AC 2010-526: A CONTENT ANALYSIS OF THE USE OF MIXED METHODS STUDIES IN ENGINEERING EDUCATION

Erin Crede, Virginia Tech

Maura Borrego, Virginia Tech

A Content Analysis of the Use of Mixed Methods Studies in Engineering Education

Abstract

The complex phenomena studied by engineering education researchers frequently require the complementary use of qualitative and quantitative approaches. In light of these needs, many researchers are utilizing mixed methods designs to take advantage of the relative strengths and individual merits of both quantitative and qualitative approaches. This article presents a brief overview of mixed methods research, and provides a content analysis how it is being used and reported in engineering education journals. Using a mixed methods approach, the authors first reviewed the application of mixed methods designs from fifteen articles from 2005 to the present against an existing set of criteria. Each article was then re-examined to explore how the authors address the integration of the quantitative and qualitative data. Finally consideration is given to how the authors of studies in engineering education interpret and report the meaning and use of mixed methods designs. The paper concludes with recommendations for engineering education researchers considering the use of a mixed methods approach.

I. Introduction

Despite the publication of several methodological texts and papers written to address the proper use of a mixed methods research design [1-4], there is still a lack of consensus on how to integrate multiple types of data and discuss the results. A content analysis of social science articles published by Bryman [5] found that researchers would state the use of both qualitative and quantitative research methods but only report the results of one data type. Another content analysis of evaluation research articles found that 44% of the articles did not integrate the quantitative and qualitative data [4]. Integration of the qualitative and quantitative data is a central tenet of a mixed methods research design. Mixing, defined by Creswell[2] involves the "explicit relating of two data sets" and may occur in a number of ways including, merging, connecting or embedding. Instrumental to this definition is the notion of making the integration of two data sets *explicit,* indicating that where, how and why this happens should be clear to the audience.

Issues of data integration aside, a standard for the presentation of mixed methods research is equally unclear. Sandelowski [6] points out that methods alone do not define the nature of inquiry, but the execution and representation of the methods that signal the key differences. She goes on to discuss the lack of uniformity in presenting qualitative versus quantitative research, highlighting the question of whether data has even been mixed at all, or how the mixing occurred. Bryman [7] suggests that more attention be paid to the writing of mixed methods articles, going a step further to suggest that the "fundamental issue of the degree to which mixed methods researchers genuinely integrate their findings has not been addressed (p.8)." A study by engineering education researchers in 2009 discussed the ways that engineering education researchers could utilize educational research methods [8]. Their results indicate that engineering education researchers could address their methods and evaluation criteria for their methods more explicitly. If engineering educations researchers are to maximize the impact of the data they collect, we argue that quantitative and qualitative data must be *both integrated and reported* in a meaningful way.

The purpose of this concurrent triangulation mixed methods content analysis is to examine the application of a mixed methods approach in engineering education journal articles with the aim of generating a set of guidelines for conducting and reporting mixed methods designs in engineering education.

1. How do the characteristics of engineering education research articles address the following criteria; collection and analysis of both qualitative and quantitative data, timing, and priority?
2. How do the authors address and justify the issue of integrating qualitative and quantitative data?
3. How do engineering education researchers interpret and report the meaning and use of mixed methods research designs?

In order to address these research questions, we first begin with a review of the current mixed methods literature, followed by the methods for qualitative and quantitative data collection and analysis. We then present the results of both the quantitative and qualitative analysis, and the integration of both data sets in the discussion section. Finally we conclude with recommendations for researchers publishing in the field of engineering education and suggestions for future research.

II. Mixed Methods Research

Mixed methods have been described as a "third methodological movement" [3] following quantitative and qualitative approaches. Mixed methods researchers follow a pragmatic approach, rather than subscribing to a qualitative or quantitative paradigm [9]. Pragmatism, in short, proposes that the research questions should drive the research design and methods in a way that offers the most useful answers. While there are multiple definitions for mixed methods both as a design and as a methodology, the definition chosen for this analysis is that of Creswell et al.

> A mixed methods study involves the collection or analysis of both quantitative and/or qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority, and involve the integration at one or more stages in the process of research [10].

This definition is not all inclusive but we would like to emphasize the idea that a mixed methods approach involves the *collection, analysis and integration of both qualitative and quantitative data*. The definition also presents the concept of assigning both a priority and implementation (or timing) to the data collection and analysis. In light of this definition we review some key mixed methods terminology.

