Quantitative, Qualitative, and Mixed Research Methods in Engineering Education

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ABSTRACT

The purpose of this research review is to open dialog about quantitative, qualitative, and mixed research methods in engineering education research. Our position is that no particular method is privileged over any other. Rather, the choice must be driven by the research questions. For each approach we offer a definition, aims, appropriate research questions, evaluation criteria, and examples from the *Journal of Engineering Education*. Then, we present empirical results from a prestigious international conference on engineering education research. Participants expressed disappointment in the low representation of qualitative studies; nonetheless, there appeared to be a strong preference for quantitative methods, particularly classroom-based experiments. Given the wide variety of issues still to be explored within engineering education, we expect that quantitative, qualitative, and mixed approaches will be essential in the future. We encourage readers to further investigate alternate research methods by accessing some of our sources and collaborating across education/social science and engineering disciplinary boundaries.

Keywords: quantitative, qualitative, and mixed-methods research

I. INTRODUCTION

Engineering education[1] as a developing field shares many characteristics of a discipline undergoing a scientific revolution as described by Thomas Kuhn (1962, 1970). As Kuhn describes the transition associated with change, he asserts that negotiation over the path and endpoint are inevitable. While engineering education is not undergoing a purely scientific revolution in Kuhnian terms, which occurs when established disciplines experience a paradigm change, development of the field bears many similarities to his scientific revolution argument (Borrego, 2007b; Borrego et al., 2008). For example, Kuhn maintains that new paradigms require prior understandings to be reconstructed. He argues that this time of "tradition shattering" is difficult, time consuming, and met with much resistance. In this case, the established disciplines which must undergo tradition shattering are the constituent engineering, education, and other disciplines in which most engineering education researchers were traditionally trained. This may be particularly frustrating to engineers and others who are more accustomed to working within long-standing paradigms (Borrego, 2007a).

Kuhn argues that formation of a paradigm is necessary and assists researchers in building a discipline. In order to establish itself as a research field, engineering education is negotiating input from both qualitative and quantitative methods advocates, both with strong investment in the field. Though there have been efforts to identify important research areas (Steering Committee of the National Engineering Education Research Colloquies, 2006) and results (Heywood, 2005), appropriate methods, convincing evidence, and standards for evaluating the quality of research studies are just as important to scientific field development.

The purpose of this paper is to open a dialog of methods in engineering education research. Our position is that no particular method (quantitative, qualitative, or mixed) is privileged over any other. Rather, the choice of method must be driven by the research questions (Creswell, 2002). For quantitative, qualitative, and mixed methods, we offer a basic definition, aims, appropriate research questions, or hypotheses. A separate section compares and contrasts evaluation criteria for the three approaches. Our references are a combination of methods texts from social sciences and examples from the *Journal of Engineering Education* (JEE) since its repositioning as a scholarly journal in 1993 (Ernst, 1993) (The journal was also repositioned in 2003 to focus exclusively on research (*Journal of Engineering Education*, 2005).) In our JEE search, we emphasized articles framed as investigating research questions or testing hypotheses over descriptions of interventions or assessment methods. One notable exception is articles directly addressing methods, which, while directly relevant to research methods, were often framed as assessment topics. Our intention is not to provide a comprehensive review of studies, but rather to use selected examples to illustrate the ways in which educational research methods have been and could be used in engineering education.

Finally, we offer some empirical data to substantiate our claims that methods need to be more openly discussed in engineering education. Observations at an international engineering education research conference uncovered a strong preference for quantitative methods and their associated evaluation criteria, likely due to most participants' technical training. While participants lamented a lack of reviewers' acceptance or understanding of qualitative work, the same participants enacted a quantitative,

[1]By Engineering Education, we refer to the field of engineering education research, not the practice of educating engineers.

classroom-experimental model in critiquing each others' work. Though classroom experiments might provide particularly compelling evidence, the approach appears to add unnecessary frustration for those hoping to publish their work. Specifically, faculty felt that they must repeat an intervention semester after semester until a statistically significant difference is established without question. We argue that expanding the repertoire of engineering education researchers through more open dialog, to the extent that alternative methods appropriately address the research questions, would greatly benefit the field.

II. Quantitative Methods

Much of engineering research seeks to identify how outcomes (i.e., mechanical failure) are determined by reducing plausible causes to a discrete set of indicators or variables. Quantitative methods are a good fit for deductive approaches, in which a theory or hypothesis justifies the variables, the purpose statement, and the direction of the narrowly defined research questions. The hypothesis being tested and the phrasing of the research questions govern how data will be collected (i.e., a locally developed survey, commercial instrument, or final course grades) as well as the method of statistical analysis used to examine the data (Creswell, 2002).

The purpose of quantitative studies is for the researcher to project his or her findings onto the larger population through an objective process. Data collected, often through surveys administered to a sample or subset of the entire population, allow the researcher to generalize or make inferences. Results are interpreted to determine the probability that the conclusions found among the sample can be replicated within the larger population. Conclusions are derived from data collected and measures of statistical analysis (Creswell, 2002; Thorne and Giesen, 2002).

