A Mixed Methods Analysis and Evaluation of the Mixed Methods Research Literature in Engineering Education

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Abstract

Mixed methods research is still emerging as an accepted and rigorous method of inquiry. Past work on mixed methods shows that there continue to be disagreements among scholars about terminology, various ways to classify research designs, and mixed methods research characteristics. Various studies have examined quantitative and qualitative research accepted as rigorous in the field of engineering education but little work has been done on the extent that mixed methods research has been utilized by researchers in the field and the quality of that research. The content analysis presented here provides an overview of the mixed methods articles published in engineering education journals and a proposed strategy for evaluating mixed methods articles. Specifically, our intention is to provide insight into the current state of mixed methods research in the field of engineering education while discussing ways to improve this mode of inquiry. Based on our analysis, we can conclude that there is considerable variability in the quality of mixed methods articles in engineering education and that there are differences between journals in terms of the mixed methods articles they publish.

Introduction

Mixed methods research is still emerging as an accepted and rigorous method of inquiry.[1] Past work on mixed methods literature shows that there is still disagreement about terminology, various ways to classify research designs, and the amount of mixing that is required to meet the minimum threshold to qualify as a mixed methods study.[(e.g., 2-4)] Just as mixed methods research is emerging, engineering education as a field of rigorous research is still developing. Various studies have examined quantitative and qualitative research accepted as rigorous in the field[(e.g., 5)] but little work has been done on the extent that mixed methods research has been utilized by researchers in engineering education. It is essential to understand this situation to help both engineering education and mixed methods research progress forward.

A 2010 article by Crede and Borrego[6] provided an initial exploration of mixed methods research in engineering education through a content analysis. Their aim was to understand the types of mixed methods articles being published in the field and to provide recommendations for future mixed methods studies. The content analysis presented in this paper expands on the work of Crede and Borrego[6] by providing a more up to date and in depth analysis of the mixed methods articles published in engineering education journals and by providing a more in-depth analysis of purposes given for using mixed methods. Furthermore, this work extends the research conducted by Crede and Borrego[6] by providing a strategy to evaluate mixed methods research articles that can be used by others to assess mixed methods study regardless of discipline. By providing such information, we hope to advance both the quality and use of mixed methods research in engineering education.

Tashakkori and Teddlie[7] define mixed methods research as the blend of "qualitative and quantitative approaches in the methodology of a study" (p. ix). According to Creswell and Plano Clark[8] mixed methods research combines "methods, a philosophy, and a research design

orientation" geared towards the combination of qualitative and quantitative data (p. 5). These two definitions clarify that mixed methods research must involve both quantitative and qualitative components that are connected or integrated in some way. Contemporary definitions of mixed methods research require the combination of the quantitative and qualitative research components.[8 & 9] This combination is often referred to as mixing. Creswell and Plano Clark[8] define mixing as "the explicit interrelating of the study's quantitative and qualitative strands and has been referred to as combining and integrating" (p. 66). Many authors substitute the terms triangulation[10] or integration for mixing, but for this study, the term mixing will be used because it specifically relates to the combination of quantitative and qualitative work during various stages of the research process, not just during data analysis and discussions.[8] Mixing can occur during the design, collection, analysis, and discussion phases. Some even argue that the extent of mixing in a research project directly relates to the quality of the research.[4 & 11] Collecting, analyzing, and discussing the qualitative and quantitative strands of a study through mixing can strengthen a study when one set of data is inadequate, can provide further insight if needed to explain an observed phenomena, can allow exploratory findings need to be generalized, or can help explain contradictory findings.[8]

Like the Crede and Borrego[6] article, our research initially emerged from the final project of a doctoral level methodology course taught by the second author. Following the class, the project was pursued further as the findings seemed useful and relevant to the engineering education community. The purpose of this study was to conduct a mixed methods content analysis of the mixed methods research literature in engineering education and to evaluate their quality in terms of their methodological consistency with contemporary definitions of mixed methods research. The study was designed to answer the following mixed methods centered research questions:

> RQ 1: What evidence is there that the authors of the sampled publications meet contemporary definitions of mixed methods research by including procedures to integrate or mix the qualitative and quantitative data?
>
> RQ 2: How do articles from the sample rank in terms of their methodological consistency with analytical and design strategies recognized in the mixed methods field?

