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By The Numbers: A Review of Quantitative Research Methods in Journal of Engineering Education from 2012 to 2022

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Abstract

Engineering education is a fast-growing field. As research questions have become more intricate and nuanced, there have been calls for more sophisticated quantitative methods in engineering education. Traditional quantitative research methods have a long history in educational research, and have been important in developing our understanding of how learning within engineering occurs. However, development of new and advanced quantitative methods allows researchers to conduct more nuanced analyses of student outcomes. In particular, methods for conducting person-centered analyses and analyzing large and nested data sets have become more pervasive in educational research. In this paper, we present a systematic review of 302 papers published in JEE from 2012 to 2022. Specifically, we examined which quantitative methods are used in JEE to develop a picture of the state of quantitative methods in engineering education. The results found that while a large number of studies used basic statistical testing, there is a trend of more advanced quantitative methods being used over the years.

Introduction

Recent decades have witnessed a continued rapid advancement in engineering education research. There has been growth in the number of engineering education departments, degree programs, and research centers, as well as a rise in engineering education-focused publication venues and research products (Borrego & Bernhard, 2011; Jesiek et al., 2009). In addition to the scale-up of engineering education research activities, an emergence of innovative research methods are contributing to the advancement of the field (Carstensen & Bernhard, 2019; Case & Light, 2011). In particular, quantitative research methods have been critical in the growth of engineering education as a field of inquiry (Borrego et al., 2009; Chou & Chang, 2010; Malmi et al., 2018). Engineering education research is benefiting from the applications of these innovative quantitative methods, especially methods designed for big data and person-centered analysis that allow researchers to tackle more nuanced research objectives such as the examination of intersectional identities in engineering (Godwin et al., 2021; Katz et al., 2021; Tan et al., 2021).

Despite recent advances in quantitative methods for educational research in general, multiple review studies in engineering education have identified significant shortcomings in the use of quantitative research methods at an aggregate level. The shortcomings include the omission of presenting and reporting research data, the over usage of simple descriptive statistics and hypothesis testing methods to investigate complex research questions, and the omission of reporting assumptions underlying the quantitative methods use (e.g., Chou & Chang, 2010; Malmi et al., 2018). In addition, many researchers note that quantitative research has remained fixed in positivist epistemologies over the years, resulting in an overreliance on quantitative methods that rely on group means, and thus an underemphasize on the experience of underrepresented or minoritized individuals (Godwin et al., 2021). As such, there is a need to discuss the current state of quantitative methods used in engineering education, and how to promote the broader use of appropriate advanced quantitative methods (Chou & Chang, 2010; Godwin et al., 2021; Malmi et al., 2018).

Given the rapid development and evolution of engineering education, it is essential to recognize, review, and critique the collaborative efforts made by quantitative researchers in recent years with a systematic literature review. Literature reviews on quantitative methods have been commonly and frequently conducted in other fields and have led to calls for increased use of advanced quantitative methods (Kieffer et al., 2001; Hsu, 2005; Zhu, et al., 2020). To address the lack of recent literature review studies in engineering education (Borrego et al., 2009; Chou & Chang, 2010; Malmi et al., 2018), this paper presents an updated and more detailed review focusing on quantitative methods. To fill this literature gap, a systematic literature review of publications in the Journal of Engineering Education (JEE) over the past eleven years, from 2012 to 2022, was conducted and driven by two research questions:

- RQ1: Which quantitative methods were used for studies published in the Journal of Engineering Education from 2012 to 2022?
- RQ2: To what extent are there trends in the use of quantitative methods for studies published in the Journal of Engineering Education from 2012 to 2022?

The answers to the above research questions enable us to make evidence-based recommendations to engineering education researchers using quantitative methods for their studies and editorial teams for engineering education research journals, thus enhancing the overall quality and relevance of research in the field.

Results from Previous Literature Reviews

Systematic literature reviews examining the state of the field of engineering education typically review the subject matter topics researched within engineering education journals (Bronzina et al., 2021; Chou & Chen, 2014; Osorio & Osorio, 2002; Wankat et al., 2014), and studies examining research methods are much less common. There have been a few efforts to summarize the research methods used in engineering education journals, however such efforts are sparse and have focused on a narrow window of time (Borrego et al., 2009; Malmi et al., 2018). To the knowledge of the authors, while there are other types of systematic literature reviews targeting JEE (Chou & Chang, 2010), no study has systematically reviewed the research methodology employed by articles published in JEE.