A. Mixed Methods Terminology

In addition to the research question and study purpose, researchers interested in conducting a mixed methods study should consider the following issues: timing, priority, and mixing. These

three elements can be thought of as decisions, with the choices made helping to define the overall research design [2].

1. Timing

One of the first key elements in a mixed methods study is deciding what the timing of the qualitative and quantitative data will be. Timing may also be referred to as implementation, or sequence of the components within the study [4]. While timing may often refer to the data collection it is often more important to consider the timing relative to when the qualitative and quantitative data are utilized [2]. Morse [11] proposed two ways for timing can be classified, either as concurrent or sequential. Concurrent timing is defined by qualitative and quantitative data collection and analysis occurring simultaneously during a single study phase. This is contrary to sequential timing, where a researcher implements each method in a distinct phase, using one type of data before the other type [2].

2. Priority

A second decision requiring careful consideration is the weighting, or emphasis, of each data type relative to the other. This could be described as determining what priority [12] is given to qualitative and quantitative research as it occurs throughout the study. This might include the way it is introduced, the literature, research questions or purpose statement as well as the data collection, analysis and interpretation [10]. Priority can either be given to one method over the other, or equally for both methods. Creswell (2007) provides more details on priority and offers practical considerations for equal or unequal emphasis as well as some guidelines for determining a studies priority based on published work. Arguably the determination of priority will differ amongst researchers and may be difficult to determine in a published work without sufficient documentation.

3. Mixing

The third, and most often overlooked, consideration for a mixed methods study is how the data will be mixed, or integrated. Mixing is the explicit relating of two data sets [2], meaning that a study containing both qualitative and quantitative data without explicitly mixing the data is may be more accurately described as a multi method study. Creswell (2007) offers three ways that data can be mixed, including: merging the data, embedding the data at the design level, and connecting from data analysis to data collection.

Merging data sets implies taking the two separate data sets individually and explicitly integrates into a new data set. Data can be merged at the interpretation stage, by analyzing them separately and then merging the two sets of results together for interpretation. Data can also be merged at the analysis stage, by transforming one data type into the other (for example qualitizing or quantitizing, see separate discussion below). Mixing at the design level may occur when the researcher chooses to embed one type of data within another type, for example qualitative data may be embedded within a larger quantitative design, and the timing may be sequential or concurrent. Finally the data may be connected, which occurs when analysis of one type of data

leads to the need for the other type of data. The connection may occur in multiple ways, such as participant selection and instrument development and validation among others.

4. Quantitizing and Qualitizing

One of the three ways that Creswell (2007) posits that data can be mixed is to merge the data at the analysis stage by quantitizing or qualitizing one data set. The term *quantitizing* has been used to describe the conversion of coded qualitative data into quantitative data, while *qualitizing* converts quantitative into qualitative data [3, 13]. Quantizing may be more thoroughly defined as the process of assigning numerical values to data conceived as not numerical [14]. Several strategies exist for quantitizing qualitative data to create a single data set. One of the more common strategies counts the number of times a code appears. Other approaches enumerate the frequency of themes, percentage of theses in a given category, or who selects specific themes [3]. Still other researchers may quantize the presence or absence of codes for each participant [13].

Qualitizing data is a process by which quantitative data are transformed into data that can be analyzed qualitatively [15]. Qualitized data is often displayed graphically, an excellent example of which is discussed in Onwuegbuzie and Dickinson [16] for comparing qualitative themes to qualitized quantitative profiles. Another example of qualitizing entails qualitative profiling by creating verbal portraits or typologies of participants according to their scores on two or more instruments [17]. Along with other data collection and analysis techniques, both qualitizing and quantitizing can be used to extract more information from the original data set, or to confirm interpretations of it. These methods, also present one way to address the issue of integrating two data sets.

III. Methods

A. Research Design

A *concurrent triangulation* design [18] was chosen for this study as shown in Figure 1. This figure shows the separate analysis stages for both the qualitative and quantitative data, and a clear indication of where and when the data were integrated. Although the timing of this design is labeled concurrent, the data were actually analyzed in a sequential manner with quantitative followed by qualitative. Each article was evaluated against the quantitative criteria and categorized into tables. Following this analysis, each article was explored for the qualitative themes. Both analyses were completed in immediate succession and with only one researcher completing the analysis we feel this is still an appropriate definition since neither data type was used to inform or bias the analysis of the other data type. This figure may also serve to guide the reader through the study design and the layout of this report.