To answer these research questions, this study was designed as a convergent sequential[8] mixed methods study with equal priority given to the quantitative and qualitative components. For this article, the first phase was qualitative in nature and the second phase was mixed using both deductive and inductive approaches. This differs from an exploratory study that requires the qualitative data to be gathered first and then the quantitative data to be gathered to expand the results of the qualitative phase or an explanatory study that would first gather quantitative data then qualitative data to explain the initial quantitative findings.[8] Mixing occurred during the design, analysis, and discussion phases of the study. A mixed methods approach to this work was used so that the articles could be evaluated compared to the literature related to mixed methods studies (quantitative - deductive) and so that new information and findings could be generated based on the published mixed methods engineering education articles (qualitative - inductive).

For this study, qualitative methods are classified as those using an inductive approach (particular to general). Conversely, quantitative methods are classified as those using a deductive approach (general to particular). Distinguishing qualitative and quantitative approaches in this way may seem simplistic but it allowed for the articles in the manuscript to be classified and evaluated

consistently. Some authors have argued that the two methods (qualitative and quantitative) share similar characteristics and are not as dichotomous as some assume them to be.[12] Consequently, the two research questions above are mixed methods research questions requiring both quantitative and qualitative analysis perspectives. In general, using mixed methods for this study has allowed the weaknesses of one set of data to be offset by the strengths of the other and for a more holistic view of the state of mixed methods work in the field of engineering education to be obtained.[8]

In this article, our intention is to provide insight into the current state of mixed methods research in the field of engineering education while promoting more rigorous use of the methods by proposing a succinct set of evaluation criteria. We are not advocating for the use of mixed methods for every research project. While we are proponents for mixed methods research as it serves as a means to holistically examine a phenomenon, we believe mixed methods should be used when appropriate for the research questions and situation at hand.

Literature Review

In this literature review, we first define a content analysis. We then provide examples of content analyses of the use of mixed methods in other fields and draw conclusions that demonstrate the similarities and differences between past studies to help identify trends in mixed methods research in general. By approaching our literature review in this manner, we were able to form a base for our inquiry and understand the statement of mixed methods research beyond engineering education.

According to Krippendorff,[13] "a content analysis is a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (p. 18). In the traditional sense, a content analysis is a review of written communication, articles, websites, videos, etc.,[14] but in recent years it has been expanded to a method of analysis that can involve the texts described above including interviews, focus groups, etc.[15] The analysis can be qualitative, quantitative, or in the case of this work, and the content analyses discussed in this paper, mixed methods.[15] A content analysis is a good example of mixed methods methodology because the texts can be examined both deductively and inductively, i.e., quantitatively and qualitatively. For example, they can be reviewed to see if they match previously established criteria, or they can be reviewed to develop novel themes and trends about a subject.

To date there have been multiple mixed methods content analyses in a variety of disciplines such as psychology, marriage and family theory, social sciences, etc. that provide a picture of the state of mixed methods research across fields. This article focuses on the reviews conducted by Bryman[16], Plano Clark, Huddleston-Casas, Churchill, Green, and Garrett[3], Crede and Borrego[6], and Gambrel and Butler.[17] Each analyzed the types of methods being used in publications by mixed methods researchers in a variety of fields similar to the analysis conducted in this study. By focusing on these texts, the current state of mixed methods literature as a whole can be more accurately portrayed.

Bryman[16] used a content analysis to analyze 232 social science articles. He focused on understanding the current methods and designs used in the field to develop general findings that

helped characterize mixed methods work. He concluded that for most mixed methods articles, structured interviews and questionnaires were used for the quantitative component and semi-structured interviews were used for the qualitative data. He also observed that the rationale for using mixed methods was weak in most published articles. Finally, his overall conclusion was that sometimes the classifications being placed on mixed methods research designs are too restrictive.