Borrego et al. (2009) discussed the use of different research methodologies in engineering education as a field and used articles published in JEE as examples. The authors articulated the distinctions between quantitative, qualitative, and mixed methods, examined their advantages and limitations, and offered guidance on how to choose the most appropriate method for a given research question. Furthermore, while the authors found a strong preference for quantitative methods among engineering education researchers, they concluded that all three genres of methods are essential for the advancement of engineering education research and encouraged researchers to seek method advancement beyond the boundary of disciplinaries. However, the authors drew their results from interviewing participants at a prestigious international engineering education conference rather than conducting a systematic review.

In contrast, Malmi et al. (2018) conducted a systematic literature review of methodologies used in 155 papers published in the European Journal of Engineering Education (EJEE) in the years 2009, 2010, and 2013. The authors examined articles across six dimensions, two of which overlap with this review; data source and analytical method. Malmi and colleagues found that questionnaires and interviews were the most used tools for data collection. In addition, the authors found that most articles used simple quantitative methods in their analyses.

Importantly, the authors defined any use of statistical testing (i.e., t-test, regression, SEM, etc.) as complex quantitative, meaning that over half of all articles (50.6%) reviewed only reported simple descriptive statistics or cross tabulations, and did not conduct statistical testing on the quantitative data. In this paper, we extend the categorization from Malmi and colleagues to examine the frequency of specific statistical tests within articles published in JEE.

While relatively rare within engineering education to this point, literature reviews of quantitative methods are commonly conducted in the broader education field (e.g., Kieffer et al., 2001; Wells, et al., 2015; Zhu, et al., 2020). Hsu (2005) conducted a literature review focusing on research methods used in articles published in American Education Research Journal (AERJ), Journal of Experimental Education, and Journal of Educational Research (JER) from 1971 to 1998. Hsu found that experimental, quasi-experimental, descriptive, and correlational study designs were the most frequently used approaches. In addition, simple data analysis techniques such as descriptive statistics, t-test, and ANOVA/ANCOVA were used most frequently. More advanced techniques, such as multivariate regression, general linear modeling, or multi-level analyses were rarely used. A similar overreliance on correlational studies and simple positivistic methodologies has been found in systematic reviews of research methods by Wells, et al. (2015) in higher education journals from 1996 to 2010, by Boreen (2018) in adult education journals, by Counsell and Harlow (2017) in Canadian journals, by Zhu et al. (2020) in articles examining MOOCs, and by Anwar et al. (2019) in examining educational robotics from 2000 to 2018.

Methods

To answer the two research questions presented above, a systematic literature review of publications in JEE was conducted for the years 2012 to 2022. Systematic literature reviews seek to methodically search for, appraise, and synthesize research evidence, and to draw together all known knowledge on a topic area (Grant & Booth, 2009) and are increasingly used within educational research to synthesize the state of the field and make recommendations about future research (Borrego, et al., 2014). This systematic review focused on papers published in JEE because, in addition to its long history and prestige, JEE publishes manuscripts in a wide variety of research areas in the field of engineering education.

The systematic review examined research articles, review articles, and the special themed sections published in JEE. Editorials and erratum articles were excluded from the review as they do not primarily discuss original research. In total, 302 articles published in JEE between 2012 and 2022 were reviewed, while 19 editorials and one erratum were excluded from the review.

In this paper, we extend the coding scheme implemented by Malmi et al., (2018) to iteratively code articles along several dimensions. To code the articles, the authors read each article thoroughly, particularly focusing on methodology, results, and discussion sections. To establish inter-rater reliability, all articles published in 2022 were coded by all three authors, and when their codes were compared, an initial agreement of 97% was obtained. Minor modifications to the coding scheme were made, and following discussion, all discrepancies in coding were reconciled and 100% agreement was reached. The remaining years 2012-2021 were then coded by one coder, with each author coding three or four years of JEE articles.

The first level of coding examined the general method used; quantitative, qualitative, or mixed methods. In this review, the general method categorization used the following definitions to code the articles. Quantitative research was defined as a set of experimental designs, methods, statistics, data analysis, and modeling that aims to represent observed outcomes numerically.

Qualitative research was defined as research that typically involves analysis of data in the form of natural language, observation, expression, and often uses iterative analysis to reexamine and refine initial findings. Mixed methods research was defined as research that collects and analyzes qualitative and quantitative data and integrates their findings to generate new insights (American Psychological Association, 2020). Following this definition, articles that used qualitative methods, such as thematic analysis or grounded theory simply for categorizing data for quantitative analysis rather than to generate or evaluate theory were coded as quantitative rather than mixed-methods articles. Note that in categorizing articles in using this rationale, we do not make any claims about the value of such an approach, nor do we evaluate the effectiveness or appropriateness of the methods used by the authors of these studies. An example of this our categorization scheme is found in Miska et al's. (2022) article. We categorized this article as quantitative because the authors emphasized quantitative analyses and, from our perspective, the thematic analyses appeared to generate categories largely to engage in quantitative comparison.

