



Exemplars of Integration in Engineering Education's Use of Mixed Methods Research

Dr. David Reeping, Virginia Tech

Dr. David Reeping is a Postdoctoral Associate in the Bradley Department of Electrical and Computer Engineering at Virginia Tech. He earned his Ph.D. in Engineering Education from Virginia Tech and was a National Science Foundation Graduate Research Fellow. He received his B.S. in Engineering Education with a Mathematics minor from Ohio Northern University. His main research interests include transfer student information asymmetries, threshold concepts in electrical and computer engineering, agent-based modeling of educational systems, and advancing quantitative and fully integrated mixed methods.

Dr. Cherie D Edwards, Virginia Commonwealth University

Dr. Cherie D. Edwards is an Education Research Assistant Professor in the Office of Assessment, Evaluation, and Scholarship in the School of Medicine at Virginia Commonwealth University. Her research and scholarship are focused on exploring the implementation of mixed methods, qualitative, and arts-informed research designs in studies examining issues of education research. Her work in these areas includes but is not limited to her dissertation study examining youth acculturation patterns through an arts-informed approach to mixed methods, exploring professional identity development in medical and engineering students, and formative joint display analysis on dissonance in a cultural competency study of first-year engineering students.

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Abstract

This theory paper explores ways in which the engineering education community can achieve more comprehensive integration in mixed methods designs. We searched for exemplars in the *Journal of Engineering Education*, the *European Journal of Engineering Education*, and the *Australasian Journal of Engineering Education* using “mixed-method” and “mixed methods” as keywords – resulting in 60 viable articles. Using Creamer’s Mixed Methods Evaluation Rubric (MMER), we found exemplar articles demonstrating considerable proficiency across one or more of the rubric’s four criteria: (1) amount of mixing, (2) interpretive comprehensiveness, (3) transparency and (4) methodological foundation. Using the exemplars as discussion points, we advocate for: (1) the use of mixing during analysis to increase the interplay between the different strands of inquiry (amount of mixing), (2) framing results using the study’s constructs, research questions, or perspectives to avoid siloing the study’s approaches (interpretive comprehensiveness), (3) using methods flowcharts to communicate design features (transparency), and (4) drawing from a more extensive body of methodological literature to justify design decisions (methodological foundation).

Introduction

Mixed methods research has gained substantial appraisal in engineering education. Still, there are concerns about using an off-the-shelf approach to conduct such designs without appropriately grounding them in the methodological literature. Methodological transparency is weakened by omitting explicit purpose statements for conducting mixed methods and tying these purposes to mixed methods research questions [1,2]. These methodological foundations have been identified as issues in engineering education research [3]. This critique is not to say that our work is illegitimate or creative work cannot emerge despite not being versed in the mixed methods literature, but there are consequences to the limited exposure in our field. For instance, integration is often relegated to the end of the research process despite being a central feature of mixed methods designs [see 1,2]. Such practices lead to a homogenized set of designs. At the same time, opportunities to mix during analyses are often marginalized [4,5,6,7] in exchange for “cognitive shortcuts” [8] – often limited to typologies – that may undermine a project’s potential.

To offer a different perspective on mixed methods and how integration can be done, we conducted a review of the literature in three journals publishing engineering education research (the *Journal of Engineering Education*, the *European Journal of Engineering Education*, and the *Australasian Journal of Engineering Education*). The goal of our review was to find exemplars demonstrating proficiency in some aspect of mixed methods quality to share with the community, especially in achieving nontrivial levels of integration. Among the designs we

reviewed, we found promising strategies other researchers could leverage in their work. Through this effort, we aim to facilitate more integration points in mixed methods designs, encouraging the engineering education research community to break away from thinking exclusively in terms of typologies and conventional practices in conducting such studies.

Research Aims

The purpose of this theory paper is to show engineering education researchers how they can creatively leverage mixed methods in their research such that they can achieve more methodologically comprehensive integration and transparency. This paper will be of interest to both newcomers and veterans of using mixed methods research designs. In addition to presenting exemplars within mixed methods research designs, we offer additional strategies for researchers who find it challenging to integrate mixed methods beyond the data collection and drawing inferences stages of a project.

Background

Many methodologists have described mixed methods with slight variations in their formulations [9]. At its most fundamental level, mixed methods research is often understood to be the combination of quantitative and qualitative methods, often positioned in terms of data in engineering education [10]. A highly cited review of research methods in engineering education by Borrego, Douglas, and Amelink [11] provides a definition of mixed methods research that is likely familiar to the community:

“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 of the data at one or more stages in the process of research [12].”

Note here the use of “both quantitative and/or qualitative data.” Positioning mixed methods in terms of data rather than approaches can promote dichotomous thinking that data is inherently quantitative or qualitative. This sentiment can crowd out other ways of thinking of data - which Bazeley [4] explains in her work on mixed methods analytical strategies. Aside from the piece by Borrego, Douglas, and Amelink [11], we currently do not have many reviews on how engineering education researchers think about mixed methods research beyond articles that package general social science research methods for a specific audience. We found only two content analyses of mixed methods research in engineering education.