Plano Clark et al.[3] conducted a review of 19 mixed methods articles in the field of family science. Their review specifically looked to classify the methods used in the field based on work from Creswell and Plano Clark[18] so they focused on overall design as well as timing and priority. Their work revealed that surveys and interviews were the most common forms of data collected. They made four recommendations to enhance mixed methods research in the field of family science. The recommendations requested common terminology related to mixed methods, urged for an increased understanding of both qualitative and quantitative techniques, suggested the use of mixed methods research questions, and finally, suggested that more attention be paid to the consideration and reporting of logistical challenges that are associated with conducting mixed methods studies.

Crede and Borrego[6] conducted a content analysis of selected articles in engineering education published from 2005 to the time of their manuscript publications in 2010 to understand the state of mixed methods research in the field. For their analysis, they retrieved 15 articles from seven engineering education related journals. They found that quantitative data was prioritized over qualitative data, most studies used a sequential design where the two strands were not collected together, and there was a lack of consistent terminology among researchers related to mixed methods research. They also observed the frequent use of surveys as the quantitative data source. In addition, they noted that little to no justifications for mixed methods were given and that as a whole, the field needed to improve on the use of mixing.

Finally, Gambrel and Butler[17] analyzed 32 mixed methods articles in the field of marriage and family therapy to understand the methods used for data collection and the rationale of using mixed methods techniques. Their mixed methods approach to a content analysis revealed that surveys and interviews were the dominant forms of data collection and that many articles used mixed methods techniques without using mixed methods language. In the final portion of their article, the authors provided recommendations to improve and enhance mixed methods work in their field. They argued that a common terminology was needed, mixing of data in a study should be determined at the very start of the research, and future researchers should use a theory or model to inform and guide their work.

The four content analyses discussed above provide findings that are both unique and yet, similar. Authors of all four articles were in agreement that surveys and interviews were the key modes of data collection in mixed methods work. They also all mentioned that explicit statements about the rationale for using mixed methods was often missing and suggest that this was a part of reporting that needed to be strengthened. In addition, Crede and Borrego[6], Gambrel and Butler[17], and Plano Clark et al.[3] argued for the need for common terminology. In terms of items that were different between the content analyses, Plano Clark et al.[3] felt mixed methods research questions were important to mixed methods work, while Gambrel and Butler[17] suggested that mixing must

be considered at the start of a mixed methods project. Based on the literature review, we expected to find a variety of terminology related to mixed methods work and to see that some form of mixing had taken place. We also expected there to be a lack of insight into the rationale for mixing.

Research Methods

To explore mixed methods articles in engineering education, a convergent sequential[8] content analysis was performed on a set of articles obtained from three journals in the field. The list of articles used as data is not completely exhaustive, but the journals and the articles chosen do, however, provide a meaningful sample of the mixed methods research currently available in engineering education. The techniques used to analyze the articles allow for the research in engineering education to be compared to the greater body of mixed methods literature (quantitative - deductive analysis) and for new findings specifically related to engineering education research articles to be generated (qualitative – inductive analysis).

Selected Journals

There are multiple publication venues for engineering education research from research based journals to regional practice based conference proceedings. For the purposes of this content analysis, journals were chosen as the source of articles because they tend to be more rigorous compared to articles published in conference proceedings and are peer reviewed by experts in the field. The following engineering education journals were chosen for this content analysis due to their impact in the field and their ability to be systematically searched:

- *Journal of Engineering Education*
- *Advances in Engineering Education*
- *European Journal of Engineering Education*

These journals were chosen as a snapshot of research in the field of engineering education from 2005 to 2011. The first journal chosen for the analysis was the *Journal of Engineering Education* (JEE) because it is the top tier US journal for engineering education rigorous research. *Advances in Engineering Education* (AEE) was chosen next because it is JEE's counterpart, publishing innovative approaches to engineering education. AEE publishes rigorous research, but focuses and highlights the innovative dimensions of research opposed to strict methodologies and in depth analyses. Many of the articles in AEE are also assessment pieces, but they follow research article guidelines and styles. The *European Journal of Engineering Education* (EJEE) was chosen as the final journal for the analysis to complement the other two journals as a source of an international perspective on engineering education research. All of these journals share in their focus on engineering education and research within that field.

