Mapping Global Trends in Engineering Education Research, 2005–2008*

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Engineering education research in many countries and regions is gaining momentum and coherence as a field of academic activity. Yet what quantity and kinds of research are currently being done, both worldwide and in specific nations and regions? Additionally, what collaborative patterns are now evident in the field, including in terms of the size and multi-national composition of research teams? To address these research questions, we first review previous attempts to quantify and characterize research on engineering education and related fields. We then use theoretical and methodological insights from social studies of science, bibliometrics, and scientometrics to perform quantitative and qualitative analysis of 2,173 journal articles and conference papers published 2005 to 2008. Our findings are presented in five main parts. First, we describe how basic criteria were used to identify 885 empirical research papers and track changes in the orientation of the major publication outlets in the field. Second, analysis of author affiliation information allows us to report on publication activity by country and region. Third, we discuss evidence of collaborative patterns, including co-authorship trends and prevalence of multinational research teams. Fourth, we examine keywords in article metadata to report on the prevalence of 38 categories representing different research topics and contexts. Fifth and finally, we examine co-occurrence of articles by category. The paper concludes with recommendations for building global capacity in engineering education research, including suggestions for expanding cross-national collaboration in targeted research areas and improving access to the field's literature.

Keywords: bibliometrics; collaborative research; empirical research; engineering education research; global; international; ontology; scientometrics

1. Introduction

Engineering Education Research is gaining global momentum and coherence as a field of academic activity. In settings as diverse as Malaysia, Australia, Europe, China, and the United States, engineering education is at the heart of new academic centers, doctoral degree programs, and even academic departments. The United States, Australia, and parts of Europe are especially visible due to the field's deep historical roots, high levels of research productivity, and active communities in each of these locales [1, 2]. In addition, publication outlets like the *International Journal of Engineering Education (IJEE)* and *Journal of Engineering Education (JEE)* have embraced the mission of publishing and disseminating high-quality research worldwide [3–5], while the Research in Engineering Education Symposium (REES) series has similarly promoted the development of an international research community [6, 7].

Another important effort to internationalize the field occurred in 2007 and 2008 through a partnership between *JEE* and the *European Journal of Engineering Education (EJEE)* titled Advancing the Global Capacity for Engineering Education Research (AGCEER). Through a series of special sessions at engineering education conferences worldwide, one goal of the initiative was to cultivate a global network of engineering education scholars and practitioners, including to identify infrastructures needed to sustain such a community [8, 9]. Yet as we report elsewhere, these sessions revealed that many advocates of engineering education research remain preoccupied with the field's sustainability in local contexts. Participants at sessions held in Australasia, Europe, and the United States, for example, felt their home institutions were not providing adequate support for engineering education research [9]. An emphasis on the local over the global was also evident at one of the European AGCEER sessions, where organizers were unable to form a discussion group on "enablers and barriers to international collaboration" due to a lack of interest among attendees [9].

While such tendencies are not surprising in a relatively young domain of research, other scholars

Table 1. Summary of Wankat's keywords (descending order of occurrence) [11, p. 39; 12, p. 14]

1. Teaching	7. ABET*	13. Distance Education*	19. Retention
2. Computers	8. Learning	14. Communication/Writing	20. Programming*
3. Design	9. First Year	15. Ethics	21. Aeronautical Eng**
4. Assessment	10. Curriculum	16. Experiential/Hands On*	22. Quality, TQM/QCI**
5. Groups/Teams	11. Laboratory	17. Entrepreneurship*	
6. Internet/Web*	12. Gender/Women	18. International/Global	

 * Keywords added in 2004, but not included in the 1999 analysis.
** Keywords included in the 1999 analysis, but dropped in 2004.

have noted that the lack of an international profile may limit the progress and potential of research fields, especially if isolated researchers "reinvent the wheel" by tackling similar problems and questions using rudimentary approaches [10, pp. 5–6]. In the field of engineering education research, extensive networks are not currently in place to connect researchers from different countries who share an interest in similar topics and approaches. Relevant research is published in a wide array of literatures that are not centrally indexed or easily searchable. It is also not yet clear which engineering education research areas would most benefit from international collaboration, and we know little about how various theories, methods, and findings might move—or not move—across national and cultural boundaries.

The present study responds to these challenges by mapping global trends in engineering education research. More specifically, we report on the results of an in-depth quantitative and qualitative analysis of relevant conference papers and journal articles published 2005 to 2008. Through this work we address the following research questions:

1. What quantity and kinds of engineering education research are currently being done, both worldwide and in specific nations and regions? If significant local variations are detected, how do we account for them?
2. What collaborative trends are now evident in engineering education research, including in terms of the size and multi-national composition of research teams?