For articles coded as qualitative research, no further categorization was conducted. Mixed methods and quantitative articles were further coded into standard quantitative research, meta-analyses, measure development, and assessment validation. In this study, standard quantitative research was defined as research that uses hypothesis testing, such as causal comparative, modeling, correlational, quasi experimental, and/or experimental methods. Quantitative meta-analysis is defined as techniques to collect findings from a group of related studies to synthesize a general conclusion, which can be used to determine factors that might be related to the outcome of the study, such as research design and demographic factors. Engineering education measure development is research that focuses on designing an instrument and measuring a specific factor relevant to engineering education (Li et al., 2008). Assessment validation is research that focuses on measuring the validity of the construct of a measure, which is defined as the extent to which an operational measure reflects the concept being investigated (Netemeyer et al., 2003).

Articles using standard quantitative research methods were further coded into 12 broad categories and 73 subcategories. The list of categories, including types of quantitative research, quantitative study design, data source, data type, and quantitative methods used, are summarized in Table 1. These standard quantitative research articles were further coded for study design, data source, data type, and quantitative methods used to analyze the data. Study designs include randomized control trials (RCT), quasi-experimental, assessment validation, and correlational. RCT is defined as an experiment under controlled conditions to demonstrate a known truth or examine the validity of a hypothesis where participants are randomly allocated to groups to minimize bias. Quasi-experimental designs approximate RCT methods but differ in the nonrandom assignment of participants into groups. Typically, quasi-experimental designs have less control over potentially confounding variables, such as differences between classrooms, schools, or years. These designs are useful when RCT is not available or possible, but a causal relationship is of interest. Correlational designs, on the other hand, seek to examine the correlational relationship between variables instead of establishing cause-and-effect relationships. Correlational designs do not fully control extraneous influences and typically use the variable 'as it appears' in practice. Correlational designs are frequently used in survey research, observational research, and analyzing existing data sets (Muijs, 2011).

Standard quantitative research articles were then examined to code for the data source used in the study. Four different data sources were found: course or demographic data, large-scale survey, author-compiled survey or self-collected data or other small-scale survey, and other types of data sources. We define large-scale surveys as surveys that involve more than or equal to 1000 participants, and small-scale surveys as those that involve less than 1000 participants. The specific data source used was reported for data sources categorized as other. The data type used in the standard quantitative research articles were coded into two broad subcategories – simple and complex. Simple data types were further divided into categorical, ordinal, and ratio or continuous data types, while complex data types were divided into cross-sectional, panel data, and time series data types. Categorical data types are data that appear in categories, such as color. Ordinal data types are special kinds of categorical data that represent an ordered sequence of values or categories, such as a Likert scale (Jamieson, 2004). Ratio or continuous data are data that are classified and ranked and have continuous intervals like temperature or speed. Cross-sectional is defined as data that observes many subjects at a given point in time. This definition also covers the cases in which both pre-test and post-test are analyzed. Panel data is defined as data that measures many subjects at three or more time points. Time series is defined as one type of data indexed in time order, such as stock market data over time (Benavides Rosales, 2019).

Table 1

Codes and categories of research methods, types of quantitative research, quantitative study design, data source, data type, quantitative methods used

Research methods (3 categories)		
1. Qualitative		
2. Quantitative		
3. Mixed		
Types of quantitative research (5 categories)		
1a. Standard (hypothesis testing)		
1b. Metanalyses	1c. Engineering education measure development	
1b. Theoretical review	1d. Assessment validation	
Quantitative study design (4 categories)		
1. Randomized Controlled Trial (RCT)	3. Quasi experimental	
2. Assessment validation	4. Correlational	
Data source (4 categories)		
1. Course data/demographic data	3. Author compiled survey/self-collected data/other small-scale survey	
2. Large-scale survey	4. Other	
Data type (6 categories)		
1. Categorical	4. Cross sectional	
2. Ordinal	5. Panel data	
3. Ratio/continuous	6. Time series	
Quantitative methods (12 categories and 73 subcategories)		
Category 1: Descriptive statistics		
1. Mean 2. Median 3. Standard deviation	4. Standard error 5. Counts 6. Percentages	7. SE in parameters
Category 2: Basic inferential statistics		
8. t-test 9. ANOVA 10. ANCOVA	11. MANOVA 12. MANCOVA	13. Chi-square 14. Discriminant analysis