Search Terms

Journal article searches were restricted to 2005 to 2011 since in 2005 JEE released its first refocused issue specifically targeting rigorous research in engineering education.[19] The article search within the journals was comprised of two phases using search terms that have previously been used to identify mixed methods articles.[3 & 8] In the first phase, the term "mixed method" was searched in each of the three journals for articles that specifically used the term. JEE and

EJEE were searched through Academic Search Complete, and AEE was searched through the journal's website. After the search term was entered into the respective systems, the resulting articles were each reviewed to ensure that the articles were indeed research articles opposed to literature reviews or opinion papers. From this phase, six articles were obtained from JEE, one from EJEE, and five from AEE.

The second phase of the article search used the terms "qualitative" and "quantitative." For an article to be found in this search, both terms must have appeared in the article. The limitation of this particular set of search terms is that if allowed for the inclusion of articles that lacked any form of mixing. Again, all the articles that were retrieved using these terms were reviewed to ensure that they were indeed research articles that discussed the use of qualitative (inductive) and quantitative (deductive) components in a specific research project. If a particular article was part of a large project and in the article only the qualitative or quantitative strand was discussed in detail, the article was not included in the sample. Also if a clear inductive and deductive component was not found, the article was not included in the sample. Following this phase, a total of 10 articles were obtained from JEE, 7 from EJEE, and 11 from AEE, which created a grand total of 28 mixed methods articles (12 from the first search and 16 more from the second).

After the initial sampling, the articles were reviewed to determine whether or not mixing occurred. An article was classified as having mixing if the authors of the article used the words triangulated, mixing, or merged. Also an article was considered mixed if the data was connected in some way where the results of one phase built off the findings of another. Finally, if there was actual evidence of qualitative and quantitative data integration in the discussion or conclusion sections, the article was considered to have mixing. After this final data evaluation, the following articles remained in the sample for analysis in this article, eight from JEE, four from EJEE, and four from AEE. These 16 articles were then analyzed to determine the quality of the mixed methods research.

Several steps were taken to ensure that the articles considered in this analysis already met accepted general definitions of quality in mixed methods research defined by modern conceptions of mixed methods designs and practices. We limited the articles we considered to those that had, first, both an inductive and deductive component and, second, clear signs of mixing. We specifically chose to focus on these papers to demonstrate that while these papers are currently the highest quality papers concerning mixed methods practices by default, there is still room for improvement in these articles. If we would have included the papers that included inductive and deductive strands but did not mix, we would not have been able to showcase the specific areas of improvement needed to have an exemplary mixed methods article.

Data Analysis

Once the articles were gathered and identified as having mixing, an inductive analysis of the rationale for using mixed methods research was conducted. To qualitatively examine these articles, a passage from each article was extracted that answered why the authors chose to collect qualitative and quantitative data. This passage could have appeared anywhere in the text, but most articles provided this information near the purpose statement for the research or in the beginning of the methods sections.

Following the qualitative rationale examination, an evaluation of the articles found in this analysis was conducted. The first three evaluation criteria (rationale for using mixed methods, research questions, and phases of mixing) are deductive in nature because they are based on Creswell and Plano Clark's[8] mixed methods evaluation criteria and are common to other mixed methods evaluation literature.[e.g., 17, 20, & 21] The fourth evaluation criterion is inductive in that it comes from the qualitative analysis where categories of rationale were developed out of the text of the articles in engineering education.