The earlier of the two reviews is attributed to Crede and Borrego [13], who reviewed sixteen articles describing engineering education mixed methods research projects from seven different journals. Of the articles they reviewed, the quantitative findings received 62.7% of the total pages spent on results - which signaled a quantitative priority among the publications. In fact,

four of the articles did not describe analyzing their qualitative data despite collecting them. Their recommendations were threefold: (1) use common terminology, (2) report the collection and analysis of both qualitative and quantitative data, and (3) don't forget to mix the data. Moreover, Crede and Borrego [13] made note that the methodological foundation of the reviewed articles was decidedly weak. Only five of the twelve self-proclaimed mixed methods studies made reference to methodological pieces. Within these five, only a small group of well-known methodological works were cited to justify their use of mixed methods.

The second content analysis was conducted by Kajfez and Creamer [3], who selected sixteen articles from three engineering education journals - the *Journal of Engineering Education*, *Advances in Engineering Education*, and the *European Journal of Engineering Education* - between 2005 and 2011. A major finding of their review was that articles published in the *Journal of Engineering Education* were the most likely to employ mixing, while *Advances in Engineering Education*'s articles were the least likely. While mixing was evident, Kajfez and Creamer [3] critiqued the articles for their weakness in identifying rationales for mixing that were grounded in the literature. They also noted the lack of mixed methods research questions in the manuscripts they reviewed, which help signal the reader to the mixed methods approach. Collectively, these two reviews (i.e., Kajfez and Creamer [3] and Crede and Borrego [13]) suggest that current research designs may be missing opportunities to leverage mixed methods research methodologies fully.

There are several criteria used to evaluate mixed methods publications. Care must still be taken to ensure the quality of the individual components of the mixed methods study, i.e., the quantitative and qualitative approaches. However, it has been clear that separate criteria are needed to evaluate the mixing [14,15,16] - leading to frameworks like the Mixed Methods Appraisal Tool (MMAT) and the mixed methods legitimation framework [17]. O'Cathian [18] identified nearly thirty criteria in her chapter on quality in mixed methods research, and there is still little agreement as to which criteria should be used [19].

We used Creamer's [2] Mixed Methods Evaluation Rubric (MMER) to guide our analyses because it considers the previous critiques of engineering education research and synthesizes much of the debate about mixed methods evaluation criteria. The rubric has four components: (1) amount of mixing, (2) interpretive comprehensiveness, (3) transparency and (4) methodological foundation. These criteria are summarized in Table 1.

Table 1: Summary of the Mixed Methods Evaluation Rubric (MMER) from Creamer [2]

Criterion	Description
Amount of Mixing	There should be nontrivial, meaningful mixing in a mixed methods publication, else the study would be better classified as multi-method. This criterion spotlights methodologists' attention to integration in mixed methods research [see 1].
Interpretive Comprehensiveness	Interpretive comprehensiveness refers to how the researcher(s) engage different perspectives in their study. This can be accomplished throughout the design by picking extreme or negative cases, testing competing hypotheses, and illustrating meta-inferences by highlighting the contributions of multiple methods necessary for the construction of the inferences [2].
Transparency	Mixed methods publications are expected to be transparent about their procedures to ensure replicability. Manuscripts should demonstrate clear alignment in their choice of using mixed methods.
Methodological Foundation	Conducting a mixed methods study places an additional citational burden on the researcher to ensure appropriate references are made to support methodological decisions. Method methods approaches must be situated in the literature just like their monomethod counterparts.

In exploring the literature with these four criteria, we hoped to uncover exemplars or portions of papers highlighting at least one criterion.

Method in Choosing Exemplars

We explored the methodological integrity of articles published in the *Journal of Engineering Education*, *European Journal of Engineering Education*, and the *Australasian Journal of Engineering Education* – beyond a U.S.-centric perspective – by searching for articles that were exceptional cases of integration – highlighting examples from each source. We excluded *Advances in Engineering Education* because a previous review suggested mixing was seen the least in their manuscripts [3]. We used the keywords “mixed-method” and “mixed methods” to locate articles claiming to employ a mixed approach, resulting in a set of 60 papers. Forty-eight of the papers were from the *Journal of Engineering Education*. Seven were from the *European Journal of Engineering Education*. Five were from the *Australasian Journal of Engineering Education*.

We grounded our evaluation using Creamer's [2] mixed methods evaluation rubric. We read the articles individually, noting cases where articles displayed exceptional qualities in one or more of

the criteria using a spreadsheet based on the MMER rubric. After identifying the articles as candidates for exemplars, we collectively selected pieces of articles to highlight as exemplars and other pieces that had potential. We tied each our exemplars to at least one specific criterion in the MMER rubric.

Exemplars of Integration Across the Four Dimensions of Mixed Methods Quality

Amount of Mixing: Transformations and using Joint Displays can be a Form of Analysis

Mixed methods analytical strategies are understood to be processes done during the analysis stage of the research design where the researcher incorporates multiple sources of data simultaneously [20]. Several authors have detailed a plethora of strategies for employing such strategies [2,4,5,10, 21]. However, opportunities to mix during analysis are often underemployed [4,5,6,7]. Aside from being the most difficult stage to integrate within [22], the lack of examples could be attributed to overriding methodological axioms for conducting analyses within certain methodologies. For example, Creswell and Plano Clark [1] describe an approach to conducting mixed methods research wherein analyses are conducted separately, then integration occurs by mixing the individual inferences to produce a meta-inference. This thinking is evident in mixed methods design typologies for both core and advanced where the integration points are described in general terms - e.g., ‘results merged’ - if mentioned at all. Some researchers are employing the strategies methodologists advocate practitioners to use despite the overriding methodological stance of keeping analyses separated.