The resulting analysis provides important new insights about the evolving character of engineering education as a research field, in both local and global contexts. For example, we identify recent key changes in the orientation of a number of journals and conferences, point to a number of "enabling factors" that may help explain particularly high levels of activity in certain countries and regions, and describe some current collaborative trends. We also present new categorization and visualization strategies to identify leading research areas and conceptualize their inter-relation. We intend to provide readers with insights about the

current state of engineering education research, ideas for analyzing similar bodies of literature, and inspiration for strategically supporting the field's development across diverse local and global contexts. As additional grounding for our study, we begin by reviewing prior attempts to systematically analyze and characterize engineering education research.

2. Literature review

2.1. Mapping engineering education research

Previous attempts have been made to quantify and characterize the breadth and depth of engineering education research, with particular emphasis on the US. Wankat, for example, performed a detailed analysis of *JEE* articles from 1993–1997 (n = 230) and 1993–2002 (n = 597) [11, 12]. Since the journal did not use author-defined keywords during these periods, Wankat placed each article in up to four categories, which are listed in Table 1. He provided little description of his specific categorization procedures, but acknowledged the subjective nature of assigning keywords and suggested a panel of researchers would likely be more reliable than a single researcher [12, p. 13]. He also analyzed whether or not articles were discipline-specific, which reduced the need to create categories for engineering sub-disciplines. In addition, he tracked trends over time and assessed the research orientation of the journal, observing notable increases in research funding, the use of theory, and number of citations.

In 2004, Whitin and Sheppard performed a similar analysis of *JEE* articles published 1996–2001 (n = 398) [13]. Describing their approach as "different and complementary" to Wankat's, they assigned each article to one of six categories: Courses and Programs (34% of articles), Faculty (23%), Assessment and Evaluation (20%), Students (12%), General/Miscellaneous (6%), and Practitioners and Alumni (5%). In addition to basing their categories on Wankat's earlier work, they also improved the validity and reliability of their procedure by having one researcher code all papers, while two researchers verified the consistency of the coding with an unspecified sample.

Whitin and Sheppard identified trends similar to those noted by Wankat, including the journal's increasing focus on research.

Taking a more international perspective, Osorio and Osorio analyzed *JEE* and *EJEE* for the period 1998–2000 (n=331 articles) [14, 15]. Three results of this work are worth noting.

First, it presents data on the geographic distribution of authors to demonstrate the dominance of US authors in *JEE* (191 of 212, or 90% of articles), followed by authors from Canada (8 articles), Puerto Rico (2 articles), and the United Kingdom (2 articles) [14, p. 60]. *EJEE* reflected greater geographic diversity, with 27 of 119 papers by first authors affiliated with institutions in the UK, then Australia (12 articles), the US (10 articles), and Denmark (8 articles) [14, p. 60].

Second, these studies examined journal contents by article type, specifically case studies, reviews/syntheses of relevant research topics and fields, editorials, program reports, research papers, reports of survey results, and descriptive accounts (i.e. descriptions of courses, project, programs, or teaching methods). For the period in question, Osorio and Osorio noted large numbers of descriptive papers in *JEE* (45.3%) and reviews of topics and fields (32.7%) in *EJEE*. Papers more ostensibly research-oriented in character—including research papers, reports of survey results, and case studies—comprised 30.2% of articles in *JEE* and 26.9% of articles in *EJEE*.

Third and finally, these researchers generated a two-tiered classification scheme to assign up to three "subjects" to each paper. While various inconsistencies make it difficult to summarize the authors' findings, we infer that the leading subjects for papers in their dataset include, in roughly descending order of occurrence: assessment (including evaluations of program and student performance), teaching, instructional/educational technology, curricula, and learning [14, pp. 63–64].

Another approach to mapping engineering education research trends is exemplified by Borrego's 2007 study of the archival publications of four US National Science Foundation funded Engineering Education Coalitions from 1990–2005 (n = 700) [16]. This analysis employed a theoretical framework of disciplinary development and a more complex, hierarchical categorization along three orthogonal dimensions:

1. Population: who was the principal group being studied or benefiting from the change (e.g. freshmen/first-year students, faculty/staff, senior design students, women/minorities)?
2. Methodology: what intervention served as the impetus for publishing (e.g. coalition created,

active learning methods introduced, new mentoring program created, an assessment instrument developed)?
3. Contribution: how was the change being communicated or transferred (e.g. web site, instructional module, survey tool, article simply describing the experience)?