This phase also incorporated data transformation where qualitative items were quantitized to provide a score for each article. Quantitizing data is a form of data transformation which is a type of mixing where qualitative components such as themes are given quantitative characteristics such as numbers.[22] Often it is believed that qualitative work cannot be evaluated with numbers, but quantitizing data is an accepted practice among some mixed methods researchers, which allows for more meaning to be made from qualitative research beside just themes and quotes.[23] It should be noted that others so not widely accept this practice, however it is a growing area of analysis in mixed methods. In this study, quantitizing has been used to help evaluate articles based on verbal and descriptive classifications in the form of a rubric.

To summarize, there were two phases to this study. The first phase was inductive in that it was based solely on the content of the articles themselves, not on past literature. The second phase was mixed methods because it used both deductive and inductive evaluation criteria along with data transformation in the form of quantitizing. For the analysis, one researcher analyzed and ranked the articles to provide consistency across the manuscripts reviews. To ensure validity in the results, there were multiple levels of peer audits of each article and peer discussions to develop the evaluation criteria and overall findings. Additionally to examine reliability in the second phase, another researcher with a subset of articles from the study tested the scoring system, which is discussed further in the following sections.

Results

Results of the study are presented below. A table summarizing the results is associated with each section of this work. Again, the results from the first phase were produced through a qualitative analysis, while results presented in the final section of the analysis were produced through the mixing of qualitative and quantitative techniques.

Phase 1 – Rationale (Qualitative Phase)

Table 1 describes characteristics of the 16 articles used in this analysis and summarizes results from the inductive analysis of statements in each article about the rationale for the use of mixed methods or of mixing. An open coding approach was used to create descriptive codes that were then grouped into larger categories. Quotes of the language used in each article to explain the rationale for using mixed methods are included in the table, along with the category name. Only 2 of the 16 articles contained no statement that could be identified to reflect a rationale for employing mixed methods.

Table 1: Articles Using Qualitative and Quantitative Methods and Mixing

Journal	Paper Title	Year	Why Collect Qual and Quant Data?	Category	Paper Letter
AEE	Enhancing the Quality…	2011	"to complement observations […] survey data were collected"; "a synthesis of the findings"	Comparison	A
	Incorporating a Systems…	2011	no discussion of why MM was used	No Justification	B
	Service-Learning Integrated…	2011	no discussion of why MM was used	No Justification	C
	Using Concept Maps...	2009	"bringing together complementary methods or data sources to offset weaknesses"	Comparison	D
JEE	An Engineering Major...	2009	no discussion of why MM was used; allowed a subset to be determined for qual component	Subset Determined	E
	Characterizing Design Learning…	2008	"these methods provide three lenses through which we may examine engineering design knowledge"	Comparison	F
	Coefficient Alpha: An…	2008	"allowed additional insight to be gained"; the author used the word "corroborate"	Additional Insight	G
	Developing and Assessing…	2005	"the qualitative information collected provided much rich and detailed information […] however the quantitative surveys allowed for a larger sample size [for] generalizable [findings]"	Comparison	H
	Gender Differences in…	2010	"transcripts provides support and additional insight to the significant results of the survey data used for this study"	Additional Insight	I
	The Relations of…	2008	"the addition of interview data to the survey dataset allowed us to study participants' perceptions in their own words and encouraged participants to elaborate on constructs explore in the quantitative portion of the study"; the author used the word "triangulate"	Comparison	J
	The Relationship Between…	2011	"the qualitative data analysis methods […] addressed the question of what types of discourse students engaged in, and the quantitative methods […] helped reveal any significant correlations"	Additional Insight	K
	The Socially Responsible…	2011	"interview transcripts […] were additionally analyzed to provide deeper insight to survey results and to triangulate data"	Additional Insight	L
EJEE	A Comparison of…	2011	"allowed for the integration of the qualitative and quantitative data during the interpretation phase"; the interviews were "reviewed for convergent themes as well as for discrepancies between reported survey results and experiences as related during focus group interviews"	Comparison	M
	Effects of Single...	2010	no discussion of why MM was used; allowed a subset to be obtained for qual component	Subset Determined	N
	I Still Wanna…	2008	the two methods were combined "in order to provide a more complete picture"	Additional Insight	O
	The Benefits of…	2006	"iterative cross-cultural mixed methodology allows fruitful comparisons that go beyond the usual statistical comparison"	Comparison	P