Various topics in engineering education have been examined through a quantitative approach. In their review article from the JEE 2005 special issue, Olds, Moskal and Miller (2005) point to a number of quantitative assessment methods pertinent to engineering education, including surveys, meta-analysis and experimental designs. While engineers often use quantitative methods in their research or applied settings, this article is designed to address multiple audiences that might employ a quantitative approach within an educational context. In the subsections that follow quantitative methods as they have been used to explore topics in engineering education are discussed. First, descriptive statistics such as percentages, means and standard deviations are reviewed, as they have been used to illustrate various points and describe a situation, particularly one that has not been studied previously (Dorato and Abdallah, 1993; Hodge and Steele, 2002; Todd, Magleby, Sorensen, Swan, and Anthony, 1995). Quantitative studies within engineering education rely heavily on descriptive statistics derived from surveys or commercial instruments (Dorato and Abdallah, 1993; Downing, 2001; Hodge and Steele, 2002; Lang, Cruse, McVey, and McMasters, 1999; Todd et al., 1995; B. K. Walker et al., 1998). Second, quantitative research designs using statistical analyses to examine whether there are significant differences between groups on various indicators (Carpenter, Harding, Finelli, Montgomery, and Passow, 2006; Davis, 1996; Kirschman, and Greenstein, 2002; Rutz et al., 2003; Webster and Haberstroh, 2002) are discussed. Third, we discuss studies that more explicitly utilize theory and advanced statistical methods to test hypotheses that concern relationships between and among various indicators (Davis, 1996; Kirschman and Greenstein, 2002; Rutz et al., 2003; Shiavi and Brodersen, 2005; Webster and Haberstroh, 2002).

A. Descriptive Statistics

Quantifiable results as they pertain to opinions, attitudes, or trends are one of the goals of conducting a survey (Creswell, 2002). Articles in JEE have relied on the reporting of frequencies, or descriptive statistics, to examine the status of engineering education related to degree requirements (Dorato and Abdallah, 1993), current educational practices (Hodge and Steele, 2002), the educational experiences of students enrolled in engineering programs (Todd et al., 1995), and to document trends in student enrollments, retention, and starting salaries (Heckel, 1994, 1995, 1996). For ABET accreditation purposes, engineering education has also examined the employer's perspective through surveys collecting perceptions on elements that should be included or emphasized within curricular design (Downing, 2001; Lang et al., 1999; B. K. Walker et al., 1998). Involvement of underrepresented groups in engineering such as women has also been examined through the use of surveys measuring their professional preparation (Robinson and Reilly, 1993). Fewer descriptive studies have employed a longitudinal design (i.e., tracking students over extended periods of time) to examine students' growth in cognitive abilities (Lumsdaine and Lumsdaine, 1995) and retention (Felder, Felder, and Dietz, 1998; Felder et al., 1993; Felder et al., 1994). In each of these studies, the authors reported only the number and/or percentage of students, employers, or faculty in each category. These are referred to as descriptive studies because they describe the situation without addressing any relationships between variables or groups. As previously stated, this approach can be useful in the case of topics about which little is known.

B. Examining Relationships Between and Among Various Indicators

In other cases, researchers want to investigate cause and effect or differences between various groups or treatments. Pre-existing theory is typically used to guide the formation of hypotheses about relationships that might exist concerning a particular group, topic, or situation. The hypothesis is typically formulated as a research question, and then data are collected and analyzed to answer the research question. Following data collection, the hypothesis will be either accepted or rejected based upon the results of the statistical analysis. The indicators, or variables, that are being used to measure a particular theory will determine what type of analysis is used (refer to Table 1).

Studies that have examined how different variables are related to students' experiences within the classroom illustrate how theory is used to develop a hypothesis and how an appropriate method is selected for analysis based upon the indicators involved. This is seen in various studies that have examined whether there is a difference in subject mastery between distributed or distance learning engineering students and students enrolled in more traditional delivery methods (Davis, 1996; Kirschman and Greenstein, 2002; Rutz et al., 2003; Webster and Haberstroh, 2002). Similarly designed studies have examined whether technology-enhanced learning

Variables	Analyses	Predictive Analyses
Categorical	Contingency Tables and Chi Squared	Logistic regression Discriminant Analysis
Continuous (i.e, scale, ordinal, ratio)	ANOVA, MANOVA, t-tests Pearson's Correlation	Linear Regression Multiple Linear Regression

Table 1. Statistical analyses used to examine relationships between variables in engineering education. Adapted from Thorne and Giesen (2002). This table only includes statistical analyses used to examine relationships between variables in engineering education as mentioned in this article.

environments make a difference in student academic success (Hsi, Linn, and Bell, 1997; Merino and Abel, 2003; Ogot, Elliott, and Glumac, 2003). Trussell and Dietz (2003) examined whether enrollment in classes using graded homework assignments were related to higher test scores than enrollment in classes with no graded assignments. Since the dependent variables examined in these studies are continuous (i.e., GPA, exam score), Pearson's correlation, t-tests, ANOVAs, or MANOVAs have been used to analyze the results to determine whether there is a significant relationship between indicators or whether the mean score of one group differs significantly from another. If variables or indicators being examined are categorical (e.g., male/female, course section, pass/fail), statistics are analyzed through Chi-square to examine the differences between groups in reported frequency of responses. This is seen in Shiavi and Brodersen's (2005) study that examined whether students favored learning in a laboratory setting or via lecture.

C. Explicit Use of Theory

Other studies have used similar statistical analyses to examine how different groups within engineering education perform in relation to a given theory. The same methodological approach is taken with regard to developing a hypothesis or research questions and collecting and analyzing relevant data, but they are more explicit in employing theory to guide their investigations. Bell et al. (2003) investigated how Stereotype Threat impacts performance by male and female students on tests in an engineering classroom setting. Terenzini et al. (2001) used learning theory related to student engagement to examine whether active and collaborative learning methods differ from traditional lecture courses in their ability to promote the development of students' engineering design, problem-solving, communication, and group participation skills. Taraban et al. (2007) used Constructivist learning theory to extend previous research by examining the degree to which engineering students' conceptual and problem solving knowledge differed based upon use of instructional software. Theory that considers the role of gender has been employed in studies that utilized categorical data to examine differences in students' experiences in the classroom (Brainard and Carlin, 1998). Theory describing gender differences has also guided studies examining mean score differences between males and females in reported self-confidence, future expectations (Hawks and Spade, 1998), and spatial reasoning (Peters, Chisholm, and Laeng, 1994).