One example of mixing during analysis using a data transformation and visualizations was Berdanier [23] in the *Journal of Engineering Education*. The purpose of her study was to examine argumentation patterns in National Science Foundation Graduate Research Fellowship Program award statements. In her analytical procedures, she used visualizations called ‘genre maps’ to explore trends in how the writers shifted between ‘rhetorical moves’ - which refers to the objective of the sentence in advancing the overall argument. The rhetorical moves were developed for the *Journal of Engineering Education* study [23] through her preliminary work [24,25].

The documents were coded at the sentence level, assigning an ordinal value corresponding to the rhetorical move the sentence employs. These discrete states shift as the writer progresses through the document, creating a sequence that could be plotted for each document - such as what is shown in Figure 1. Berdanier [23] used these sequences to examine the documents for trends in argumentation structure and found four orientations: methods, process, motivation, and outcomes.

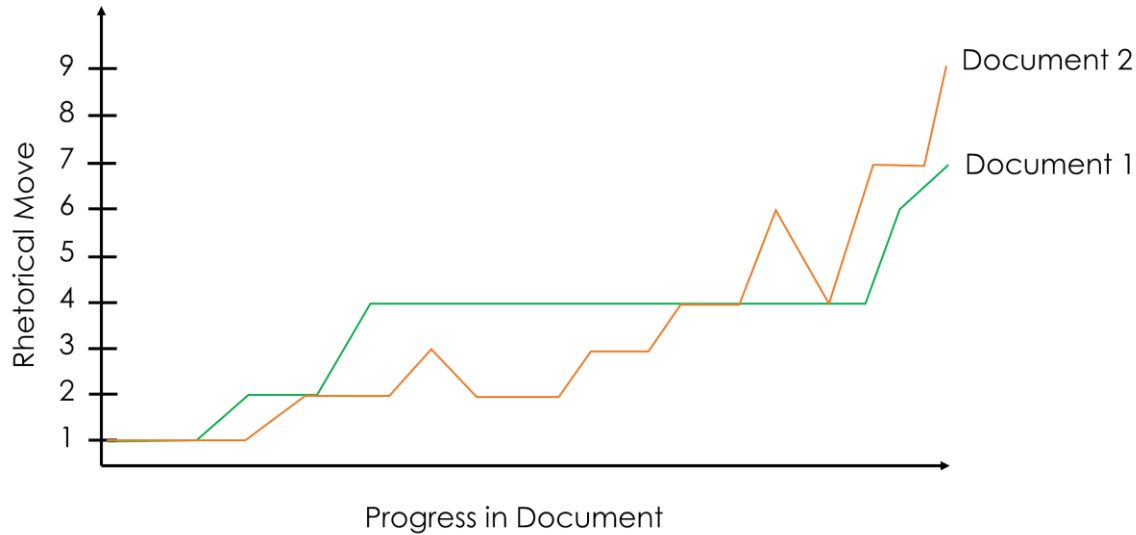


Figure 1: Mock-up example of a genre map used in Berdanier [23] with two documents plotted simultaneously

Berdanier [23] references the methodological literature by stating mixed methods researchers would term her approach as quantifying qualitative data - i.e., quantizing [26] - a specific type of data transformation. Consequently, a weakness of this exemplar may be the author's over-reliance on the literature to describe her approach to analysis. This is illustrated by the author seemingly disqualifying her approach as novel because she is not presenting statistical results and instead uses visualizations of quantized data to generate themes:

“Mixed methods researchers might describe the method as quantifying qualitative data [27]; however, the purpose of the visualization is not to report any statistical or otherwise quantitative data, so I prefer to envision this as a visualization tool that can be extended to other researchers who study argumentation or process-oriented qualitative data.” [23]

This was perplexing to read as there is additional methodological literature that supports her analytical approach. In particular, the use of joint displays - visuals that juxtapose quantitative and qualitative data, or different facets of data, within the same display - as tools to facilitate integration in a design is a burgeoning area of discussion in mixed methods research [28,29]. Her approach would indeed be termed quantizing, but quantizing is broader than reporting statistical inferences or quantitative data - especially in her use of visualizations.

In fact, the use of genre maps is an example of a mixed methods analytical strategy. Berdanier [23] engaged in an inductive quantitative coding procedure with her textual data by transforming it in such a way that revealed a latent structure - the argumentation pattern of rhetorical moves - that could be clustered into patterns. Using visualizations to develop themes inductively is an example of using joint displays formatively [30], which is a novel approach to analysis - as she asserts. At the risk of becoming too convoluted, we can also make the claim that writing

narratives to describe the rhetorical moves is qualitzing, the transformation of quantitative data to qualitative data [26] - which is much rarer than quantizing [2]. Summarizing the trajectories as 'methods-orientation,' for example, captures a specific element of the genre-map, characterizing the shape qualitatively - which is supported by excerpts from the GRFP documents themselves. Generally, these qualitized features could also be grouped using qualitative approaches if the authors prefer not to engage with traditional quantitative methods.