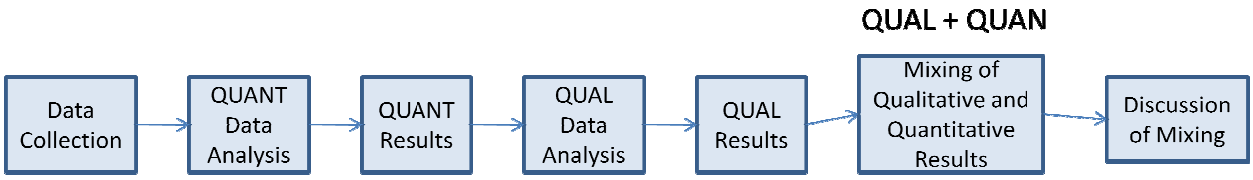

Figure 1. Diagram of Research Design (adapted from Creswell (2007))

Data were collected from journals publishing engineering education research, and the same data set was used for both phases of the study. The quantitative evaluation of each article was accomplished first, with articles selected based on a subset of an existing set of mixed methods criteria discussed in Creswell (2007). Following the quantitative evaluation was a qualitative exploration of the ways the authors addressed the issue of data integration, or mixing. During the qualitative phase we examined the same sample to explore the themes that emerge regarding the issue of integrating the data. The sample chosen for this study included 16 journal articles published in seven journals from 2005 to present. Table 1 summarizes how the data were collected from the sample population for the two major phases of the project.

Table 1. Research Design: Questions, Data Collection and Analysis

Research Question	**Phenomenon of Interest**	**Data Collection**	**Data Analysis**
RQ 1 (quantitative)	How do current articles published by engineering education researchers meet the criteria for mixed methods research?	Articles were identified based on the use of qualitative and quantitative data or self described mixed methods studies	Elements from each article were evaluated based on four criteria: collection and analysis of qualitative and quantitative data, timing, and priority
RQ 2 (qualitative)	How do the authors address the issue of mixing (or integrating) the qualitative and quantitative data?	Articles were identified based on the use of qualitative and quantitative data or self described mixed methods studies	Thematic coding of the individual articles using a constant comparative method
RQ 3 (mixing)	How do engineering education researchers interpret and report the meaning and use of mixed methods research designs?	Specific combinations of themes and evaluation criteria were extracted from the qualitative and quantitative analysis	Data were integrated by means of mixing tables as shown in the discussion section

B. Data Collection: Selection of the Sample

Selecting the sample for this study involved reviewing articles published in several journals from 2005 to the present. Initially three journals were selected: *The Journal of Engineering Education, Advances in Engineering Education, and the International Journal of Engineering Education.* These journals were selected for their engineering education specific audience and full article content availability online. Selection criteria for the articles included the classification of the article as "mixed methods" by the author(s) or by the specific mention of qualitative and quantitative data collection in the abstract. Following an initial review of the articles in each publication, the sample (nine articles) was insufficient to fully characterize mixed methods research in the field. In light of this an internet search was conducted for additional engineering education research articles featuring a mixed methods design. Only articles with a complete version available were selected for review (several additional articles were located but full manuscripts could not be obtained). This search resulted in a total of 16 articles from seven journals published from 2005 to the present. A summary of the 12 articles defined by the authors as mixed methods are given in Table 2, while the additional four articles citing both qualitative and quantitative data collection in the abstract are listed in Table 3.

Table 2. Reviewed Articles Listed as Mixed Methods.

Paper Number	Paper Title	Journal	Date	Quantitative Data Collected	Qualitative Data Collected
1	Assignment submission, student behaviour and experience	Engineering Education: Journal of the Higher Education Academy	2009	Submission records	interviews and email survey
2	Considering Context: A Study of First Year Engineering Students	Journal of Engineering Education	October 2007	experience and engagement survey	student written responses
3	An Engineering Major Does Not (Necessarily) and Engineer Make: Career Decision Making Among Undergraduate Engineering Majors	Journal of Engineering Education	July 2009	national survey	student interviews
4	The Relations of Ethnicity to Female Engineering Students' Educational Experiences and College and Career Plans in an Ethnically Diverse Learning Environment	Journal of Engineering Education	October 2008	web based survey	individual student interviews
5	Characterizing Design Learning: A Mixed Methods Study of Engineering Designers' Use of Language	Journal of Engineering Education	July 2008	closed-ended survey questions	design scenarios and lab problems
6	K-12 Outreach: Identifying the Broader Impacts of Four Outreach Projects	Journal of Engineering Education	July 2007	pre-post test, existing test data	focus groups and questionnaires
7	Student Perceptions of Engineering Entrepreneurship: An Exploratory Study	Journal of Engineering Education	July 2006	national survey	student justification
8	Developing and Assessing Students' Entrepreneurial Skills and Mind-Set	Journal of Engineering Education	April 2005	existing national instruments	focus groups
9	The Impact of Faculty Gender on Students' Ratings of Instruction	International Journal of Learning	2008	teacher ratings	interviews and student comments
10	Gender Ratios in High School Science Departments: The Effect of Multiple Dimensions of Students' Science Identities	Journal of Research in Science Teaching	2007	longitudinal survey data	interviews
11	Impact Assessment of a Microprocessor Animation on Student Learning and Motivation in Computer Engineering	IEEE Transactions on Education	May 2007	closed-ended survey questions	open-ended survey questions
12	Delivering Core Engineering Concepts to Secondary Level Students	Journal of Technology Education	Fall 2008	pre-post test	focus groups