Category 3: Simple correlation		
15. Pearson’s r 16. Spearman’s rho (ρ) 17. Phi (Φ)	18. Point-biserial correlation 19. Tetrachoric correlation 20. Kendall’s tau (τ)	21. Canonical correlation 22. Partial correlation
Category 4: Linear regression		
23. Simple linear regression (1 independent variable) 24. Multiple linear regression (>1 independent variable)		25. Stepwise linear regression
Category 5: Generalized linear regression		
26. Logistic regression/Probit regression 27. Multinomial logistic regression 28. Tobit regression 29. Ordinal regression	30. Poisson regression 31. Zero-inflated Poisson regression (ZIP) 32. Negative binomial regression	33. Zero-inflated negative binomial regression (ZINB) 34. Gamma regression 35. Other regression*
Category 6: Hierarchical Linear Regression		
36. Multi-level regression 37. Fixed-Effect Regression	38. Hierarchical Linear Modeling (HLM)	
Category 7: Data reduction		
39. Exploratory Factor Analysis (EFA) 40. Confirmatory Factor Analysis (CFA)	41. Primary Components Analysis (PCA)	42. IRT (Item Response Theory) Modeling
Category 8: Time series modeling		
43. Growth Curve Modeling	44. Autoregression	
Category 9: Complex structure		
45. Path Analysis	46. Structural Equation Modeling (SEM)	
Category 10: Data mining/machine learning		
47. Cluster Analysis 48. Text Mining 49. Natural Language Processing	50. Random Forest 51. Neural Nets/Deep Learning	52. Reinforcement Learning 53. Decision Tree
Category 11: Nonparametric statistics		
54. Mann-Whitney U 55. Kolmogorov-Smirnov Test 56. Kruskal-Wallis 57. Log likelihood	58. Fisher's exact test 59. Kendall's W 60. Wilcoxon Signed Ranks 61. Cramer's V	62. Welch's F 63. Friedmann Rank Sum Test 64. Nemenyi Multiple Comparison Test
Category 12: Effect sizes		
65. Cohen's d 66. Odds ratio 67. Coefficient of determination (r^2)	68. Standard error in effect size 69. Confidence Intervals 70. eta-square	71. Average Treatment effect (ATT) 72. Standardized Regression Coefficients 73. Percentage variance Z/sqrt(N)

Note: Other regression methods that were observed in the publications and categorized in “Other regression” were Negative Binomial Mixed Model (NBMM), Marginal Regression Model, Cox Proportional hazard, Linear Regression with propensity score matching, and Discriminant Function Analysis. One publication did not specify the regression method they are using (Jackson et al., 2021).

Results

A total of 302 papers published in JEE from 2012 to 2022 were reviewed. Figure 1 presents the proportion of quantitative, qualitative, and mixed research methods published per year in JEE from 2012 to 2022. Because the numbers of publications change every year, the results are represented using the percentage of articles published in a given year to allow for comparison and to better visualize trends in research methods over time.

As can be seen in Figure 1, quantitative methods were the dominant research method with 167 out of 302 (55.3%) articles, while 106 out of 302 (35.1%) articles used qualitative methods, and 29 out of 302 (9.6%) articles used mixed methods. While the proportion for each method fluctuated over time, the percentage of articles using qualitative methods were higher in 2019 and 2021 compared to previous years. The proportion of mixed methods also varied yearly, between 18% in 2016 to 0% in years 2013, 2018, and 2020.

Figure 1

Proportion of quantitative, qualitative, and mixed methods research in JEE from 2012 to 2022