To understand the structure of the data relative to the visually-based coding of the documents, one might also be able to treat the genre maps as a set of time series, correlate them with one another to create a similarity matrix, use a hierarchical clustering algorithm to find groupings, then compare the result(s) to the coding by hand. This process could comprise a convergent mixed methods coding scheme. Remember that we are not trying to generalize in this process. The quantitative methods we use certainly have typical objectives that we tend to ascribe to them. However, generalizability is not their only purpose, provided we acknowledge the limitations of our work. Trying to understand the structure of qualitative codes or themes through a quantitative perspective is not necessarily new either. EFA has been used to understand the relationships among qualitative themes [e.g., 31] and cluster analysis has been used in cases where the sample size is insufficient to conduct an EFA [e.g., 32,33]. Researchers can benefit from thinking about ways to represent their data in a different form and how to code for structure in their data rather than approaching the data thematically - as appropriate to their research question.

Interpretive Comprehensiveness: Framing Results by Construct, Perspectives, or RQs

A barrier to integration is in our style of reporting results. That is, quantitative and qualitative results are often reported separately, and occasionally a mixed section is featured - else the mixing is done in the discussion without a dedicated heading. Templates for writing dissertations and journal articles recommend the divided format [see 30]. This reporting approach often aligns with how the design was conducted, e.g., a quantitative phase followed by a qualitative phase or two phases concurrently, but more integrated designs with multiple stages are not easily split cleanly between quantitative and qualitative results.

Some designs have transgressed the separate quantitative and qualitative results sections and instead framed their results from their themes. Fogg-Rogers, Lewis, and Edmonds [34] in the *European Journal of Engineering Education* and Crede and Borrego [35] in the *Journal of Engineering Education* provide examples of this approach. Another possible approach is offered by Allendoerfer et al. [36] and Hammack and Ivey [37] in the *Journal of Engineering Education*, who organized their results and discussion by research question, respectively. However, one particular approach demonstrated by Atman, Kilgore, & McKenna [38] does represent a high degree of a 'mixed way of thinking' [39] in comparison.

One manner of discussing results in a mixed methods publication is by reporting how the unit of study was examined from multiple perspectives or lenses. This approach is most reminiscent of the premise of dialectical pluralism [see 6,39,40,41,42]. The underlying idea of this paradigm is the purposeful engagement in multiple perspectives - different worldviews, theories, and stakeholders. Atman, Kilgore, & McKenna [38] in the *Journal of Engineering Education* provide one such example of how one could organize their findings by perspective. Their study sought to explore how students learned engineering design by using several data collection methods. What was unique in this approach was the explicit use of language that embodies how mixed methods is discussed in the methodological literature:

“These methods are closed-ended survey questions, open-ended design scenarios, and lab-based engineering design problems. These methods provide three lenses through which we may examine engineering design knowledge. We refer to these lenses in terms of the actions elicited from respondents: select, generate, and demonstrate.” [38 p. 311]

In the case of Atman, Kilgore, and McKenna [38], one data source was associated with a single perspective. However, if different stakeholders frame the perspectives, then multiple sources of data can be associated with a single perspective. For researchers looking to explore contradictions and divergence, this type of approach aligns well with the initiation design posed by Greene, Caracelli, & Graham [43] in their typology of purposes for employing mixed methods [2] - evaluation designs could also benefit. Considering dialectical pluralism is about allowing different perspectives to mix, divergence is likely to occur.

Evaluation designs invite multiple data sources and likely have several stakeholders interested in the outcomes of whatever program is being evaluated, so organizing results by perspectives is possible. Alignment and divergence could then be explored in a section closing the results. Table 2 summarizes the three different approaches we found to organizing results aside from the standard format. Fetters and Freshwater [44] provide similar guidance in their editorial describing how to publish a mixed methods manuscript but tie the recommendations to specific designs. Our advice will apply generally independent of design choices, in most cases. Our suggestions should not imply the typical templates are inadequate organizational tools – they work well with conventional designs. However, if a project goes beyond the three core designs - convergent, explanatory sequential, and exploratory sequential - then other templates may be more appropriate.

Table 2: Approaches to Organizing Findings To Emphasize Mixing

Approach	Results Format Order	Example
Common Recommended Format	QUAN findings, QUAL findings (swapped with QUAN depending on priority), Mixed Findings	Recommended by Creswell & Plano Clark [1]
Mixed Findings Recommended Format	Mixed Finding 1, Mixed Finding 2, ...	Recommended by Fetter & Freshwater [44]
Research Question Oriented	Research Question 1, Research Question 2,	Allendoerfer et al. [36]
Construct/Theme Oriented	Construct/Theme 1, Construct/Theme 2, ...	Fogg-Rogers, Lewis, & Edmonds [34]; Crede & Borrego [35]
Perspective/Lenses Oriented	Perspective 1, Perspective 2, ... , Divergence/Alignment in Perspectives*	Atman, Kilgore, & McKenna [39] *not as presented in example publication, but could be organized as such

Transparency: Methods Flowcharts Can Help Communicate Design Features

Few studies made use of illustrations to describe their methods in our search for exemplars. Timing is a critical descriptor of a mixed methods design [2] for both data collection and analysis, and projects with multiple stages can quickly become difficult to follow if the procedures are not clearly outlined. Integration can be made explicit through visualizations, showing how the different components of the study conversed with one another throughout the design. Using flowcharts of data collection and analyses assist in describing one’s study as mixed methods and, with sufficient detail, can help in arguing the degree to which the design mixed throughout and determine priority. The Morse notational system [45,46] and later modifications by Plano Clark [47], Natasi et al. [48], and Morse and Niehaus [49] are also helpful in characterizing these aspects of mixed methods designs but were decidedly absent in our search of the literature.