While the analysis was initially conducted to understand dissemination patterns for engineering education innovations, the more significant findings emphasized progress over time, and especially the role of reform, innovation, and assessment in laying foundations for more rigorous and systematic engineering education research.

Taken collectively, these prior analyses indicate that the long-term, historical trajectory of engineering education tends toward more systematic, evidence-based research. Given the similarities of findings across cases, and relatively significant changes in the foci of the journals in question, it is unlikely that additional analysis going back over a long period of time is warranted. The relevance of such efforts is also limited by ongoing contextual shifts, including changing definitions of engineering and the continued impacts of technology, communication over distance, globalization, and concerns about sustainability and other engineering "grand challenges."

2.2 Mapping computing education

Casting a wider net reveals efforts to develop categorization schemes and map literature in other related research fields. While a comprehensive review of such work is beyond the scope of this paper, studies of computing education are especially relevant due to topical and community overlaps with engineering education. Simon, for example, reviewed prior efforts to classify publications in computing education, including by type of paper, methods employed, and subject areas [17]. He also developed a new classification scheme based on research topic, context of study, and nature of the paper (position, report, analysis, or experiment). Finally, he categorized relevant papers (n=175) from seven Australasian Computing Education and National Advisory Committee on Computing Qualications conferences. Simon concluded that descriptive papers and practice-oriented "reports" dominate this body of literature; computer programming was the most common focus of papers; and teaching/learning techniques was the most prevalent research topic, followed by curricula and teaching/learning tools.

In a follow-up study, Simon et al. used the same system to categorize papers (n=43) from a series of

International Computing Education Research workshops held 2005–2007 [18]. In addition to using various methods to improve the reliability of classification by multiple researchers, the authors reported a relatively high percentage of "research" papers (88%) and multi-institutional studies (33%) in their dataset. Fincher et al., on the other hand, examined multi-institutional and multinational trends as potential markers for the development of computer science education as a research discipline, but used a more descriptive, case study approach to examine a small number of specific projects in detail [19]. This approach allowed for richer comparisons across projects, including in terms of the composition of research teams, study design, methods, target populations, and findings.

2.3 Engineering education research agendas

The analyses presented above are mainly concerned with mapping historical and contemporary research trends, including identification of areas of vitality and opportunities for future growth. Yet using such findings to set directions for future research may be difficult, especially if strong and coherent bodies of literature do not yet exist. Enlisting relevant experts and/or stakeholders to develop a research agenda can provide a more forward-looking approach to both characterizing and envisioning the landscape of engineering education research.

In 1980, for example, a special issue of *Engineering Education* (now *Journal of Engineering Education*) included an article that presented "A Proposed Educational Research Agenda" [20]. Developed by one author in consultation with four of his colleagues, the agenda featured eight major areas:

1. skills inventories,
2. career preparation,
3. laboratories,
4. faculty recruitment and hiring,
5. motivation,
6. instructional modes,
7. dynamics of innovation,
8. the learning process.

Based on the publication analyses cited above, as well as our own work, we conclude that most of these areas have indeed developed into vibrant research areas, or at least remain a concern in the field.

Much more recently, the Engineering Education Research Colloquies "were designed to collaboratively develop a national research framework and agenda to conduct rigorous engineering education research" [21]. Various strategies were used to organize and synthesize the views of more than seventy participants, leading to a 2006 publication that described five main research clusters:

1. Engineering Epistemologies,
2. Engineering Learning Mechanisms,
3. Engineering Learning Systems,
4. Engineering Diversity and Inclusiveness,
5. Engineering Assessment [21].

While these five areas have not served well as a categorization system for organizing or classifying research efforts or publications in the field, they are increasingly credited with expanding the range of topics considered within the boundaries of engineering education research. Previously, legitimate engineering education research topics were often focused narrowly on the undergraduate/baccalaureate classroom, or "how people learn engineering" [22, p. 286]. Now more attention is being paid to the systems (governments, policies, institutions), faculty/staff members, and ways of knowing that impact students and learning [9]. These trends may help explain why our own analysis revealed a broader range of research topics and contexts as compared to previous studies.

Our own study complements and extends the literature reviewed here. It differs from previous studies because it engages a more contemporary and diverse body of literature and applies novel analytic strategies, including the systematic identification of empirical research papers, use of co-authorship data to reveal collaborative research patterns, and application of new algorithms to categorize articles. Our findings also contribute to a larger, ongoing conversation about the extent to which current trends in engineering education research are aligned with various agendas and visions for the future of the field.