In some cases, researchers seek to examine relationships between different indicators so that they can make predictions. When more complex statistical analyses such as these are conducted, theory is utilized to justify the survey instrument selected (Felder, Felder, and Dietz, 2002; Hunkeler and Sharp, 1997) as well as which items will serve as predictor variables for the dependent variable. In the case of regression analyses, theory guides how independent variables are entered in the regression equation and how the influence of certain variables is controlled for during the analysis. Regression analyses reported in the JEE have used a particular theory to guide the selection of predictor variables such as high school grade point average, SAT score, gender, and race and examine their relation to student retention (French, Immekus, and Oakes, 2005; Moeller-Wong and Eide, 1997; Ohland and Zhang, 2002) and academic success (Bjorklund, Parente, and Sathianathan, 2004; Haines, Wallace, and Cannon, 2001; Lackey et al., 2003). Social Adjustment Theory provides the basis for regression analyses that have been employed to examine the effect of cooperative education experience on student outcomes such as grades and starting salaries (Blair, Millea, and Hammer, 2004; Parsons, Caylor, and Simmons, 2005). In Burtner's (2005) study utilizing Tinto's (1993) Interactionalist Theory, discriminant analysis was used to identify attitudes and perceptions that influence students' decisions to remain in an engineering program.

The use of statistical analysis such as the examples given here is often familiar to engineering researchers, and as such, provides well-established methods for conducting quantitative research. Given the fact that consensus is well-established in quantitative methods, there are many textbooks that provide insight to the utility of statistical analyses and appropriate research design when employing these methods (Hinkle, Wiersma, and Jurs, 2002; Thorne and Giesen, 2002). However, researchers should also consider the issues that are encountered when utilizing quantitative methods within engineering education (Larpkiataworn et al., 2003; Tebbs and Bower, 2003). Quantitative methods are one technique that can be employed when examining a particular issue but other research designs, such as qualitative methods, may offer additional insights.

III. Qualitative Methods

Qualitative research is characterized by the collection and analysis of textual data (surveys, interviews, focus groups, conversational

Theoretical perspective	Post-positivist	Interpretivist (constructivism, social constructionism, hermeneutics, phenomenology)	Critical/ emancipatory	Postmodern/poststructural
View on reality	Single falsifiable reality	Multiple subjective realities	Multiple subjective and political realities	Multiple fragmented realities
Purpose	To find relationships among variables, to define cause-and effect	To describe a situation, experience, or phenomenon	To produce a socio-political critique	To deconstruct existing 'grand narratives'
Methods	Methods and variables defined in advance, hypothesis driven	Methods and approaches emerge and are to be adjusted during study	Methods and approaches designed to capture inequities	Methods and approaches generated during the study
The role of researcher	Researcher is detached	Researcher and participants are partners	Researcher and participants are activists	Researchers and participants have various changing roles
Outcome or research product	Context-free generalizations	Situated descriptions	Critical essays, policy changes	Reconceptualized descriptions of the phenomenon

Table 2. Comparison between theoretical perspectives from Koro-Ljungberg and Douglas (2008).

analysis, observation, ethnographies (Olds et al., 2005)), and by its emphasis on the context within which the study occurs. The research questions that can be answered by qualitative studies are questions such as: What is occurring? Why does something occur? How does one phenomenon affect another? While numbers can be used to summarize qualitative data, answering these questions generally requires rich, contextual descriptions of the data, what is often called "thick" description. Several texts provide descriptions and examples of qualitative research in the social sciences (Creswell, 2007; Denzin and Lincoln, 2005; Merriam, 2002; Patton, 2002), and two recent publications describe the conduct of qualitative research within the context of engineering (Chism, Douglas, and Hilson Jr., 2008; Koro-Ljungberg and Douglas, 2008).

Several authors have pointed out the danger in assuming that qualitative research is easier and less rigorous than quantitative research (Hoaglin et al., 1982; Koro-Ljungberg and Douglas, 2008). As these authors point out, qualitative research is rigorous and involves its own set of data collection and analysis methods that ensure the trustworthiness of the findings. Tonso (1996) specifically contrasts qualitative research with anecdotal information; anecdotal information is collected haphazardly as it becomes available, while qualitative research involves the careful planning of a research design that encompasses all aspects of the study, from research questions to sampling to data collection and analysis. However, engineering educators who have been trained primarily within the quantitative tradition may not be familiar with some of the norms of qualitative research. Important differences exist between the two, with some of the most significant being the assumed nature of truth, the role of theory, sampling, and generalizability. Each of these issues is discussed further.

A. Assumed Nature of Truth

The *theoretical perspective* of a study (not to be confused with a theory describing a phenomenon) describes the approach used to explain reality, and is related to a particular epistemology, or way of understanding reality (Crotty, 2003). Quantitative research is invariably conducted from a post-positivist perspective, which posits the existence of an absolute truth that can never be confirmed, only disconfirmed (the concept of falsifiability). Although not the usual approach, qualitative research in engineering has also been conducted from a post-positivist perspective, often in combination with the collection of quantitative data. These mixed methods studies are described further in Section IV. More commonly, however, qualitative research uses alternate perspectives, which are summarized in Table 2, taken from Koro-Ljungberg and Douglas (2008). For a full discussion of these perspectives see Crotty (2003), and for descriptions in the context of engineering see Koro-Ljungberg and Douglas (2008) and Chism et al. (2008). Examples of how these perspectives are used exist within the engineering education literature. Klukken, Parsons, and Columbus (1997) used a phenomenological interpretive perspective to describe the experience of being a creative engineer; Donath et al. (2005) used the interpretive perspective of social constructionism to examine how knowledge is created within an active learning group; and Tonso (1996) utilized a critical feminist perspective to examine how the discourse in a design class defines gender roles. As with all aspects of the research design, the theoretical perspective one chooses, whether positivist, interpretivist, or critical, is ultimately driven by, and must be consistent with, the research questions of the study.