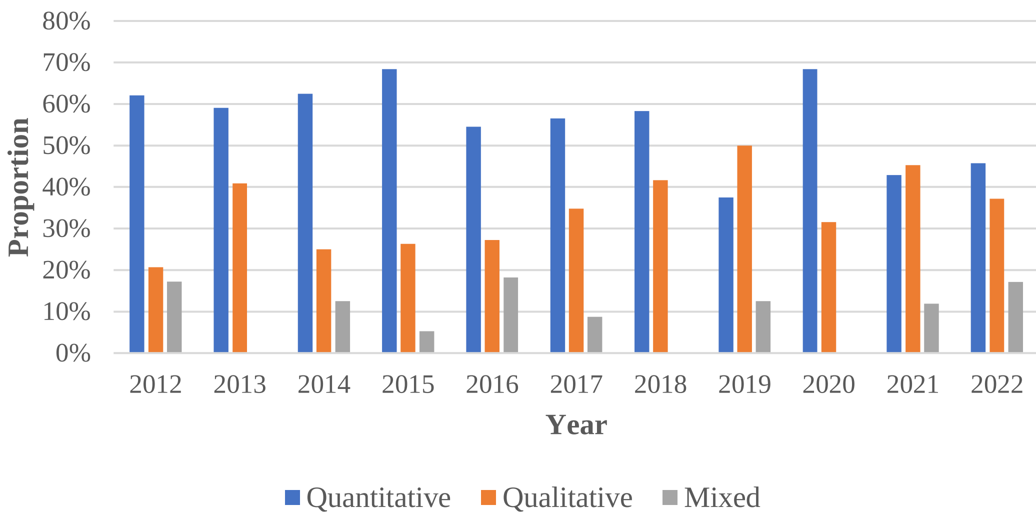


Figure 2 displays the proportion of types of quantitative research in JEE. Standard quantitative research is the dominant type of quantitative research, with a total of 111 of 167 (66.5%) quantitative research articles. The yearly proportion of standard quantitative research fluctuated from 89% in 2019 to 46% in 2017. There was a significant proportion of engineering education measure development publications in 2017 at 31%. The trend of non-standard quantitative research fluctuated over time, as there were certain years where a specific type of quantitative research was trending, such as assessment validation in 2015 (31%), and there were years where there were no publications that used a specific type of non-standard quantitative research.

Figure 2

Proportion of types of quantitative research in JEE from 2012 to 2022

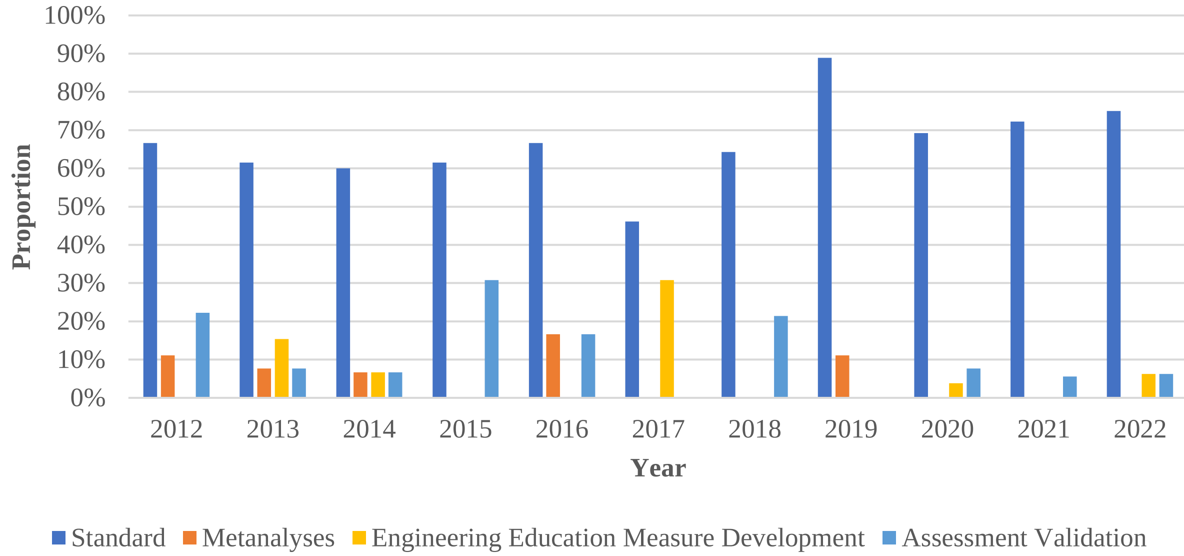


Figure 3 shows the proportion of quantitative study design in JEE. Correlational studies were the dominant study design in quantitative research, with a total proportion of 71.1%, while the trend of other quantitative study designs fluctuated over time. RCTs were relatively uncommon with the exception of 2013, where 42.9% of articles used RCT methods. Quasi-experimental studies saw a surge in popularity in 2022, when 40% of standard quantitative articles used a quasi-experimental study design.

