth and final conceptual difficulty is valuing a collaborative approach to engineering education research and incorporating the perspectives and methodological expertise of multiple disciplines. In the absence of individuals formally trained in both technical engineering and social science research methods, a team of collaborators with diverse disciplinary backgrounds is needed to provide the necessary expertise to perform rigorous engineering education research. This multidisciplinary approach was built-in to the RREE project; the 2005 facilitator team comprised two engineers and four social scientists.

Evidence of skepticism among workshop participants emerged almost immediately. When the facilitator from a medical education department first introduced himself to the assembled group, participants were overheard to comment that they were unsure someone with a medical education background had anything to offer engineering education. By the end of the week, however, when the participants were organized by the facilitators into small groups for research design consultation, most participants were active in seeking (and apparently accepting, as they took notes and updated their posters) advice from the facilitators to whom they were assigned.

There were several illuminating exchanges during the workshop whereby engineering faculty participants realized what their social science colleagues have to offer. At one point, participants raised the concern that mapping psychology theories to engineering is not groundbreaking research and therefore psychologists might not be interested. The facilitators countered that this type of mapping is indeed cutting edge because it helps establish the transferability of existing theories. Participants also expressed concern that social science collaborators would not appreciate the unique challenges of engineering: "Do they accept that there are differences across disciplines? I mean, are there journals in education in all the disciplines?" To which many participants and facilitators answered, "Absolutely!" Later in the same discussion, another participant discovered out loud, "So we don't need to collaborate with a cutting edge ed[ucational] psychologist? Any run-of-the mill psychologist would work?" In this way, many misconceptions about the motivation, expertise, and interest of potential social science collaborators were dispelled during the workshop.

Several times during the week, participants attempted to draw the discussion toward practical strategies for recruiting social science collaborators. Many of the individual participants (not institutional team members) expressed intense frustration that colleagues



on their campuses were not interested in the work or motivated by funding opportunities. At times, the education faculty in attendance tried to explain the career concerns of their disciplinary colleagues, specifically that engineering work sometimes draws focus away from core research interests. The facilitators attempted to postpone this discussion until the scheduled collaboration session at the end of the week. When this session came around, surprisingly, the same frustration was not expressed. This could be because collaborators and advice were found at the workshop, or necessary venting had already taken place. For this structured session, participants were asked to brainstorm potential collaborators. In the participant journals collected, there was some variation. Some simply copied down the general suggestions given to the entire group (e.g., lists of departments and centers common to many campuses), while others created long lists of specific names and positions of people they knew of and intended to contact after the workshop. By the evaluation period the next morning, 61 percent of respondents listed finding a collaborator as one of their first three steps upon returning to campus. In a specific question about mentoring and collaboration, 95 percent of respondents said they would look for a mentor or collaborator. Of those searching for a local collaborator, all mentioned education, psychology, or educational psychology departments as sources.

There are also excellent examples of how institutional teams worked together to establish lasting collaborative relationships. Consider the case of one mega-team, which had formed when two engineers missing their education colleague combined with another institutional team interested in the same research topic: engineering student retention. (Nearly one-third of all participants were interested in planning retention studies.) The engineering faculty looked to their education colleague for guidance when the group was charged with selecting a theoretical framework for their study. The discussion began with motivational theories, which was one of the first categories on the list provided in the slides. There was some question among the engineers of whether motivational theories were most appropriate. The engineers had a problem with the motivation label, stating "maybe lack of motivation is not the reason students leave engineering." They were then reminded by their education team member that the facilitator used retention as an example when presenting motivation theories and that this was a hint that they should consider them more closely. The education team member read aloud from notes taken on the different motivational theories then stressed to the engineers that they were the ones that worked with engineering students and would ultimately be the ones to select the theory.