B. The Role of Theory

The role of theory (a description or explanation of a phenomenon) is very different in qualitative and quantitative research. As stated earlier, in quantitative studies, theory is utilized early in the research design to identify hypotheses and to select appropriate measurement instruments. In contrast, the use of theory in qualitative research comes much later, if at all, as a lens through which the findings can be interpreted. In general, qualitative research takes an inductive approach to data analysis. The data are examined without preconceptions as to existing theory or pre-determined categories, allowing themes or categories to emerge from the data. In order to accomplish this, potential biases of the researcher are examined and made known (in phenomenology, the process of identifying biases and then setting them aside is called "bracketing"). This process allows new insight that would not be possible if an existing theory or concept were imposed on the data. Klukken et al. (1997) used a phenomenological approach to identify the characteristics of creative engineers, the first step towards building a theory of creativity in engineering. Even when theory development is not the goal of a study, one of the strengths of qualitative research is that its open, emerging approach to the conduct of the research allows new phenomena to be identified which would not have been expected (and thus not identified if *a priori* hypotheses or specific measurement instruments drove the research). As one example, McLoughlin (2005) identified a new type of gender bias in her study of women in engineering. Because this type of bias had not been previously identified, a quantitative study of gender bias would not have revealed it. Only by examining the words of the participants and interpreting those words with qualitative analysis techniques was McLoughlin able to identify a new phenomenon. Her results now provide opportunities for additional qualitative and quantitative studies to examine this phenomenon further.

C. Sampling

In comparison to quantitative studies, with their emphasis on large, representative samples, qualitative research focuses on smaller groups in order to examine a particular context in great detail. The goal is not to provide a broad, generalizable description that is representative of most situations, but rather to describe a particular situation in enough depth that the full meaning of what occurs is made apparent. This approach is particularly useful when considering unusual or non-traditional cases. For example, as described by Foor et al. (2007), statistical analysis can bury the voices of underrepresented groups: "Using surveys with large sample sizes, null hypotheses, and the expectation of statistical significance cannot meaningfully describe marginalized individual's experiences." In most cases, several participants are studied to provide sufficient description of a particular situation. Studies in the engineering education literature, for example, have involved interviewing 55 practicing engineers (Trevelyan, 2007), and observation of seven student design teams (Tonso, 2006). However, even a single case can be illustrative (Foor et al., 2007). By reading the rich contextual descriptions afforded by focusing on only a few cases, engineering educators can recognize practices that occur within their own schools.

D. Generalizability and Transferability

The concept of *generalizability* in quantitative studies is replaced by the term *transferability* in qualitative studies. Quantitative research is focused on generalizing to the larger population independent of context, and thus there is a heavy emphasis in the research design on random sampling and statistical significance. In contrast, qualitative research seeks to generalize through thick description of a specific context, allowing the reader to make connections between the study and his or her own situation. In short, quantitative research places the burden of demonstrating generalizability on the researcher, while qualitative research places the burden of identifying appropriate contexts for transferability on the reader. Just as rigorous statistical analysis is essential in quantitative research to ensure reliability and generalizability of the results, so too is rich description of the context and experiences of the participants essential in qualitative research to ensure trustworthiness (see section V) of the findings and transfer to other contexts. Foor et al's (2007) study illustrates the difference between generalizability and transferability. From a quantitative perspective, the use of a single case does not provide any means for generalizing, as there is no way of knowing if that single case is typical. From a qualitative perspective, however, the thick description of that single case allows readers to identify elements that can be transferred to their own situations.

IV. Mixed Methods

Mixed methods has been described as the "third methodological movement" (following quantitatively and qualitatively oriented approaches) (Teddlie and Tashakkori, 2003). Many descriptions of mixed methods place it in the context of more established traditions, criticizing some for being too divisive by artificially emphasizing differences, specifically the "incompatibility thesis" (Howe, 1988) that quantitative and qualitative paradigms "cannot and should not be mixed" (Johnson and Onwuegbuzie, 2004, p. 14). Instead, they are proponents of pragmatism, in which "[w]hat is most fundamental is the research question—research methods should follow research questions in a way that offers the best chance to obtain useful answers" (Johnson and Onwuegbuzie, 2004, pp. 16–17).

Creswell et al. define a mixed methods study as follows:

> A mixed methods study involves the collection or analysis of both quantitative and/or qualitative data in a single study in

Design Type	Timing of quan and qual phases	Relative weighting of quan and qual components	Mixing – when quan and qual phases are integrated	Notation
Triangulation	Concurrent	Equal	During interpretation or analysis	QUAN + QUAL
Embedded	Concurrent or Sequential	Unequal	One is embedded within the other	QUAN(qual) *or* QUAL(quan)
Explanatory	Sequential, quan then qual	Usually quan is given priority	Phase 1 informs phase 2	QUAN -> qual
Exploratory	Sequential, qual then quan	Usually qual is given priority	Phase 1 informs phase 2	QUAL -> quan

Table 3. Adapted from Creswell and Plano Clark (2007). Uses abbreviations and notation from Morse (2003).

which the data are collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research (Creswell et al., 2003, p. 212).