Note. AEE: Advances in Engineering Education, JEE: Journal of Engineering Education, EJEE: European Journal of Engineering Education

In Table 1, comparison is defined as gathering two types of data to parallel analysis and findings simultaneously where both data types play a leading role in the work. Additional insight is defined as the author taking a deeper exploration into specific area of study or topic using a new data type to supplement findings initially established. For the subset determined category, no distinct rationale was given as to why mixed methods were used, but both articles did use one strand of data to determine the participants for the other strand.

Of the 16 articles, four categories emerged from the inductive analysis, which were named: comparison, additional insight, to determine a subset, and no justification. Seven articles (43%) fit within the category "comparison." Comparison was defined as gathering two types of data to parallel analysis and findings. Rationale statements that fit in this category reflected the deliberate intention to compare qualitative and quantitative data for similarities and differences. Five articles fit within the second category, "additional insight." This category was used when the authors of an article expressed the intent of combining qualitative and quantitative data on a specific area of study or topic to gain new insight. It was different from the category called "comparison" in that authors expressed the intent to further explain the findings of one data strand or support one data strand with another. As a note of interest, these articles would have most likely fallen under Creswell and Plano Clark's[8] definitions of exploratory and explanatory studies. The third category was "subset determined." It contains only two articles. For this category, no distinct rationale was given as to why mixed methods were used, but both articles clearly stated and used one strand of data to identify the participants for the other strand. Again, these articles would have most likely been classified as exploratory or explanatory. Finally, the fourth category that emerged from the data was the complete lack of a rationale with no other supporting reason for why the collection of both qualitative and quantitative data was necessary. Of the 16 articles, only two were in this category.

Phase 2 – Evaluation

A rubric to evaluate the mixed method articles found in the field of engineering education was created in the second phase of the analysis (Table 2).

Table 2: Evaluation Criteria for Scoring Rubric

Mixed Methods Evaluation Criteria	Score			
	0	1	2	3
Rationale for Using Mixed Methods	No Rationale	Rationale with No Citations	Rationale with Any Citations	Rationale with Citations from MM Literature
Research Questions	No Research Questions	General Research Question(s)	At Least One Quant and One Qual Research Question	Specific MM Research Question
Phases of Mixing	No Mixing	Mixing in One Phase Only	Mixing in Two Phases	Mixing in Three or More Phases
Degree of Comparisons	No Comparison	Mention Comparison, but No Evidence of Comparison	Comparison for Similarities Only	Comparison for Similarities and Differences

Note. The first 3 criteria are deductive coming from Creswell and Plano Clark.[8] The 4th criterion is inductive coming from the items in Table 1.

Table 3 is a mixing table that reports on the scores assigned to each article. The analysis reported in Tables 2 and 3 are restricted to the seven articles in the comparison category (articles A, D, F, H, J, M, & P). This selection is based on the argument that comparison is a higher form of mixing than the other categories because it includes consideration of both similarities and differences in the data strands opposed to simply one of the other. As discussed in the methods section, tables related to evaluation are an example of quantitizing, where qualitative components such as themes are assigned a quantitative value.[22] For this table, one researcher initially evaluated all of the articles. Later, another researcher evaluated a subset of the articles using Table 2. Based on an initial review of the subset of articles, 83% agreement was reached (3 articles reviewed based on the 4 criteria where 10/12 scores were exactly the same). For the items that did not match, the two researchers discussed their findings and decided on the final scoring shown below in Table 3.