One publication made use of a methods flowcharts to illustrate their design and where mixing occurred. Faber and Benson’s [32] work in the *Journal of Engineering Education* sought to explore the relationship between the approach an engineering student takes to solving an open-ended homework problem and different latent constructs: epistemic motivation, engineering epistemic beliefs, and epistemic cognition. They used a sequential explanatory mixed methods study to do so, which can be quickly gleaned from the flowchart in Figure 2. A sequential explanatory design involves conducting a quantitative phase and following up with a qualitative phase in an attempt to expand upon the quantitative findings. The figure could be even more transparent by appending ‘quantitative phase’ and ‘qualitative phase’ to the larger boxes. The

flowchart even expands upon the timing of data collection and analysis by showing how each stage maps to the constructs in the overall research question.

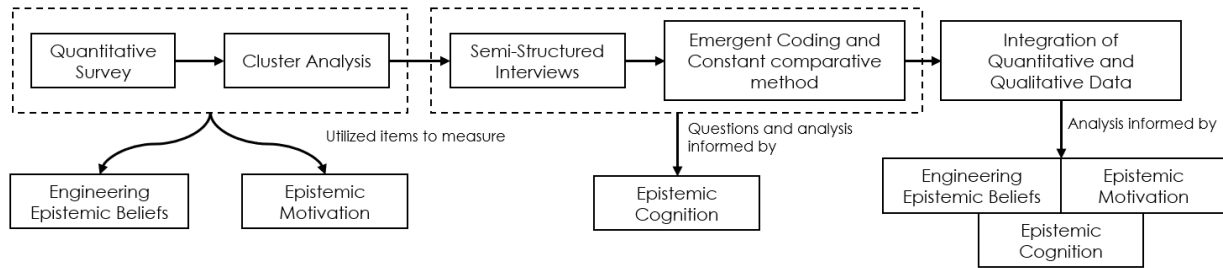


Figure 2: Example of a methods flowchart reproduced from Faber and Benson [32]

There are several ways to construct a method flowchart to illustrate the interrelations of the design’s components. Bazeley [4], Creamer [2], and Creswell and Plano Clark [1] all have examples in their textbooks. The methods flowchart can feature whatever argument the author is trying to make - whether it is about priority, comprehensive coverage of the construct(s) of study, or something else entirely. We provide examples of these alternative approaches in Appendix B.

Methodological Foundations: Grounding Approaches and Supporting Contributions

Creamer’s [2] rubric emphasizes the methodological foundation as a vital component of a mixed methods study’s quality. Mixed methods research is more than combining quantitative and qualitative methods, or collecting both ‘types’ of data. As one would expect references to support the quantitative and qualitative inquiry used in a study, the integration of the two merits literature to reference strategies or paradigmatic assumptions embedded in the process. We found two articles to have a particularly well-constructed methodological foundation: Faber and Benson [32] from the *Journal of Engineering Education* and Shekhar et al. [50] from the *European Journal of Engineering Education*.

These two articles go beyond the cursory citation to common textbooks like Creswell and Plano Clark [28] and draw from broader methodological discussions. In fact, Shekhar et al. [50] made explicit references as to how their approach to mixed methods advanced the field:

“Employing qualitative approaches to help develop quantitative instruments is one of the most common applications of mixed methods to engineering education research. Creswell and Clark (2007) term this an Exploratory Design: Instrument Development Model. However, our design differs from some of this prior work in a few distinct ways.” [50, p. 15]

They emphasize how their design expands upon the ‘Exploratory Design: Instrument Development Model’ described by Creswell and Plano Clark [51], which is a useful component

of the discussion section to situate the engineering education research study into the broader mixed methods research literature. What could have strengthened this argument was a methods flowchart to visualize how the design was more iterative than the generic version presented in the design typology - such as our interpretation of the design in Appendix A, Figure A1. Such a picture could complement their discussion on ways in which they integrated that could get lost in the details of the discussion - like their manner of mixing during the instructor interviews:

“For example, quantitative data collected from initial drafts of our survey instruments were incorporated into the instructor interviews. Instructors were allowed to see this student response during the interview and were asked to reflect on and interpret this numerical data.” [50, p. 15]

This method of integration could be represented in the mixed column and explicitly referenced near the end of the design as shown in Figure A1 in Appendix A. They could also refer to such a process as blending across strands [2] as they used one type of data to elicit additional data as elaboration.