Table 3. Reviewed Articles Listing both Qualitative and Quantitative Methods

Paper Number	Paper Title	Journal	Date Published	Quantitative Data Collected	Qualitative Data Collected
13	Future Cities Engineering: Early Engineering Interventions in the Middle Grades	Advances in Engineering Education	Summer 2008	Attitude Survey	observations, student work
14	Blended Teaching and Learning of Computer Programming Skills in Engineering Curricula	Advances in Engineering Education	Winter 2009	Course Evaluation Survey	comments in an online survey
15	Exploring the industrial placement experience for mechanical engineering undergraduates	Engineering Education: Journal of the Higher Education Academy	2009	attitude questionnaires	semi structured interviews
16	Student learning teams: viewpoints of team members, teachers and an observer	Engineering Education: Journal of the Higher Education Academy	2007	customized student survey	ethnographic observation, course materials

C. Quantitative Data Analysis: Article Evaluation

Upon completion of the data collection process each of the articles was reviewed against a subset of four criteria established by Creswell[2] for mixed methods research designs (adapted from Table 3.2 pg 44). The first criterion chosen was the collection of both qualitative and quantitative data. Since this was one of the criteria for sample selection, most (if not all) of the articles should automatically meet this criterion. Paired with the collection of qualitative and quantitative data, we also examined each article to see if both data types were analyzed. A distinguishing feature for this stage of the evaluation was whether both data analysis results were presented in some form in the published work. The final two criteria for the quantitative evaluation were the priority the authors assigned to the qualitative and quantitative data as well as the timing of the data collection. Using these four criteria each article was systematically reviewed to determine whether engineering education researchers were publishing articles that meet the standards of mixed methods designs.

D. Qualitative Data Analysis: The Issue of Mixing

Constant comparative method [19] was used to systematically analyze the data and arrive at conclusions. Using the overarching theme of mixing, and guided by the literature, we developed an initial coding scheme. The initial coding scheme contained categories such as how the authors addressed the integration of the data, how they justified using both types of data (or mixed methods as a design) and who they referenced regarding mixed methods research designs. This initial coding scheme made determining categories possible, while still allowing for additional themes to emerge. A visual representation was created to begin grouping the textual data into general categories, and to determine the relationship between categories. Data were re-coded and new categories were created as necessary to capture emerging themes and relate them back to the research questions. From this analysis, several themes evolved, which are discussed in the next section.

IV. Results

Although the same set of data was used for both the qualitative and quantitative portions of this study, separate results were determined independently. The following sections discuss the results and findings from each of these data types.

A. Quantitative Results: Article Evaluation

During the quantitative data analysis (RQ 1), each article was evaluated against a subset of criteria established by Creswell *et al* (2007) for mixed methods research. The criteria not addressed in this quantitative analysis formed the basis for some of the qualitative analysis discussed in the next section. For each article we addressed the following:

1. Were both quantitative and qualitative data collected?
2. Were both qualitative and quantitative data analyzed?
3. What priority was assigned to the results or findings?
4. What was the timing of the collection and analysis of the data?