This is distinguished from multimethod approaches (D. Campbell and Fiske, 1959), which may include multiple quantitative or qualitative studies but not necessarily both. Based on decisions regarding the sequence of data collection, relative priority, and stage at which integration of quantitative and qualitative components takes place, Creswell et al. identify four basic mixed methods designs (Creswell and Plano Clark, 2007). These are summarized in Table 3, and this section is organized around these basic designs. Only one of our JEE examples self-identifies with one of these categories; the others we use to illustrate examples and aspects of each design.

A. Triangulation Designs

The term *triangulation* in research was first used by Denzin (1978) to describe bringing together complementary methods or data sources to offset weaknesses in each. Data are collected concurrently in one phase, and interpretation involves comparing the results of each to best understand the research question (Creswell and Plano Clark, 2007; Morse, 1991).

One engineering education example is a survey with approximately equal numbers of quantitative and qualitative questions. Sageev and Romanowski (2001) collected quantitative data about time spent on communication tasks and qualitative data on the impact of communication coursework on alumni participants' careers. The results section is organized by survey question, but the authors allow responses to "spill over" from one section to the next to illustrate important connections. Additionally, they included an extensive (over one page) conclusions section addressing the responses and implications for technical communication faculty through integration of the findings.

Another recent example actually used mixed methods terminology to describe the overall project design:

> The [Academic Pathways Study] uses a concurrent triangulation mixed-methods design, in which both qualitative and quantitative methods are employed to collect and analyze data. The integration of results occurs during the interpretation phase (Creswell et al., 2003), enabling researchers to address a broad range of research questions toward discerning complex phenomena like student learning and development (Johnson and Onwuegbuzie, 2004) (Kilgore et al., 2007, p. 323).

The article itself describes analysis of an open-ended design task, with a thick description of the categories and their relationships, as well as quantifying frequencies of various behaviors and strategies employed by their participants (Kilgore et al., 2007).

B. Embedded Designs

Embedded designs are not distinguished by the concurrent or sequential nature of data collection (either is allowed). Rather, one type of data takes a supplemental role to the other. Creswell and Plano Clark offer the criterion that a study is embedded if the secondary data are not useful or meaningful without the primary study (2007).

Following this criterion, we can identify several engineering education articles with very limited secondary components as embedded designs. As might be expected, engineering education studies exhibited a strong preference for assigning priority to quantitative data and analysis. For example, it was quite common to develop an extensive control group or pre-test/post-test quantitative design to assess learning and augment it with one or a few open-ended questions to students about their attitude toward the intervention (Campbell et al., 2002; Lee, Castella, and Middleton, 1997; Morell et al., 2001; Raju and Sankar, 1999; Weisner and Lan, 2004). The extent to which authors presented the qualitative results ranges from referencing another publication (Brown, Morning, and

Watkins, 2005) to nearly a full page (Morell et al., 2001; Raju and Sankar, 1999). Most included one or two paragraphs discussing student attitudes and intervention logistics (Campbell et al., 2002; Lee et al., 1997; Weisner and Lan, 2004).

C. Explanatory Designs

Explanatory mixed methods designs are characterized by an initial and extensive quantitative phase built upon by a subsequent qualitative phase. Usually, the qualitative results serve to explain the quantitative results. Integration occurs between phases, as the quantitative results often inform the questions or sampling in the second phase (Creswell and Plano Clark, 2007; Creswell et al., 2003).

A few JEE articles provide hints that authors pursued a mixed methods approach (likely explanatory) to provide complementary data:

> As a complement to the statistical FCQ analysis, two mid-semester classroom interviews were conducted (Gall et al., 2003, p. 340).

> Finally, open-ended comments were analyzed as a qualitative component to shed light on numerical results (Hackett and Martin, 1998, p. 87).

> Since we found no statistically significant ACT/SAT or GPA data that could explain the dramatic increases in the graduation rates of Connections students, we administered a follow-up survey in the fall of 2000 asking participants in the program to reflect about their experiences (Olds and Miller, 2004, p. 30).

In a few cases, authors were explicit in how the first phase informed the second:

> This study employed both quantitative and qualitative analysis methods. Quantitative data came from statistical analyses of hundreds of megabytes of access log files stored on the web server. ... Qualitative data came from user interviews. ... Empirical findings from the quantitative analysis helped to form some of the initial questions used during the interviews (Liang, Bell, and Leifer, 2001, p. 520).

Here, quantitative results provided ideas for qualitative interview questions. In another example, the quantitative phase identified interview participants (who had the highest number of entries in the database), as well as providing findings for participants to react to in interviews:

> Readers will see that the publication analysis alone raises many questions with respect to the motivation of the publication authors. To provide additional context for understanding the impact of the coalitions, selected coalition personnel reflected on the quantitative analysis results and described their perceptions of the work at the time and in light of recent calls for rigor. For the interview component of the study, the preliminary [quantitative] results of the publication analysis were shared with coalition leaders and first authors of the highest number of publications (Borrego, 2007b, p. 9).

In both cases, we can also argue based on the publication space dedicated to each type of results that the authors assigned priority to the quantitative phase.

D. Exploratory Designs

Exploratory designs begin with a primary qualitative phase, then the findings are validated or otherwise informed by quantitative results. This approach is usually employed to develop a standardized (quantitative) instrument in a relatively unstudied area. The qualitative phase identifies important factors, while the quantitative phase applies them to a larger and/or more diverse sample (Creswell and Plano Clark, 2007).

Baker et al. describe how they used an initial interview pilot study to develop survey questions (which were also mixed):

> Guided by a modified Glaser and Strauss approach (1967)[grounded theory, a qualitative tradition], the [interview] tapes were analysed [sic] in order to isolate either the relevant themes of data units which were then sorted into conceptual categories. These categories formed the basis of the survey questionnaire that we used in the second phase of the study (Baker, Tancred, and Whitesides, 2002, p. 46).