Figure 3

Proportion of quantitative study design in JEE from 2012 to 2022

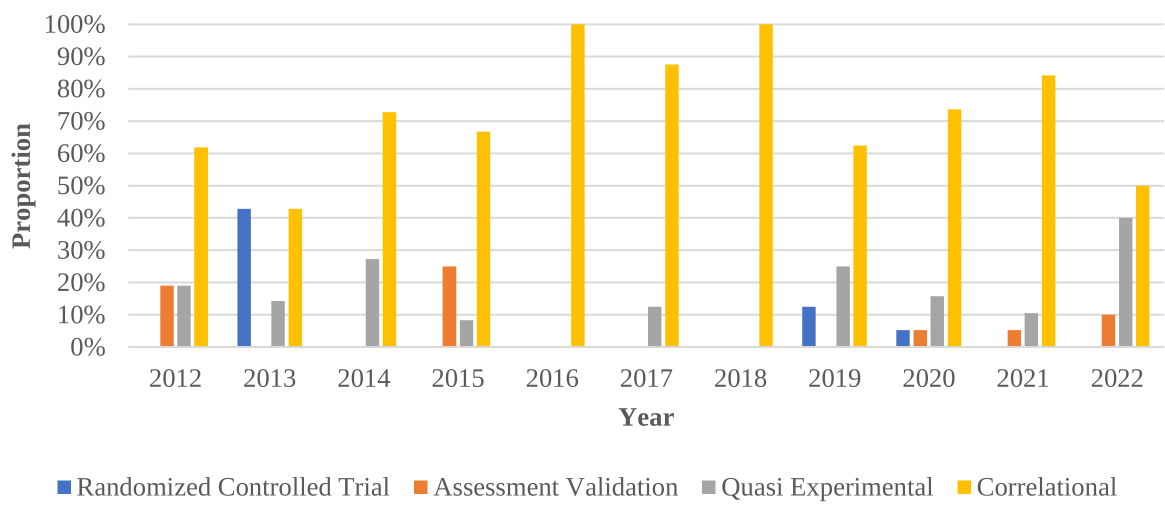
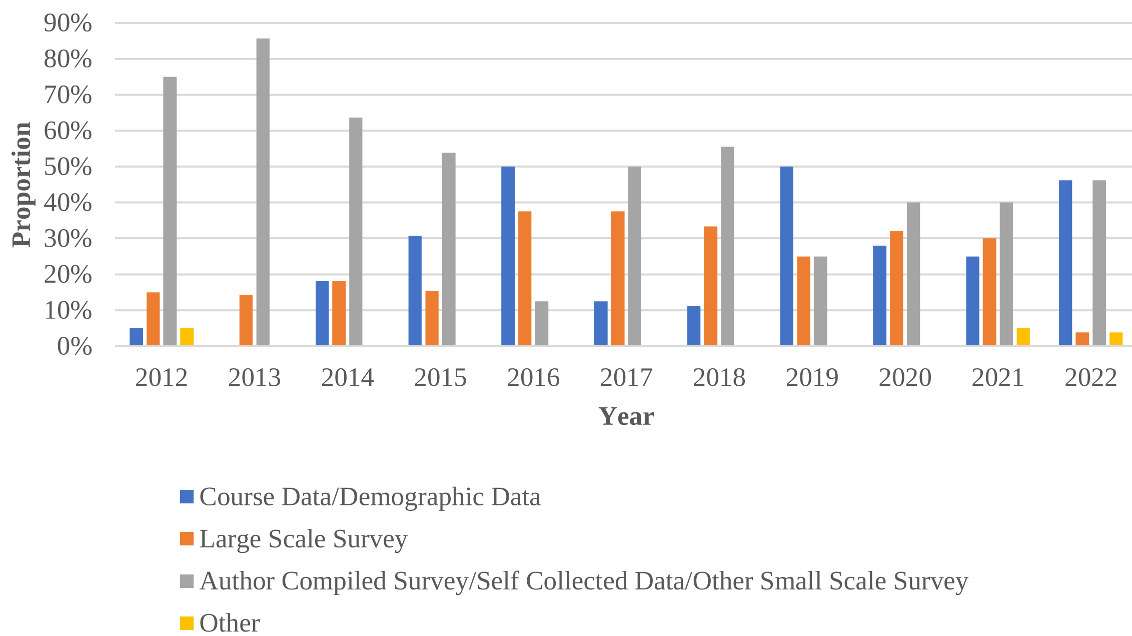


Figure 4 exhibits the proportion of quantitative data sources over time. Author-compiled surveys, self-collected data, and other small-scale surveys were the dominant data sources, with a total proportion of 49.65% of the standard quantitative research articles. The use of course data increased over the past decade and has become predominant since the start of the COVID-19 pandemic. This shift in data sources could reflect the difficulty that researchers had in recruiting study participants during the pandemic, or may reflect a shift in research focused towards instructional interventions. An interesting area for future research could examine the reason underlying this shift and whether this shift remains post-pandemic. Large-scale surveys were consistently found in more than 10% of the articles from 2012 to 2021, however, this ratio dropped in popularity in 2022 with only 3.85%. Other types of data sources were observed three times, namely observational data (Marra et al., 2022), stratified random sample of institutions in the United States (Reeping & Knight, 2021), and MIDFIELD large-scale database (Brawner et al., 2012).