Table 3: Scoring of Selected Articles Using the Evaluation Rubric

Paper	Rationale for Using Mixed Methods	Research Questions	Phases of Mixing	Degree of Comparisons	Total Score	Journal
M	3	2	3	3	11	EJEE
D	3	1	3	3	10	AEE
H	3	2	2	2	9	JEE
J	1	2	2	3	8	JEE
F	2	0	2	3	7	JEE
P	1	0	2	2	5	EJEE
A	1	0	2	1	4	AEE

Note. AEE: Advances in Engineering Education, JEE: Journal of Engineering Education, EJEE: European Journal of Engineering Education

Total evaluation scores ranged from a low of 4 to a high of 11, with the highest possible score being 12. The two articles with the highest scores (articles M and D), which came from EJEE and AEE respectively, shared three qualities: (1) a rationale was provided for using mixed methods that was grounded in the literature, (2) mixing occurred in three or more phases of the study, and (3) the degree of comparison was considered high in that both similarities and differences between the qualitative and quantitative data were addressed. The two articles also shared the same weakness; while they had at least one research question that was clearly quantitative and one that was clearly qualitative, both articles failed to have a research question that explicitly addressed mixing. The two articles that ranked the lowest in the evaluation rubric shown in Table 5 (articles A and P), which also came from EJEE and AEE respectively, shared some common characteristics as well. Both failed to (1) provide citations from the methodological literature to support their rationale for using mixed methods, (2) present separate research questions for the qualitative and quantitative components of the study, (3) mix in more than one phase of the study, and (4) provide much discussion comparing the findings from qualitative and quantitative analysis. It should be noted that while these were the lowest scoring articles in the evaluation table, they were still among the highest quality articles in the entire sample of engineering education articles because they do indeed have an inductive and deductive strand, demonstrate mixing at some level, and compared the different strands for both similarities and differences.

Discussion

Results from this content analysis are both similar and different from past studies in engineering education and other social science fields. The results of this study have some limitations, but they allow for recommendations to be made in reference to the future of mixed methods research in engineering education. Also it should be noted that while the articles evaluated in this study scored relatively well according to the rubric (e.g., no article scored below a four), there is still room for improvement to strengthen mixed methods research in engineering education.

There were different trends in the mixed methods articles appearing in the three journals we examined. Of the articles initially reviewed (before we evaluated for mixing), 11 were published in AEE, 10 by JEE, and 7 by EJEE. There appears to be differences in some of the characteristics of mixed methods articles published in these different journals. One way the journals differed was on the criteria of mixing of qualitative and quantitative data. Mixing of some kind was most likely to be found in the articles published in JEE (8 of 10) and least likely in AEE (4 of 11), with EJEE falling in the middle (4 of 7). Also, the highest scoring mixed methods article according to the evaluation criteria used in this study (Tables 2 and 3) came from EJEE, which had the smallest number of mixed methods articles in the total sample. Of the two articles ranking the lowest in the evaluation scheme, one was published in EJEE and one in AEE. The variations between the journals suggest that either the different journals have differing criteria for publishing mixed methods articles or that the reviewers identified for the mixed methods publications had different expectations of a mixed methods study. If there was commonality across engineering education, we would expect to see the same percentage of articles in each journal exhibiting mixing qualities.

The general results of this analysis follow findings made by other researchers, but also present new results, which help demonstrate growth in the area of mixed methods research and engineering education. Regarding the categories used to initially group the articles, our findings parallel some of the categories determined by Greene, Caracelli, and Graham[21] where our "additional insight" group is similar to their "complementary" category and our "comparison" group parallels their "triangulation" category. However, our categorization did not have a grouping that paralleled their "initiation" or "multi-level" designs. Another main similarity between the findings in this work and the literature is that many studies do not provide a clear and supported rationale for why mixed methods are used. Past researchers[(e.g., 6 & 16)] have also argued that this is weakness in mixed methods research. Having only two out of the five best articles identify rationales grounded in the literature supports the claim that this is an area of weakness in mixed methods research both generally speaking and in engineering education. This lack of supported rationale also relates to the lack of common terminology observed in past work.[(e.g., 3, 6, & 17)] At this time, there do not seem to be common conventions for presenting mixed methods work. To strengthen the quality of mixed methods research, we suggest that future mixed methods articles clearly articulate a supported rationale for mixing to provide insight into their methodological choices and to assist in the development of common conventions.