While Shekar et al. [50] showed how one could situate their study as a methodological contribution, a component of Faber and Benson [32] we would like to highlight is the idea of ‘mixed methods data quality.’ Because data analysis is often intertwined with a particular paradigmatic stance or set of assumptions, mixing data together and conducting analyses on the consolidated data carries additional considerations, which is often not acknowledged. Faber and Benson’s [32] paper contained a section explicitly discussing the implications of mixing data and reference the idea of ‘legitimization’ [17] in mixed methods data. It is not necessary to address all nine, as some may not be applicable. Faber and Benson addressed four of the nine. A sample of the section’s introduction is presented here:

“The quality of the mixing in this study was assessed using the legitimation framework [17]. Of the nine legitimation types presented in this framework, the ones most relevant to this study include sample integration, inside-outside, weakness minimization, and sequential.” [32, p. 694]

These types of methodological considerations aid in raising the quality of a mixed methods publication, as they recognize the implications of data integration and draw from the literature to manage the inherent difficulties in the process. They continue by outlining their considerations of the remaining legitimation criteria. For example:

“Inside-outside legitimation, which refers to the degree to which the researcher represents insiders’ (individuals taking the course) and outsiders’ (“objective” observers) views, was addressed throughout the mixing process by reviewing and discussing inferences with other researchers in the field not on the research team” [32, p. 694]

Importantly, we are not advocating for adherence to formulaic approaches in reporting; instead, we offer this suggestion of reporting mixed methods legitimation considerations as a mechanism to address the additional expectations of a mixed methods publication. What we

would like to point out that summarizing these considerations in a table could be more effective in conserving space – a brief table is usually easier to glean as a reader. Writing prose around a laundry list of legitimization criteria could take up valuable space word-count-wise. Some journals might count tables toward the word count, which could be compensated for by using short phrases to explain the considerations to the applicable legitimization criteria. This approach also provides a quick resource that readers concerned about facets of the mixing can refer to as needed. An example is provided in Appendix C.

Discussion

The exemplars we highlighted show the potential of mixed methods research in engineering education and how the integrity of our methods can be strengthened. We had hoped to capture a broader perspective outside of the journals associated with the American Society for Engineering Education through our choice in journals, but the articles we found in the *Australasian Journal of Engineering Education* did not offer much beyond what we reviewed in the *Journal of Engineering Education* and the *European Journal of Engineering Education*. While our review agrees with previously conducted reviews [i.e., 3,13], we have a few additional observations to share with the community.

Observation 1: Methods flowcharts are terribly underused

Echoing Crede and Borrego [13], we found the number of flowcharts used to illustrate mixed methods designs to be underused and, at times, damaging to the accessibility of the manuscript. Mixed methods designs can quickly become difficult to describe, so using different media to communicate them would greatly assist readers and reviewers. Considering the avalanche of scientific work published each year, making the manuscript as easy to grasp as possible is essential to meet the needs of all of the potential audiences. These audiences range from the dispassionate reader skimming for critical points and the seasoned researcher wading through a meta-analysis of tens or hundreds of papers to identify trends in the field.

Flowcharts are recommended by several methodologists [e.g., 1,2,4] to showcase the timing of data collection and analysis. One could also use the Morse notational system [45,46] for communicating the different components of the design. In some cases, the flowcharts would help provide evidence to support the authors' claims. For example, Shekhar et al. [50] claimed they advanced a specific type of mixed methods design by discussing different integration points and their combination of concurrent and sequential strategies. Having a figure handy to reference that emphasized the conversation of different strands of data would ease the need to reread portions of the manuscript to find evidence to substantiate their claims. A *mixing-oriented* flowchart likely would have shown the reader precisely what they wanted to emphasize.

Observation 2: Methodological references are lacking and are homogenized

Again, we are in agreement with Crede and Borrego [13] that the use of literature to support the use of mixed methods is lacking. If we cite papers arguing that mixed methods is a paradigm in of itself [e.g., 52], it is incumbent upon us to support our arguments with the appropriate methodological literature. This expectation would be consistent with how one would legitimize qualitative methodologies such as grounded theory and ethnographies or quantitative methods like social network analysis and regression discontinuity designs. These legitimization frameworks and measures of quality for mixed methods exist and are ready for us to use [see 2,14,15,16,18].

Moreover, a survey of the citations used by the papers we examined for exemplars revealed a relatively homogenous set of authors. Nearly half of the references to the methodological literature were attributable to John Creswell - *this is one perspective of mixed methods research* backdropped by a specific set of philosophical assumptions. We encourage the community to look beyond the foundational methods textbooks and explore the broader methodological literature.

Observation 3: Mixed methods as data rather than methods or perspectives

Likely influenced by the homogeneity in the methodological citations, the field tends to think about mixed methods by positioning data as a primary qualification for a mixed methods study. This thinking is made explicit in authors' statements like "mixed methods assessment data" [53, p. 302] or "qualitative and quantitative data" in describing their designs. Crede and Borrego [13] mirror this understanding of mixed methods in terms of data through their suggestions to the community, specifically in 'reporting the collection and analysis of qualitative and quantitative data' and 'don't forget to mix the data.' While this conceptualization is rather uncontroversial in practice, authors can potentially be forced into choosing a 'legitimate' design from a typology [e.g., 1] if their imagined approach does not fit the nomenclature as they understand it. Moreover, authors can be needlessly concerned with splitting hairs as to what it means for data to be quantitative or qualitative. Bazeley [4,54] explains that data have multiple facets, in both quantity and quality. Our methodological decisions promote meaningful mixing when our methods draw from those different facets of the data, not necessarily that we collected both 'types' of data.

Conclusion

This review of exemplars serves as a resource to researchers in the field to see the frontier of possibilities in mixed methods research. While there are still areas to explore and methodological advances to grasp, many of the scholars in the community are providing excellent examples of integration and mixed methods analytical strategies. We hope these exemplars inspire both

novices and experienced mixed methods researchers in engineering education to push the boundaries on what a mixed methods design can be - even if it means breaking free from the comfort of typological thinking.

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Appendix A: Methods Flowchart for Shekhar et al.