3. Methods

3.1 Methodology

Previous bibliometric and scientometric studies of engineering education research have been characterized by a lack of supporting theory. To address this shortcoming, we draw theoretical inspiration from the sociology of science, especially to:

a. apply bibliometric and scientometric methods to identify large-scale trends and patterns of scientific and technical research,
b. understand how these patterns are linked to the more localized practices and activities of journal editors, researchers, research groups, etc. [23, Ch. 3].

We also take inspiration from Fujigaki, who more

Table 2. Description of categories (descending order of occurrence)

Category	Description of Research Area or Context (including representative terms)
learning	Cognition and Learning, inc. Deep, Inclusive, Informal, Lifelong, Self-Directed
assessment	Assessment (of Student Performance), inc. Evaluation, Exams, Grading, Outcomes-Based
edtech	Educational/Instructional Technology, inc. Online, Distance, Web-based Learning
design	Design, inc. Education, Methods, Practices, Processes, Projects, Skills, and Thinking
collab	Collaborative/Group/Peer/Team Learning, Performance, Roles, and Skills
students	Student Attitudes, Characteristics, Identity, Motivations, Perceptions, Personalities
pbl	Problem- and Project-Based Learning, inc. Projects, Project Work
competencies	Attributes, Capabilities, Competencies, Outcomes, and Skills (general/unspecified)
mathsci	Math and Science Education and Subjects, Scientific Literacy, Scientific Thinking
global	Global Competence and Education, Intercultural Skills, Foreign Language, Mobility
curriculum	Design, Reform, and Development of Curricula and Courses (general/unspecified)
engskills	Engineering Skills, inc. Creativity, Innovation, Problem-Definition/Solution, Systems
diversity	Diversity, inc. Gender, Masculinity, Minority, Race, Underrepresentation, Women
active learning	Active, Experiential, Hands-on, Inquiry-based, and Interactive Learning
envsust	Environmental Education/Curricula, Sustainability, Sustainable Development and Design
teaching	Teaching, inc. Pedagogy, Methods, Modes, Skills, Strategies, Student-Centered
profession	Studies of Alumni, Careers, Continuing Education, Employment, Postgrads, Professionals
industry	Industry-Related Education and Training, inc. Cooperative, Vocational, Work-Based
comm	Communication, Interpersonal, Language, Presentation, Rhetorical, and Writing Skills
labs	Labs, Laboratories, Lab Work, Remote Labs, Studio Learning, and Virtual Labs
business	Business, Management, Entrepreneurial, and Leadership, inc. Skills, Experiences
first year	First Year, Freshman, and Foundation Year, inc. Experiences, Programs, Students
interdisciplinary	Interdisciplinary, Cross-Disciplinary, and Multi-Disciplinary Education and Learning
recruit retain	Recruitment and Retention, inc. Attrition, Increasing Enrollment, Pipeline
k12	K-12, Middle School, High School, Pre-College, and Pre-Engineering
graphics	Engineering Drawing and Graphics, inc. CAD, Spatial Abilities, and Visualization
progeval	Program Evaluation, inc. Accreditation, ABET, Educational Quality, Quality Assessment
support	Academic Advising and Support, inc. Coaching, Mentoring, Study Groups, Tutoring
socpolorg	Social, Organizational, Philosophical, and Political Studies, inc. Ethics, Policy, STS
service learning	Service Learning, Community-Based Learning, Engineering Outreach, Social Impacts
compskills	Computer Skills, inc. Excel, MATLAB, Programming, and Software Design
faculty	Faculty Attitudes, Perspectives, Scholarship, Training, and Development
genskills	General/Transferable Skills, inc. Cognitive, Critical Thinking, Information Literacy, Logic
conceptual	Conceptual Understanding, inc. Concept Inventories, Learning, Mapping, and Tests
learning styles	Learning Profiles, Styles, Types, inc. Auditory, Tactile, and Visual Learning
reflection	Reflective Learning, Writing, and Skills, inc. Portfolios
capstone	Capstone, Centerpiece, Final Year, and Senior Projects
graduate	Graduate-Level Courses, Education, Student Perspectives, Programs, Projects

specifically demonstrates that large-scale studies of journal articles and conference papers can help illuminate local-global links in scientific research communities, including across time and place [24].

3.2 Data sources

This study analyzed all 2,173 articles and conference papers published from 2005 to 2008 in *International Journal of Engineering Education (IJEE)*, *European Journal of Engineering Education (EJEE)*, *Proceedings of the European Society for Engineering Education (SEFI) Annual Conference*, and *Proceedings of the ASEE Global Colloquium on Engineering Education*, as well as all papers from 2006-2008 in *Australasian Journal of Engineering Education (AJEE)* and *Proceedings of the Australasian Association for Engineering Education (AAEE) Annual Conference*. For the *Journal of Engineering Education (JEE)*, we only examined papers with one or more non-US authors since other sources already included a large, representative sample of papers with US-based authors. To contextualize and enrich our findings, we also cite sources such as editorials published in the aforementioned journals and other relevant reports, documents, and commentaries. While many relevant papers appear in other outlets, limitations related to our available language expertise, time, and labor demanded that we restrict our study to an internationally diverse assortment of English-language publications known for publishing engineering education research.