A summary of the results of the quantitative data analysis is shown in Table 4. Refer back to Table 2 for detailed information on each article including the article number. Evidence for data collection included comments discussing how the data were collected or presentation of the actual data. For the analysis criterion, we looked for evidence of an inductive approach along with thematic results for qualitative data. Evidence for quantitative analysis was generally summary tables or statistical results. In the event that the data presented did not meet the criteria for qualitative or quantitative analysis, an "X" was placed in that column. Timing was determined based on statements in the methods section related to when each type of data were collected and analyzed. For most cases, this was either sequential (qualitative followed by quantitative or vice versa) or concurrent, with data collection and analysis occurring simultaneously for both data types. Establishing the priority for each article was a bit more challenging as authors may not have been clear on the importance of weight of each data type. In addition, many articles interwove the results sections, without separately discussing both data types. For this analysis, priority was determined based on the perceived relative weight of each data type as given in the reported results. To assist in determining the priority, Table 5 was created to establish the relative page weighting of each data analysis.

Table 4. Quantitative Evaluation of Data Collection, Analysis, Priority and Timing

Paper Number	QUANT Data Collected?	QUAL Data Collected?	QUANT Data Analyzed?	QUAL Data Analyzed?	Priority	Timing
1	✓	✓	✓	✓	QUANT	Initial quantitative assignment submission analysis, followed by qualitative email questions to develop a quantitative survey
2	✓	✓	✓	✓	QUANT	Both types of data were collected at approximately the same time
3	✓	✓	✓	✓	QUAL	Quantitative data was collected first, followed by the qualitative data
4	✓	✓	✓	✓	QUANT	Quantitative data was collected first to develop a qualitative interview protocol
5	✓	✓	✓	✓	QUANT	Three studies in one paper, quantitative appears to come before qualitative
6	✓	✓	✓	✓	Equal	Both types of data were collected during the same time frame
7	✓	✓	✓	✗	QUANT	Quantitative data was collected pre and post, with qualitative survey questions administered at the end of the course
8	✓	✓	✓	✓	Equal	Quantitative survey followed by qualitative focus groups
9	✓	✓	✓	✓	QUAL	Quantitative analysis of student ratings were followed by open ended responses, focus groups and interviews
10	✓	✓	✓	✓	QUANT	Quantitative modeling followed by qualitative exploration of results.
11	✓	✓	✓	✗	QUANT	Both types of data were collected through the same instrument
12	✓	✓	✓	✓	QUANT	Quantitative pre test post test, followed by qualitative focus groups
13	✓	✗	✓	✗	QUANT	Pre-post quantitative survey, no reported evidence of qualitative data collection or analysis
14	✓	✓	✓	✗	QUANT	Quantitative survey followed by qualitative online survey
15	✓	✓	✓	✓	QUANT	Qualitative interviews formed the basis for quantitative attitude questionnaires, which were then followed by focus groups
16	✓	✓	✓	✓	Equal	Data were collected simultaneously over the given time period

As shown in Table 4, the majority of the articles cited collected and analyzed both qualitative and quantitative data. For all of the articles where this was not the case, the qualitative data was lacking, most often in the results section. This is not to say that the authors did not collect or analyze qualitative data, just that evidence regarding the collection or analysis was not discernable in the report. As mentioned previously, determining the Priority for each article was assessed based on the representation of each data type in the results or findings section of the article.

Table 5. Determining Priority through Analysis of Page Weighting for Reporting Qualitative and Quantitative Data Analysis

Paper Number	Qualitative or Quantitative Data Discussed First?	Pages Spent on Qualitative Findings	Pages Spent on Quantitative Results
1	Quantitative	1.5	7.5
2	Quantitative	0	5
3	Quantitative	2	0.25
4	Quantitative	3.5	2
5	Quantitative	2.5	5.5
6	Qualitative	3	2.5
7	Quantitative	1.75	1
8	Neither	Both results were discussed together	
9	Quantitative	5.5	2.5
10	Quantitative	4	5.5
11	Quantitative	Less than 0.5	1.5
12	Quantitative	1	2.5
13	Quantitative	0	5
14	Quantitative	1.25	4
15	Quantitative	2.5	4
16	Neither	Both results were discussed together	
Total Pages		29	48.75
Percentage of Total Pages		**37.3%**	**62.7%**

As shown in Table 5, quantitative results were almost unanimously discussed first, with article six serving as the only article leading off with qualitative findings. Of the nearly 78 pages devoted to results and discussion, 63% were devoted to quantitative results. There were also two cases where the qualitative and quantitative results were so intermingled it was impossible to separate the two. For most articles, priority was determined based on the relative written emphasis placed on each data type. Articles eight and sixteen, which features results discussed together were given equal priority. Article six was the only other article with equal priority given to both qualitative and quantitative data. This article was especially challenging to categorize, and might actually have a slight tendency towards qualitative priority. Overall there were ten articles that featured quantitative data as the priority, and three each of equal and qualitative priority.