One engineering group member jumped on task value theory as soon as it was mentioned as a specific motivational framework, saying "I like that one." After all three motivational theories were listed, he started to argue vehemently for task value theory. A less assertive engineer expressed preference for goal orientation after pausing to consider all three. Vocal engineer team members began applying task value theory to their problem, in terms of "is [the task of] engineering worth it?" They stated that engineering students go through "all this work" and perhaps find no job at the end. Examples offered by various engineer team members included jobs and employment interests of engineering students. The education team member observed aloud that the discussion now really sounded like goal orientation theory. The rest of the group agreed. On their final rejection of task value theory, the point was raised by the team that

task value theory was framed during the presentation as comparing two tasks, while interest in this research context is in the very large task of engineering itself, with no comparison tasks.

Unfortunately, it was not the case that all participants saw the value of interdisciplinary research by the end of the workshop. On an open response item on the evaluation sheet, one participant wrote that in order to improve the program, "life-long engineering educators" who can "discuss topics with an engineering flair" should be involved as facilitators. It is worth noting that this comment came from an institutional team member that did not have the opportunity to work with a social scientist during the workshop.

## V. DISCUSSION

Engineering education is just beginning to emerge as a discipline, and its research is fundamentally different from engineering research in a way that adds additional explicit steps to the research process for engineers embarking on engineering education work. The scientific paradigm of engineering research is so widely understood that considerations of transferability, theoretical frameworks, measurement, and research approaches need not be defended, often because they seem the only logical choice. This theory alone accounts for a significant number of the conceptual difficulties the RREE engineer participants encountered in developing rigorous research plans for their engineering education interests. Appreciation that collaborators from other disciplines can provide unique and necessary expertise is a natural extension of fully realizing the differences between engineering and education research which require additional expertise.

Going into the 2005 RREE workshop, the executive committee focused on two types of "paradigm changes" they wanted to guide participants through. The first was essentially the major result of this research: understanding the fundamental differences between engineering and education research that make additional considerations necessary in education work. The second was that engineering faculty naturally first approach engineering education as practitioners (teachers) rather than researchers. Three sessions were planned for day one in the attempt to address these. The observer was sensitive to evidence during the 2005 workshop that participants were either changing or resisting change with respect to both paradigm shifts. Very little evidence was found that participants were approaching the workshop content as teachers. In a few cases, participants used examples from their teaching to understand a new concept, but were quickly able to apply the concepts to their research plans without dwelling on teaching. By no means did all participants enter the workshop ready to abandon discussions of teaching in favor of a research focus; fully 30 percent of participants responding to an open-ended evaluation question about the most helpful sessions listed the day one presentations. Instead of approaching the content as teachers, participants spent a significant amount of time struggling with the research steps as they were presented throughout the week, as described in the previous sections. The facilitators were also largely successful in affecting this type of paradigm shift, but the five days of the workshop (not just sessions on day one) were required to help participants make the change.

Several activities built into the workshop structure were particularly effective at helping the participants overcome these obstacles. These are summarized as recommendations for similar programs in