A main difference between our findings and past findings relates to the mixed methods research questions. In their most recent textbook, Creswell and Plano Clark[8] argue that having a research

question that requires the integration or mixing of qualitative and quantitative data is a key feature of the design of a mixed methods study. It is logical that one consequence of this omission might be a failure to be explicit about the insight gained from integrating qualitative and quantitative findings. None of the evaluated articles in this study had a mixed methods research question and three articles did not have research questions at all. This finding suggests that engineering education still has room for growth in terms of the framing of research questions to reflect mixing. This is important because models of exemplary mixed methods publications in engineering education are needed so that researchers will employ them in their work in the future. For future studies, we suggest that a mixed methods research question be present in the article to demonstrate the intention of mixed methods research and the insight gained from integrating the strands.

Overall, the results of this study align with the findings from the literature, but they also provide new insight into this form of inquiry. Based on our analysis, we can conclude that there is considerable variability in the quality of mixed methods articles in engineering education including the rationale for mixing and that journals show different trends in terms of the mixed methods articles they publish. Specifically, this study builds on previous work[e.g., 6] by providing the new finding that there is a lack of research questions in the literature that reflect mixing and that these articles can be evaluated with a set of criteria developed out of the mixed methods literature (Table 2). At this time, continued work is still needed to fully understand the relationship between mixed methods research and engineering education, but this study provides future direction.

Limitations

O'Cathian[24] catalogued and provided references for almost 30 different criteria that have been identified in the literature to evaluate a mixed methods research publication. The breadth of the criteria underscores that consensus has yet to emerge among leading mixed methods scholars about core criteria to evaluate a mixed methods study. Paradigm differences among mixed methods researchers limit the likelihood that complete agreement will ever be reached. We utilized a systematic approach to evaluate mixed methods publications in engineering education, using a selected set of core criteria whose utility and applicability to other studies was intuitively obvious. That is not to say that other evaluation criteria would not also be useful or appropriate.

Other specific limitations to the findings should also be noted. First, the 16 articles fully analyzed in this content analysis are only a subset of the articles published in the engineering education field. In engineering education, many articles are published in other journals and conference proceedings that were not included in this sample. Similarly, the findings in this study are specific to engineering education and may not be applicable to other fields.

Conclusions

Based on our work, the key results of our study were:

- Mixing of some kind was most likely to be found in the articles published in JEE and least likely in AEE. Also the highest scoring mixed methods article, according to the evaluation criteria used in this study, came from EJEE.

- A current area of weakness in mixed methods research both generally speaking and in engineering education is identifying rationales grounded in the literature for the methodology.
- Mixed methods research questions are not currently being used in engineering education mixed methods literature, and research questions in general are not always supplied in manuscripts.

From these points, we conclude that there is considerable variability in the quality of mixed methods articles in engineering education and that journals show different trends in terms of the mixed methods articles they publish.

One of the major criticisms of mixed methods research as a whole is the lack of clearly supported, in-depth rationales for mixed methods. This was showcased by the articles identified for this study in engineering education. Future mixed methods studies should strive to incorporate such a rationale to ground and guide their work. Additionally, future works should incorporate mixed methods research questions into their studies to demonstrate their intentionality in mixing and methodological choices. If future studies employ these suggestions, engineering education will begin to build a stronger foundation of exemplary mixed methods studies that can serve as examples of excellence for new researchers. The fields of mixed methods research and engineering education have come a long way since their early beginnings but further work is needed to supply researchers with the tools and examples they need to conduct and present high quality mixed methods research.

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