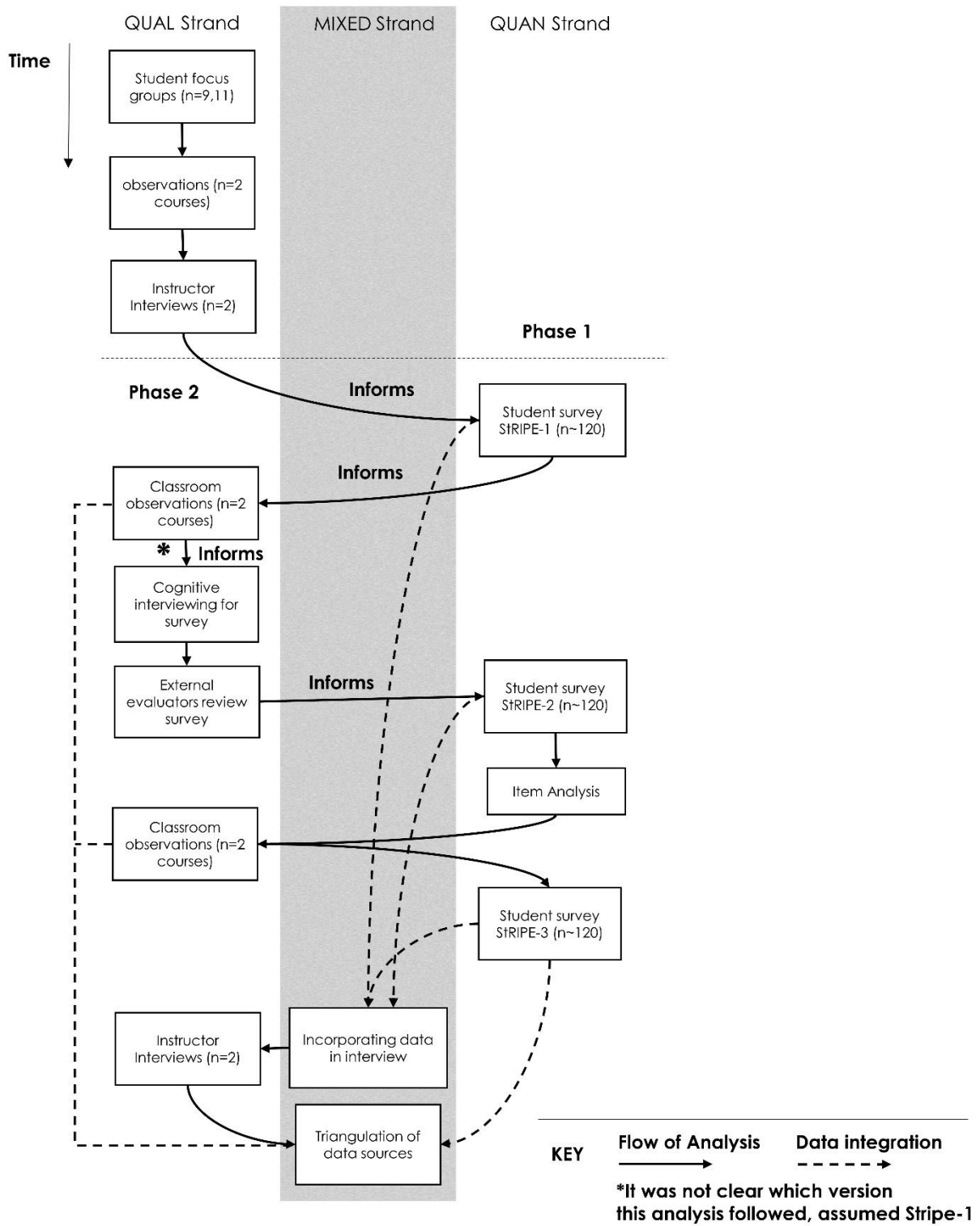


Figure A1: Representation of Shekhar et al.'s [50] design as a methods flowchart to highlight the integration points

Appendix B: Other Ways to Do Methods Flowcharts

Creamer [2] advocates for ‘MIXED priority’ to be considered alongside the usual designations given to priority in mixed methods designs - QUAN, QUAL, or EQUAL. A mixed priority design would make use of multiple mixed methods analytical strategies across the study, which can be displayed in a manner like what is seen in Figure B1. The space dedicated to a ‘mixed strand’ explicitly creates a region in the flowchart where the mixing strategies can be called out and the integration made obvious. Here integration occurs after analyzing both data sources separately, which makes this type of approach less effective. For multistage designs that mix several times, this type of flowchart illustrates the mixing argument more thoroughly.