Conceptual Difficulty	Recommendations for Workshops, Programs, or Courses
Transferability	<ul style="list-style-type: none"> <li>• Exposure to the interests of others through community (posters), conferences, and/or literature to see the need for transferable studies</li> <li>• Discussion of contextual variables that might make a study non-transferable</li> <li>• Refinement of research questions to make them transferable</li> </ul>
Theoretical Framework	<ul style="list-style-type: none"> <li>• Exposure to a variety of theories and relevant examples of engineering education or classroom applications</li> <li>• Direction toward resources and key search terms for exploring other theories</li> <li>• Assignments to flesh out research design, which illustrate either the need for theory or the ease of design when using a theory</li> </ul>
Measurement	<ul style="list-style-type: none"> <li>• Attempts or criticism of others' attempts to operationalize abstract constructs</li> <li>• Awareness of methods for developing and validating an instrument</li> <li>• Direction toward resources for locating validated instruments</li> <li>• Examples from engineering education to illustrate standards and practices</li> </ul>
Qualitative Methods	<ul style="list-style-type: none"> <li>• Open-form "why" or "how" research questions that dig deeper</li> <li>• Exposure to qualitative research perspectives, practices, and standards</li> <li>• Open discussion about presenting qualitative results to an engineering audience</li> <li>• Consulting help designing a qualitative study or study component</li> </ul>
Interdisciplinary Collaboration	<ul style="list-style-type: none"> <li>• Instruction in rigorous methods and related necessary skills to help participants see where they need significant additional expertise</li> <li>• Informal interaction with knowledgeable colleagues from other disciplines</li> <li>• Strategies for finding local collaborators</li> <li>• Reassurance/clarification of the motivation of others to collaborate</li> </ul>
(Overall)	<ul style="list-style-type: none"> <li>• Positive, supportive community setting with learners and facilitators/instructors to interact informally as well as formally</li> <li>• Working through research design from beginning to end on one engineering education example of interest to participants (each step reinforces learning in previous ones)</li> </ul>

*Table 4. Recommendations for workshops, programs, or courses aimed at trained engineers developing rigorous engineering education research skills.*

Table 4. Participants saw the value of transferability in the similar interests being pursued by others and displayed on their posters. Sessions to refine research questions and discussions of the characteristics of a transferable question were also helpful. An organized catalog of several theoretical frameworks helped immensely when participants were asked to select one, and the value of a framework became clear to participants as they selected methods, variables, and populations for study. The importance of operationalizing constructs became evident during an activity centered on measuring an abstract construct. This example also made participants aware of the effort and expertise that goes into developing and validating an instrument, helping them to see the value of collaborators and catalogs of validated instruments. A presentation on qualitative methods as well as informal interaction with the facilitator eased reservations about qualitative methods. "Why" or "how" research questions may have also lent themselves to qualitative or mixed methods. The workshop provided extensive exposure for the participants to interested education researchers, many of whom have experience working with engineers on engineering education projects. This experience, perhaps coupled with a chance to vent frustrations, helped many participants to focus by the end of the week on proactively seeking out social science collaborators for their engineering

education research. In general, the community of practice model, featuring knowledgeable facilitators and informal time to interact, was particularly effective at facilitating learning of the participants with varied backgrounds and interests. Following the research design process from beginning to end with engineering examples also helped reinforce learning. Participant journals and feedback indicated that time for the concepts to "sink in" was key. As in engineering design, in considering later stages, the participants were forced to rethink earlier steps of the design and refine when necessary.

## VI. SUMMARY

Through study of the 2005 Rigorous Research in Engineering Education workshop participants, five conceptual difficulties for engineers embarking on engineering education research were identified: (1) framing research questions with broad appeal, (2) grounding research in a theoretical framework, (3) fully considering operationalization and measurement of constructs, (4) appreciation of qualitative or mixed-methods approaches, and (5) pursuing interdisciplinary collaboration. Nearly all of these difficulties can be understood in terms of engineering education as an emerging

discipline with far less consensus of methods and standards of rigor than the engineering disciplines in which faculty were originally trained as researchers. The scientific paradigm of engineering is so widely accepted and understood that many technical research decisions need not be defended. Thus, education research requires additional explicit steps that are implicit in engineering research. Difficulty viewing engineering education as research rather than teaching was a secondary conceptual difficulty, which was largely overcome by a series of sessions presented on day one of the workshop. A variety of observations, participant deliverables, and survey-style assessments were thoroughly and systematically analyzed to arrive at these results. Initial impressions of the workshop executive committee were considered and tested, and the workshop facilitators reviewed this manuscript to triangulate the findings. Recommendations are offered for the design of similar programs, including engineering education doctoral programs, targeted to trained engineers learning educational research methods. These practical solutions, coupled with theory of disciplinary development, will help to advance engineering education as a discipline that values the contributions of both research and scholarly teaching activities.

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