One of the final criteria listed by Creswell et al[2] concerns the mixing (or integration) of both the qualitative and quantitative data. As previously discussed is Section II, integration of the data is often overlooked in reporting mixed methods research designs. In order to address this criterion, a inductive analysis was preformed to explore the ways that the authors of the various studies

listed in Table 4 addressed both the justification for using a mixed methods design and integration of both data types.

B. Qualitative Findings: The Issue of Mixing

To address the second research question, each article was thematically analyzed to explore how each author addressed the issue of mixing the data, and what types of justification were given for collecting and analyzing both qualitative and quantitative data (or using a mixed methods approach). Along with the textual justification for methodological designs, the mixed method literature cited by each author related to mixed methods research was explored for commonalities. A summary of the results is given in Table 6 below.

Table 6. Qualitative Mixing and Justification Themes

Mixing Themes	Codes
One data type used to inform the collection of the other type	• analysis of the submission patterns were used to inform the construction of the survey questions • The results from these [quantitative] analyses gave us direction in developing a semi-structured interview guide for the second phase
Direct comparison and explanation of one type with the other	• Quantitative summary of student decisions followed by the qualitative exploration of these decisions • Qualitative data help to explain the "why" and "how" of some of the results obtained from the larger survey dataset, revealing insights once data were triangulated. • To further interpret these [quantitative] findings, we now turn to the qualitative analysis • The results of the qualitative data were directly compared to the results of the quantitative data
Transforming one data type into the other	• quantizing of the qualitative data (two occurrences)
Justification Themes	**Codes**
Used to take advantage of the relative strengths of both data types	• The interview data also revealed additional emergent themes that would have gone otherwise un-captured in a purely quantitative study • more pragmatic approach to answering the evaluation questions • Qualitative information provided much rich and detailed information regarding the potential benefits, while the quantitative survey allowed for a larger sample size to be collected with the expectation that the results would be generalizable to the larger population
Address a broad range of research questions directed towards a complex phenomena	• address a broad range of research questions directed toward discerning complex phenomena • a more comprehensive, cohesive understanding than could be obtained by a single inquiry method
Offers different perspectives and a more thorough understanding of the same phenomena	• provide a better understanding of the issues under investigation • provide different perspectives on the same phenomenon
Triangulation of both data for drawing conclusions	• Combination of both qualitative and quantitative assessment techniques • Triangulation of data for the purpose of drawing conclusions

While there was no overwhelming consensus on the issue or mixing the qualitative and quantitative data, there were several themes that emerged from a few articles. First, three articles used one data type to inform the collection of the other data type. Gregory & Moron-Garcia [20], used qualitative email survey data to inform the design of their quantitative survey, where as

Trenor *et al*. [21] used the quantitative results from their survey to develop a semi structured interview protocol. In Lock *et al* [22], qualitative interviews were used to create a quantitative attitude questionnaire, the results of which were further explored using small group interviews. Several authors used another method of mixing the data by using one type of data to explain the results of the other data type. In several other articles [23-25], qualitative data were collected and analyzed to help explain quantitative results. Similar methods were discussed in Lichtenstein *et al* and Trenor *et al* [21, 26]as well. A slight majority (six) of the articles attempted to mix the data through direct comparison of the quantitative and qualitative results. In Kilgore *et al* [27] and Atman *et al* [28], the researchers quantized the qualitative data, and then compared the newly quantized results to the other quantitative data. Ferens *et al* [29] collected both data types at the same time, using an instrument with both qualitative and quantitative questions. Other articles [30-32] had no separate results sections for their qualitative and quantitative data, and reported only the integrated results. The final three articles appeared to have no evidence or discussion related to mixing.

Another issue of interest was the methodological citations used to justify or explain the use of mixed methods research designs. In exploring this theme we hope to propose a set of guidelines for future publications. In the 12 self-described mixed methods articles, five (42%) contained at least one citation for mixed methods literature. Of the 13 explicit references to mixed methods literature, five were articles from Tashakkori and Teddlie [3], three of which were articles written or co authored by Creswell *et al* [10]. Another article cited Creswell[10]. Other literature included justification for qualitative methods, with two citations for Leydens *et al* [33] related to assessment in engineering education. Other notable citations specifically for mixed methods literature included a reference to Johnson and Onweugbuzie [9].