E. "Quantitizing" Qualitative Data

Another very important trend in engineering education research involves transforming qualitative behaviors or work products into quantitative data for statistical analysis. Teddlie and Tashakkori (2003) credit Miles and Huberman (1994) for the term and concept of "quantitizing" to convert qualitative data into numerical codes. Sandelowski (2003) describes this process in greater detail, as well as its less common analog of "qualitizing" quantitative data.

We found many examples of this in the engineering education literature. All involve applying a framework of categorization or a scoring rubric to qualitative data such as publications, open-ended responses, or concept maps. Most simply reported frequencies and percentages of themes or categories of responses (Compton, 1995; Dabbagh and Menasce, 2006; Gall et al., 2003; Napp, 2004; Olds and Miller, 2004; Whitin and Sheppard, 2004). One also reported descriptive statistics (i.e., means) (Vanderburg and Khan, 1994), while another reported validity statistics for the rubric (Walker and King, 2003). Only one publication went as far as calculating statistically significant differences between rubric scores of various treatment groups (Rayne et al., 2006). Several of these included examples of quotes, responses, and other qualitative data, but generally did not provide enough qualitative data to be organized around categories. An exception is Pavelich and Moore, who assigned a Perry development level to students based on interviews, and reported descriptive statistics, but then also included several quotes to describe how students were characterized as well as evidence of transitions from one level to another (Pavelich and Moore, 1996).

It is interesting to consider whether these studies should be evaluated as quantitative, qualitative, or mixed methods. In the absence of labeling by the authors themselves, we can speculate that these hold up to quantitative criteria and most mixed methods criteria (although whether they actually include a qualitative

Quantitative Research Criteria	Qualitative Research Criteria
Validity: project and instruments measure what is intended to be measured	Credibility: establishing that the results are credible or believable
Generalizability: results are applicable to other settings, achieved through representative sampling	Transferability: applicability of research findings to other settings, achieved through thick description
Reliability: findings are replicable or repeatable	Dependability: researchers account for the ever-changing context within which the research occurs
Objectivity: researcher limits bias and interaction with participants	Reflexivity: researchers examine their own biases and make them known

Table 4. Quantitative and qualitative research criteria, from Lincoln and Guba, 1985; Tashakkori and Teddlie, 1998; and Chism et al., 2008.

component to qualify them as mixed is questionable), but that are generally not consistent with qualitative criteria. Evaluation criteria are described in detail in the following section.

V. Evaluation Criteria for Quantitative, Qualitative, and Mixed Methods Research

Evaluation of quantitative, qualitative, and mixed methods research has similar aims, although the details differ. In all cases, the goal is to establish that the results provide convincing evidence sufficient to answer the research questions. A number of factors go into establishing the quality of quantitative and qualitative research, some of which are listed in Table 4.

In quantitative research, these criteria are met through objectivity, reliability, and validity of the instrument (e.g., questionnaire), and generalizability of the findings. Conclusions of studies are furthered by reporting the *validity*, or whether the instrument used actually measures the variables or theory it claims. *Reliability* of scores associated with the instruments employed, or whether the same result is derived on repeated trials, is also an important consideration. Moskal et al. (2002) illustrate how these concepts can be used to improve assessment efforts in engineering education, and Blumner et al. (1997) discuss how reliability and validity have been established on a locally developed instrument to measure study habits among engineering students. Fewer articles have discussed Chronbach-alpha scores (Cronbach, 1951) relative to the construction of classroom tests (Allen et al., 2008).

Comparable criteria exist for qualitative research, although the terms used and the focus of how these criteria are met are different (see Table 4). The term *trustworthiness* is often used to describe the extent to which a study meets these criteria. Some of the important ways in which trustworthiness can be established are a clear statement of the theoretical perspective of the study, member checking (asking participants to review the research findings), triangulation (use of multiple data sources), thick description, peer debriefing (asking other researchers not directly involved in the research to review the findings), creating an audit trail (a clear link between the raw data and the findings), and a statement of researcher subjectivity.

Regarding mixed methods criteria, Creswell and Plano Clark (2007) first briefly review quantitative and qualitative criteria, then list four criteria for evaluating mixed methods studies:

1. Whether the study is indeed mixed methods (collecting, analyzing and mixing quantitative and qualitative approaches). The most inclusive definitions allow for representation of quantitative and qualitative perspectives in at least one of: data collection, data analysis, or theoretical perspective (III.A).
2. Detail and consistency in describing the design, theoretical perspective, need for both quantitative and qualitative approaches, and how the two components are mixed. Detailed quantitative and qualitative procedures should be described, as well as sequential or concurrent data collection and analysis. Interpretations should be defended.
3. Inclusion of advanced mixed methods features, including (a) specified type of design, (b) a visual diagram of the procedures, (c) mixed methods purpose statement, research question and data analysis, and (d) citation of mixed methods studies and methodological articles.
4. Sensitivity to the challenges of using the mixed methods design. Authors should acknowledge the challenges and how they are addressed. Specific challenges include threats to validity such as sampling, sample sizes, and integration phases.

In light of these criteria, it is clear that although there are several engineering education studies utilizing quantitative and qualitative data, we are not as open as we should be about describing the methods and related challenges. Similarly, we might argue that authors in the emerging research field of engineering education should also explicitly address quantitative or qualitative research evaluation criteria (as appropriate) as a cue to readers and reviewers. In the following section, we provide a summary of empirical data from conference discussions to further support our arguments that methods are not being discussed as openly as they should be in engineering education.