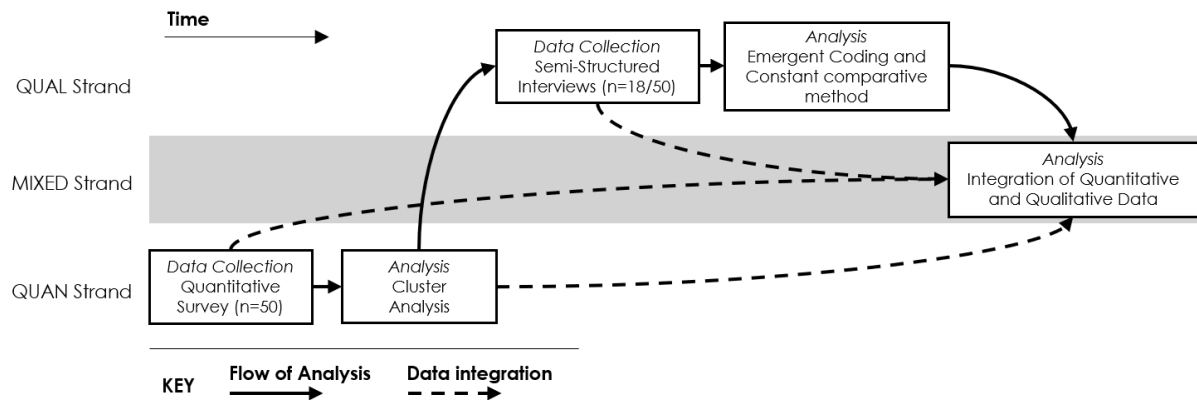


Figure B1. Redesigned methods flowchart prioritizing how mixing is done from Faber and Benson [32], a *mixing-oriented* flowchart

Note also that the “X Strand” naming formula is not compulsory and could be less powerful than other potential names. For example, Reeping [33] framed the strands in terms of constructs, “language” and “fragmentation.” Data collection and analyses that aligned with either construct were placed under the most appropriate column. The mixed strand then allowed the author to emphasize the interplay between the two constructs throughout the design and argue the design was ‘fully integrated’ - and thus had a ‘mixed priority.’

If the goal of the methods flowchart is less about spotlighting the level of integration in the design and more about demonstrating alignment with certain constructs, we could use a flowchart like Figure B2. Such a flowchart shows *coverage* across a specific framework or theory, which could be useful to the author wanting to emphasize that their designs incorporate data collection and analyses across the different components of the study’s framing.

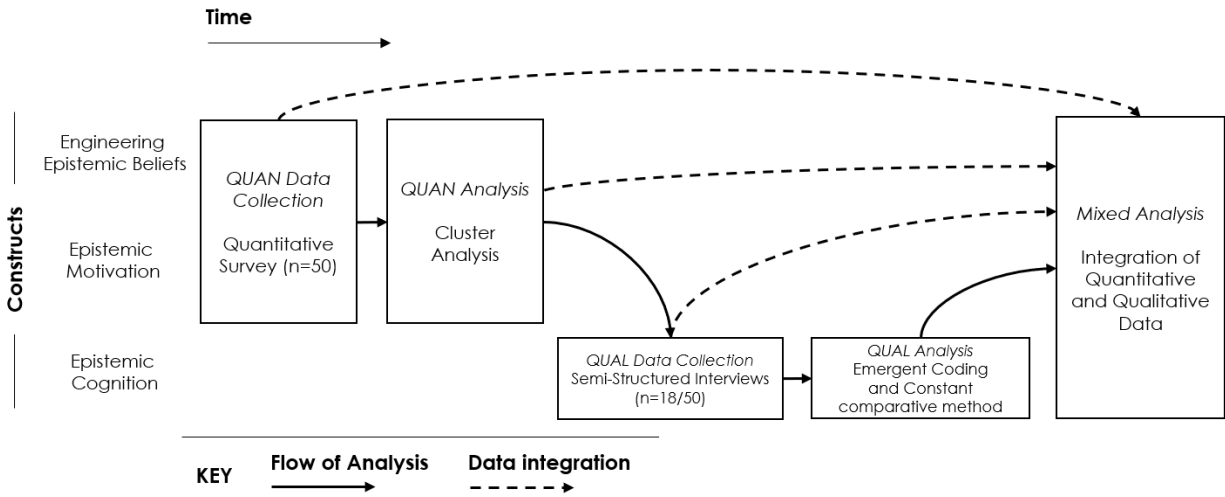


Figure B2. Redesigned methods flowchart prioritizing how data collection and analyses are aligned with constructs from Faber and Benson [32], *an alignment-oriented flowchart*

Appendix C: Summarizing Mixed Methods Legitimization

Table C1: Reframing Faber and Benson's [32] Appraisal of their Mixed Methods Legitimization as a Table

Type	Description	Appraisal
Sample Integration	Consideration of the relationship between qualitative and quantitative sampling designs, can they produce quality meta-inferences?	The sample for the qualitative portion was a subset of the quantitative sample and the results from the quantitative phase were used to inform participant selection for the qualitative phase. This sampling method, which is consistent with recommendations in the literature, reduces the chance of inconsistencies in inferences because of divergent views between the two phases [27]
Inside-Outside	How were the perspectives of the insiders and outsiders accurately considered?	Addressed throughout the mixing process by reviewing and discussing inferences with other researchers in the field not on the research team.
Weakness Minimization	How do the different methods compensate for each other's weaknesses?	Implemented through the use of interview questions that expanded upon student responses to the quantitative survey items. Important to consider because the quantitative scales have not been extensively used to study engineering students.
Sequential	How does the order of your phases affect the meta-inferences?	Considered by interviewing only students who completed the survey and who were equally likely to be influenced in the interviews by the quantitative survey.

Note: The legitimizing criterion for sample integration is not about convergence - it is about the sampling designs synergizing to create quality meta-inferences. Convergence appears to be prioritized in Faber and Benson's [32] design, hence the reference to the sampling methods minimizing the chance of encountering dissonance in their results.