Figure 4

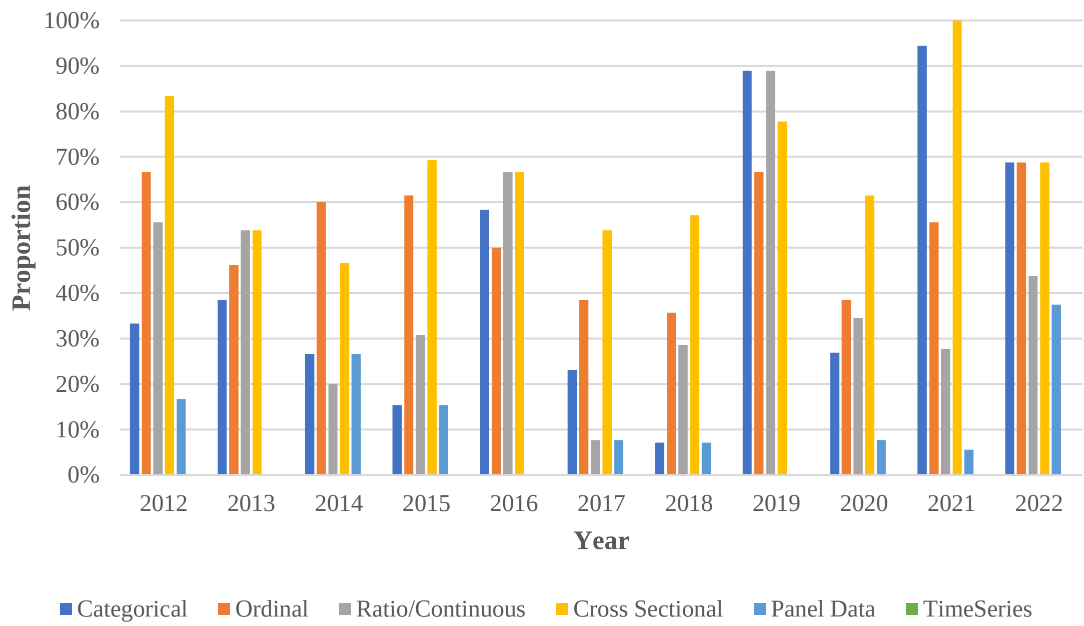
Proportion of data source trend in quantitative research in JEE from 2012 to 2022



The proportion of data types can be seen in Figure 5. The percentages were found by dividing each data type by the number of quantitative studies published in that year. It is important to note, however, that because quantitative research often employs more than one data type, percentages in a given year do not necessarily sum to 100%. Cross-sectional data was the dominant data type used in quantitative articles published in JEE. The proportion of quantitative studies that used cross-sectional data was above 50% every year except in 2014, and in 2021 all 18 quantitative publications used cross-sectional data. Panel data gained a significant increase in popularity in 2022, with up to 37.5% of quantitative publications using panel data type. There were no quantitative studies in JEE that used time series data from 2012 to 2022.

Figure 5

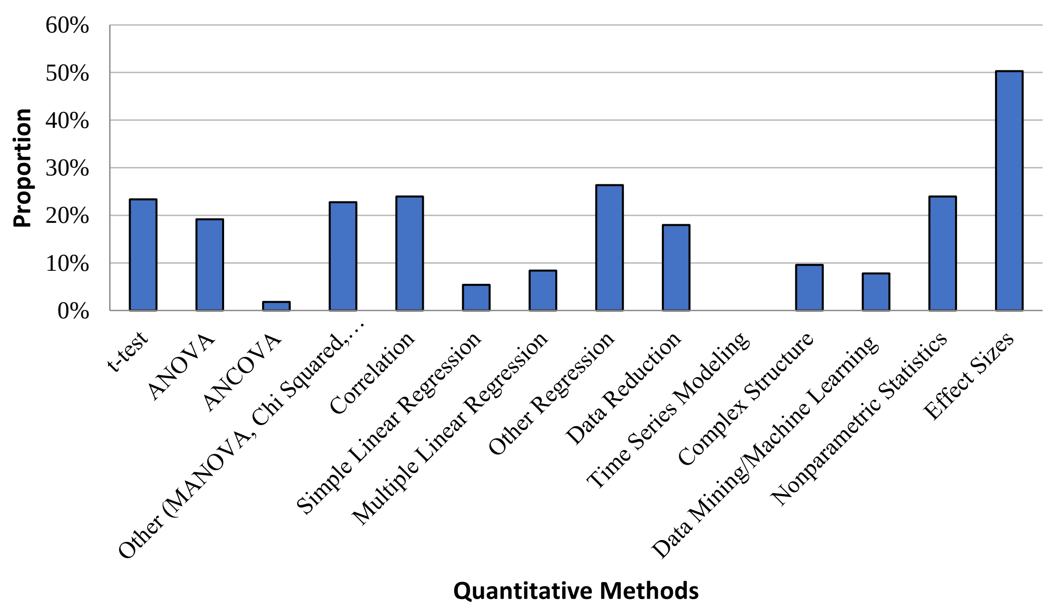
Proportion of data type trend in quantitative research in JEE from 2012 to 2022