VI. Empirical Results

In this section we present empirical results from observations at a prestigious international engineering education research conference. The conference and analysis methods are described elsewhere (Borrego, Froyd, and Knight, 2007; Jesiek, Newswander, and Borrego, 2009). The format of this conference was unique because each paper was read by other participants assigned to the group and discussed for 45 minutes to an hour rather than being presented. As expected, methods entered the conversation frequently and in a variety of ways. Many participants appeared more comfortable with quantitative approaches, either by virtue of their training, or based on expectations of reviewers' preferences. Therefore, we focus the first portion of our findings on ways that qualitative methods entered the conversation.

A. Discussions of Qualitative Methods at the Conference

When qualitative methods were presented in the paper sessions, it was often in the later and deeper discussions of specific papers. Five-minute summaries opening each paper discussion generally described quantitative results (if any). Later, when discussion shifted to conjecture as to why certain phenomena were observed, qualitative results were described. As other participants mused about underlying explanations, authors described emerging results not included in their conference papers to flesh out description of learning or motivation mechanisms. It appears these authors were more comfortable in face-to-face discussions of qualitative methods (rather than blind review), perhaps because initial conversation was going well. It should be noted that many other authors were able to describe the purposes of their qualitative work comfortably.

One of the very few extended discussions about qualitative methods focused on ethnography. Using question and answer format, participants learned about ethnography perspectives, including its relationship to traditional views of validity and reliability. It is interesting to note that the facilitator did not necessarily view this as a useful discussion and directed the author toward presenting results, requesting, "please talk about what you found." In various sessions on the second day, several presenters refocused on methods discussions in their papers for feedback, one stating "So [I] wanted to focus this session more on method than results" or were in general more open about research design weaknesses for which they wanted advice. In other words, an initial implicit assumption of participants was that the paper discussions should focus on results, but upon reflection, authors presenting on the second day decided that they would benefit more from discussions of methods. This attests to the importance and interest in open discussion of methods in engineering education.

B. Applying a Quantitative Model in Critiquing Research

Perhaps the most interesting finding was that although participants lamented the low representation of qualitative methods, many of these same participants enacted a quantitative model in critiquing others' research during the paper sessions. Though the conference papers represented a range of quantitative approaches, the discussion at the conference seemed more restricted to a single model: classroom-based experiments comparing a control group to a treatment group. More often than not, the first questions asked of a presenting author focused on control groups, representative sampling, and triangulation of results with course grades.

1. Control Groups: Participants wanted to know whether student gender and major were represented in the samples studied, or whether any differences were detected between these groups (e.g., "What was the gender ratio of the students in your study?") If an author went into too much detail about the intervention itself and neglected to describe the experimental design, participants asked about control groups, for example, "Are you going to do a comparison with traditional problems [given to students]?" In one exchange, there was even evidence that participants perceived a setting to be unworthy of study if a control group is not available. Specifically, once a course becomes required for all students, there is no control group. "It is compulsory for all, so there is no comparison available," was spoken by one participant with a dejected tone and bowed head.

There was mention of a few alternatives to an experimental design with a control group. In at least one case, the author employed historical controls by administering a few instruments before the intervention was implemented. A third type of experimental or assessment design discussed was pre-test/treatment/post-test. However, in at least one case, participants perceived this to be inferior to a control group design, as is also reflected in the literature (Leedy, 1997; U.S. Department of Education, 2007). Even Scientific Research in Education (Shavelson and Towne, 2002), cited as criteria for "rigorous research in engineering education" (Borrego, 2007a), has been criticized for valuing quantitative approaches over qualitative methodologies (St. Pierre, 2002). One participant at this meeting stated, "So you didn't have a control group. That makes it questionable about whether you can say there was a difference from pre and post as a result of the intervention." Another participant present during this conversation attempted to describe the merit of this alternative design:

> I have been doing this for a while, and I learned when I was working on my Ph.D. in [research area] that there is a huge difference between proving that your intervention is adequate and wanting to prove it is better. If you want to prove that it's adequate, which is what I think [this author] wants to do, [then pre-test/post-test is fine]. I suspect he wants to show that it's better, which would require a control group, but he is still able to show that it works [without a control].

2. Statistical Significance: As suggested in the quotation above, the ultimate goal of a treatment-control design is to show that the treatment is superior through a statistically significant difference. It should be noted that while this approach is common in engineering research, it may establish an impossible burden of proof in engineering education, as students cannot be controlled as carefully as "I-beams or fruit flies" (Wankat et al., 2002). In fact, many conference discussions focused on alternative interpretations and confounds. Participants asked, "Can you rightly compare these groups?" and authors apologized with responses like, "I admit that the sample size ought to be expanded to 200–300 to be more representative," and "Because the sample size was small, the numbers are not statistically significant."

(It should be noted that authors were not observed to discuss calculating the power (Cohen, 1988), which would indicate whether a larger sample size is likely to produce the desired statistically significant difference.) Surprisingly, considering the focus on quantitative studies, there were also a few instances in which authors presented numerical data and tables but did not run statistical analyses to show whether highlighted differences were significant or not. (Other conference participants suggested running these analyses.) It should also be noted that other participants, particularly those in a measurement group, were notably more comfortable discussing various statistical tests.

Even though authors were striving for high sample size, some were reluctant to emphasize a statistically significant difference even when they found one. In one particular case, it was evident that most participants in the discussion felt the intervention had established its effectiveness by virtue of a doubled pass rate, but the author was hesitant to claim victory before a carefully controlled experiment could be executed: "I know. I'm being very cautious. Next round will be more in-depth. Next year we'll hopefully have two groups of students, randomly assigned." While it is important to skeptically evaluate and replicate results in educational studies (Shavelson and Towne, 2002), controlled classroom experiments are not the only means of replication. For example, many variations of pre- and post-testing designs, combined with control group designs can establish a finding across diverse settings with various constraints on experimental design. The few times these were mentioned by participants, they were described as less desirable than controlled experiments and often dismissed.