V. Discussion

The quantitative analysis showed strong preference for quantitative methods, as indicated by 11 of the 16 articles prioritizing quantitative data and 63% of the published pages devoted to quantitative results. From the qualitative data we see that there are several themes that emerge related to both how the authors justify collection of both data types as well as how then proceed to mix the data. What we would like to explore further is the question: how do engineering education researchers interpret and report the meaning and use of mixed methods research designs?

In Table 7 we present the integration of the quantitative data on priority with the qualitative mixing themes. From this table we see that engineering education researchers prefer to directly compare the results of both the qualitative and quantitative analysis (six occurrences) when they give priority equally or to the quantitative data. There was also one case of direct data comparison for a qualitatively prioritized study. This was followed by using one type of data to inform collection of the other type with three cases, all quantitative priority. Finally there were two cases where the authors quantitized qualitative data. It should also be noted that the language of article four mentioned two mixing themes, so it was placed in both locations. Of the 12 articles evaluated for mixing themes, only article nine offered no evidence or discussion of mixing.

Table 7. Article Number, Design Priority, and Qualitatively Derived Themes Integrating both QUAL and QUANT Data

Mixing Themes	**Qualitative Priority**	**Quantitative Priority**	**Equal Priority**
One data type used to inform the collection of the other type		1, 4, 15	
Direct comparison and explanation of one type with the other	3,	10, 12, 4	6, 8, 16
Transforming one type of data into another type		2, 5	
No evidence or discussion of mixing	9		

These findings indicate that engineering education researchers most commonly interpret "mixing" as the direct comparison of two types of data, representing 58% of the articles reviewed. However, if we refer back to Table 6, within this mixing theme we see quite a bit of variation in how this type of mixing was reported. What other issues are engineering education researchers facing when interpreting and reporting mixed methods data? To answer this question we turn to other aspects of mixed methods research: justification and timing.

Table 8. Article Number, Design Timing, and Qualitatively Derived Themes about Justification for Collecting and Analyzing both QUAL and QUANT Data

Justification Themes	**Sequential Timing**	**Concurrent Timing**
Used to take advantage of the relative strengths of both data types	4, 8,	
Address a broad range of research questions directed towards a complex phenomena	5	2
Offers different perspectives and a more thorough understanding of the same phenomena	1, 4, 5	
Triangulation of both data for drawing conclusions	3,	6,
No justification given	9, 10, 12, 15	16

When it comes to timing, sequential data collection and analysis were used considerably more often than concurrent designs. Integrating timing decisions with the justification themes (Table 8) that emerged from the qualitative data yield some interesting insights. Several different types of justification were given for using mixed methods research, and discarding the cases of no justification given, the idea that mixed methods offers a more thorough understanding of the same phenomena was the most often used. These articles all featured sequential timing, and often mixed the data by using one type to inform collection of the other. The second most often used justification for mixed methods was to take advantage of the relative strengths of both data types (two studies). These studies were either of equal or qualitative priority, and featured various opinions on mixing the data. Articles that gave equal priority to both qualitative and quantitative data justified their use by the pragmatic nature of using both data types. These studies also credited the relative strengths of both types, indicating that "qualitative data was found to be extremely valuable in providing information on some of the constructs that are difficult to measure". Equal priority articles used both sequential and concurrent timing.

Perhaps most alarming from this analysis is the amount of studies that did not report a justification for using mixed methods research. Of the 12 studies included in the table, four were excluded for not analyzing qualitative data (Table 4), approximately 41.7% did not report a reason for using a mixed methods design. Additionally two studies cited "triangulation of data" as a justification for using mixed methods research; however seven articles interpreted mixing as

direct comparison of both data types. This suggests a possible disconnect between the language used in the literature and the language used for reporting the research.

Another element worth discussing with respect to how engineering education researchers address mixing and justify mixed methods research is to compare how the justification themes relate to the mixing themes. Table 9 contrasts each of the qualitatively derived mixing themes against the qualitatively derived justification themes. We have chosen to leave out the articles that did not list a justification or address the mixing of the qualitative and quantitative data for simplicity. What this comparison shows is that for many engineering education researchers, the justification themes and mixing themes are often the same, motivated by each other. Consider for example the justification of addressing a broad range of research questions towards a complex phenomenon. The two authors who justified the use of a mixed methods study this way both addressed the issue of mixing by quantitizing qualitative data. However when authors justified using a mixed methods approach as offering different perspectives and a more thorough understanding of the same phenomenon, all three mixing themes were used. It is also interesting to note that in many cases the justification for using mixed methods is directly related to the type of mixing accomplished, such as direct comparison through triangulation (Articles 3 and 6).