The proportion of quantitative methods trend in JEE can be seen in Figure 6. For this diagram, we aggregated the number of times each method is used in quantitative studies and divided it by the total number of quantitative studies published in JEE from 2012 to 2022. Since quantitative research studies often use multiple methods, percentages in a given year do not add up to 100%.

Figure 6

Proportion of quantitative methods trend in JEE from 2012 to 2022



As has been found in other review studies, simple and group-centered analyses were the predominant quantitative methods used in articles published in JEE from 2012 to 2022. However, there were some articles that employed advanced modeling methods such as Hierarchical Linear Modeling, Structural Equation Modeling, or Random Forest Regression. In addition to the predominant use of simple analytical methods, only about half of quantitative studies (84 out of 167, 50.3%) reported effect sizes in their analyses.

Limitations

Our study has the following limitations. First, this study focused on one Journal, JEE, which does not allow for a complete picture of the state of quantitative methods used in engineering education research. While JEE was selected for this study given its high reputation and broad readership in the field, it is plausible that other journals exhibit different trends in the usage of quantitative methods. Future research efforts should include a comparison of publication trends in JEE to other engineering education journals, such as the International Journal of Engineering Education, to draw more comprehensive and robust conclusion.

Another caveat of this study is that most of the articles were coded by a single researcher, which could have resulted in discrepancies and mistakes. While inter-rater reliability was examined for all articles published in 2022, it is possible that additional discrepancies may have been resolved by having multiple coders for every article. Future research should aim to employ multiple coders for every article to examine the inter-rater reliability, as well as investigate the potential for using Natural Language Processing (NLP) as an automated coding solution, which would minimize human error and potentially enhance the precision of the coding process.

Discussion and Conclusion

In this paper, we conducted a systematic literature review to examine the quantitative methods used in engineering education research published in JEE between 2012 and 2022. Our review encompassed a total of 302 papers and revealed the use of a diverse array of quantitative methods in engineering education research, including newer, more advanced, and person-centered methods that have emerged recently. Our findings indicate that there is an inclination towards utilizing more sophisticated quantitative methods over time, which suggests that researchers are increasingly making use of techniques that facilitate a more nuanced analysis of data. However, there is a need for a more widespread use of advanced statistical analyses to address complex and nuanced research questions important to the field.

Our results are consistent with Borrego et al. (2009), highlighting the importance of quantitative methods in engineering education research. Nevertheless, our results also documented the prevalence of using all quantitative, qualitative, and mixed methods in JEE, as asserted in Borrego et al. (2009). Finally, our results echo Borrego et al. (2009)'s call for using advanced quantitative research methods beyond the boundary of disciplinaries, as many of the advanced methods originated from other social sciences fields. While the excessive reliance on basic descriptive statistics is still common, our results underscore joint efforts made by engineering education researchers toward using person-centered analyses and examining large datasets, consistent with the latest advancements in quantitative research in education (Godwin et al., 2021; Katz et al., 2021; Tan et al., 2021).

Understanding the current methods used in the literature has several important implications: it enables researchers to make informed decisions about which methods to use, helps them identify areas where methodological advancements are needed, and supports the development of more effective and impactful research in engineering education. Furthermore, the findings of our analysis can serve as a basis for further investigations and could be used to create suggestions and standards for using quantitative methods in engineering education research and to make recommendations to engineering education programs for the preparation of doctoral scholars. While this initial systematic literature review sheds light on the state of quantitative methodology in engineering education, future research should seek to expand the data to other journals to more accurately describe the current state of the field. In addition, future research should aim to scrutinize the status quo of quantitative methods in engineering education research by further examining issues related to undeclared method assumptions, unsupported causal claims, and a lack of reported effect sizes.

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