3. Validity, Reliability, and Triangulation: In most of the groups, validity, reliability, and triangulation were discussed very little, at least explicitly. One exception was triangulating research results with course grades, e.g., "Did you compare performance based on something like grades? You saw higher motivation. Is that correlated with performance like grades?" This reliance on grades to triangulate engineering education research findings is particularly problematic when faculty researchers don't find the significant difference they were looking for. One group of participants bemoaned, "We're all kind of stuck because the correlations [between grades and other data] aren't there."

David Labaree (2003) writes about this phenomenon, in which new educational researchers with extensive classroom experience approach educational research as proving that an intervention works, rather than being skeptical or objective as their experimental design requires. However, it is also a possibility that these interventions do indeed work, and that other constructs or subjectivities reflected in course grades are overshadowing actual increases in learning. For example, the reliability and validity of the tests and homework assignments are usually not established (Allen et al., 2008). In this case, it is important for engineering education classroom researchers to consider other sources for triangulation, such as scores on specific assignments or test questions, concept inventories or focus groups that complement the principal measurement procedure, and retention or passing rates in subsequent courses.

C. Perceived Implications for Publishing in Research Journals

1. "Enough to Publish:" While the classroom-experimental approach to engineering education research complete with control groups seemed a well-suited one to many participants, this focus was also a source of anxiety with respect to publishing results. Throughout the conference, there was much discussion of what constitutes "enough" to publish in top journals like JEE. To followers of the classroom-experimental model, "enough to publish" directly translated to high *n*, multi-year, multi-institution studies. Classroom research which had not yet expanded was described by participants several times as action research. *Action research* is a type of inquiry in which instructors make documented, systematic improvements in their classrooms as a means of applying new knowledge as it is generated (Feldman and Minstrell, 2000). While this approach allows findings to be quickly applied, a common criticism is that it lacks the rigor traditionally applied in experiments to more systematically or objectively establish the effectiveness of the intervention (Gentile, 1994). One participant asserted:

> Action research is not enough to get into JEE now. That's where we have the dilemma. We need people within the content area, but the JEE is on a level that's cross-institutional, cross-national studies. Just one case is not enough.

Particularly for traditional engineering faculty who are often not directly rewarded for their engineering education research, repeating an intervention semester after semester is simply too much of a time investment for one article. Statements like, "We don't have the luxury of people who are full-time researchers," were made a few times, indicative of perceptions that such high publication standards exclude practitioners from engineering education research.

2. Perceptions of Review Criteria: Participants frequently expressed the perception that peer review in engineering education is unintentionally biased toward quantitative studies. One example was,

> If we devise a questionnaire, if we make a statistical analysis and submit to JEE, probably they will accept it. Same action research, just analyzed differently… I could have used questionnaires or surveys, statistical analysis, this would qualify as quantitative analysis, but this could miss things.

The explanation offered for this perceived bias was the limited, traditional training and exposure of reviewers. Since peer reviewers are members of the community, conference presentations and discussions are an important means of exposure to different methodological approaches. We observed that groups which were most balanced between quantitative and qualitative papers were most open in exploring methods and questioning customary approaches. The two examples we can cite of transformative participant experiences were improved quantitative designs openly discussed by methodologically diverse groups. In one case, a paper initially framed as naturalistic (qualitative) was reframed as a well-controlled assessment of improved learning resulting from an intervention. In the other case, a participant limited by availability of validated instruments was encouraged to, "jump off the deep end and start validating your own measure that addresses this issue." These important examples illustrate that open dialog across methods orientations does lead to better research. As a comparison case, one group consisting of entirely quantitative papers had a much more focused discussion which resulted in valuable but specific feedback unlikely to result in methodological breakthroughs. Since there were no entirely qualitative groups to study, we cannot speculate on the dynamics or potential outcomes; however, our analysis points to diversity of viewpoints as the critical feature of inclusive, generative, constructive discussions at this particular conference.

VII. Discussion and Conclusion

There are several plausible explanations for why engineering education researchers appear to strongly prefer quantitative methods. Creswell (2002) lists three criteria for selecting from among quantitative, qualitative and mixed methods approaches: (1) the research problem, (2) the personal experiences of the researcher, and (3) the audience. The majority of engineering education researchers is engineering faculty members who were trained within the post-positivist perspective. As a result, the personal experiences of the researchers would tend to favor quantitative experimental approaches. Similarly, the audience for much of engineering education research is also engineering faculty, who have more experience interpreting quantitative results. However, we take the view that the approach used by a given study should be driven by the research questions of that study. Given the wide variety of issues still to be explored within engineering education (Steering Committee of the National Engineering Education Research Colloquies, 2006), we would expect that all of these approaches would be represented. While examples of all three approaches do exist within the pages of JEE, the empirical results for an engineering education conference described here show that they are not being used equally. There appears to be a trend towards the use of quantitative methods, and even within the quantitative area only certain approaches are deemed to be worthwhile. These results provide a further example of engineering education as a low consensus field, which may be caused by the lack of training of researchers in alternate methods, or perceived requirements for publication. We encourage readers to further investigate alternate research methods by accessing some of our sources and collaborating across education/social science and engineering disciplinary boundaries with those who have spent more time applying these research methods in educational settings. In addition to seeking expertise in the various methods, educators should consider the criteria outlined in this article that would frame a study employing a quantitative, qualitative or mixed method approach.

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