Table 9. Comparing Qualitatively Derived Mixing and Justification Themes

	Justification Themes			
Mixing Themes	Used to take advantage of the relative strengths of both data types	Address a broad range of research questions directed towards a complex phenomenon	Offers different perspectives and a more thorough understanding of the same phenomena	Triangulation of both data for drawing conclusions
One data type used to inform the collection of the other type			1	
Direct comparison and explanation of one type with the other	4, 8		4	3, 6
Transforming one type of data into another type		2, 5	5	

A further take on the justification given in each article can be explored through the literature cited by the featured authors. Each of the articles listed for each justification theme cited mixed methods literature to support their justification. Four of the eight citations featured articles written by Creswell and Plano Clark [10, 34] as the methodological justification for conducting a mixed methods study. The majority of the authors did not however use the language or notations systems proposed in this literature, but when comparing the language used in the mixing themes to the language used by Creswell[2] there are several similarities.

In short, engineering education researchers are using interpreting and reporting mixed methods research in a variety of ways. While Creswell et al[2] was the most often cited reference for mixed methods research, several other sources were used as well. Mixing themes and justification themes were often similar, but the language used by the authors to report these themes was diverse. Using the insights gained from these comparisons, we would like to propose a few ways to increase the salience of mixed methods designs in engineering education research articles as well as make fuller use of the prescribed advantages of mixed methods designs.

Consider the summary of how Creswell and Plano Clark address mixing in Section II. The authors propose that there are three ways that qualitative and quantitative data can be mixed, including: merging the data, connecting the data, and embedding the data at the design level. In the articles we reviewed that addressed how they mixed the data; all of these use language similar to that of Creswell and Plano Clark, without using the explicit terminology. For example, both Kilgore et al[27] and Atman et al[28] mix the data by what Creswell and Plano Clark call merging the data at the analysis stage through quantitizing qualitative data. Similarly Gregory and Moron-Garcia[20] connect the data by using one type of data to inform the collection of the other type. Through the use of a common terminology offered by the literature, engineering education researchers will be able to more clearly situate their methods, increasing the perceived rigor of the published results. In addition to establishing methodological rigor, using a common terminology will allow engineering education researchers to communicate their research designs more effectively, enabling others to interpret and utilize their research.

Along with a common language, engineering education researchers should look more carefully at how they are mixing their data. While Creswell and Plano Clark offer a succinct package of terminology, we should also heed the advice of Bryman[7] by taking advantage of the possibilities when mixing data. In many of the articles reviewed for this study, the mixing of the data was not readily apparent, making evaluating the research more difficult. Coupled with common terminology, engineering education researchers should utilize the mixed methods designs suggested in the literature as a starting off point for designing their studies. These designs are not the only choices, but offer valuable insight for those just getting acquainted with a mixed methods approach.

VI. Conclusions

So what does this mean for the future of mixed methods research in engineering education? We would like to conclude with recommendations for how engineering education researchers can better showcase mixed methods studies by proposing a set of guidelines for reporting mixed methods research.

1. Common Terminology

Using existing terminology from the literature allows researchers to communicate their work quickly and efficiently without a lot of extra explanation, enabling more time to be spent on the results. This includes issues like priority, timing, mixing, and the overall research design. Including a diagram of the study, or using a notation system greatly increases the salience of your methods. Additionally using a common discourse can assist in prescribing measures of quality for mixed methods research designs. Several possible sources were discussed in this paper, and future research will explore a larger survey of studies to help ascertain both the issue of common discourse and measures of quality.

2. Report Collection and Analysis of Both Qualitative and Quantitative Data

Considering the criteria mentioned previously for mixed methods designs, it is important to collect and analyze both qualitative and quantitative data. It is equally important to discuss these

steps when publishing the study. Explicitly relating your collection and analysis to the literature will enable your audience to better understand the how and why of your methods.

3. Don't Forget to Mix the Data

Not only is mixing (or integrating) the qualitative and quantitative data a key criterion for mixed methods research, the benefits of this step are often underestimated. Think of the additional information that may be uncovered when data are combined in new ways. While answering the research question should be the paramount concern, researchers who do not explore new ways to integrate their data may be missing out on valuable insights not immediately apparent in the qualitative or quantitative data alone.

The growing field of engineering education makes mixed methods designs an excellent opportunity to increase our understanding of the complex research questions under investigation. Through the use of a common set of terminology and taking care in the reporting procedures, engineering education researchers can use mixed methods designs to carry the discipline into the future.

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