3.3 Data analysis

The data collection and analysis presented in this paper builds on previous results [25, 26]. The first stage of our analysis involved reviewing our entire dataset to identify all empirical research papers, which by definition is the focus of our study. Given the difficulties inherent in using complex guidelines to determine what counts as scientific research, such as the six criteria proposed by the US National Research Council [27], we simplified our procedure by identifying all papers that discussed empirical data or evidence, most often presented as results from surveys or learning

assessments. This allowed us to exclude purely descriptive accounts, such as those that only discussed the development and/or content of modules, labs, courses, and/or curricula. Papers that presented only technical engineering data were also omitted.

Three researchers used these criteria to evaluate a large subset of the 2,173 papers in our original collection of literature. All articles that were not unanimously qualified or disqualified as empirical research papers were reviewed and discussed until consensus was reached. As the rate of discrepancies dropped, one researcher evaluated the remaining articles and asked the other researchers to review borderline cases as needed. A total of 885 papers meeting our broad definition for empirical research were entered into an EndNote database. Institutional affiliations of authors were used to record country (or countries) of origin for each article. Author-defined keywords were also added to the database, and papers without keywords were given researcher-generated keywords based on a careful examination of paper titles, abstracts, and/or full article text, as needed.

The lead author then sorted a master list of all keywords from the 885 papers into one or two of about 40 major categories. This keyword-category map was revised three times after careful review by a second researcher and critical evaluation of interim results by the lead author. Our final categorization scheme includes the 38 categories shown in Table 2, presented in descending order of occurrence and including representative keyword terms. Each category is focused on a clearly identifiable research area (e.g. design, educational technologies) or context (e.g. labs, first year engineering). It was not within the scope of our study to develop categories for specific engineering disciplines, sub-disciplines, or technical topics. Of nearly 1800 unique terms in our database, about 70% (or 1263) are associated with at least one category and 128 with two categories. The number of unique terms within any given category ranges from 6 to 109.

After using only keywords to categorize papers, we observed that many articles were mis- or under-categorized, often due to a lack of appropriate author-assigned keywords [26]. To address this problem, we developed and applied a more robust algorithm. For each article in our dataset, one list of candidate categories was generated based only on that article's author-assigned keywords. A second list of candidate categories was generated by searching for relevant terms in that article's title. If a candidate category appeared on both lists, it was considered validated and the category was assigned to that article. If a given category only appeared on one list, the article's abstract was then searched for *any* term associated with that category. If one or more of the associated terms was found, the category was validated. If no associated terms were found, the category was dropped. Implemented in Microsoft Excel and Visual Basic, this algorithm placed 865 of 885 articles (or 97.7%) in at least one category. The average number of categories assigned to each article was about 2.3, and the maximum number of categories assigned to any one article was seven.

Two co-authors then performed a manual, independent replication of the categorization procedure with a random sample of 88 papers (or 10% of the dataset). For each of these papers, simple percent agreement between the two raters and between each rater and the algorithm was calculated by dividing actual number of matching categories by total number of possible matching categories. This provides a reasonable estimate of interrater reliability because chance agreement between raters is low when the number of categories available for assignment is large [28]. Average agreement between raters 1 and 2 was 69%, rater 1 and algorithm 69%, and rater 2 and algorithm 65%. Kendall's coefficient of concordance (or Kendall's W) is another measure of the extent to which multiple raters agree in ranking or categorizing a set of objects [29]. It can range from 0 (no agreement) to 1 (complete agreement). For this study, Kendall's W was calculated at 0.931, indicating high overall agreement among the raters. Based on these results, we believe the algorithm is performing at an acceptable level and is generating valid and meaningful insights. However, we are also continuing our efforts to refine the category structure and algorithm.

Previous efforts to categorize the engineering education research literature have not explored relationships between research areas. To begin addressing this shortcoming, we generated a table indicating co-occurrence of articles between every pair of categories (i.e. co-occurrence occurs when an article is placed in two or more categories). While there are many ways to represent this type of data, we used the open source Network Workbench (nwb) and Graph Exploration System (GUESS) to generate a circular diagram of all categories, presented as Figure 2 in Section 4.5 below [30, 31]. This type of representation makes it easier to see the relative size of categories, and to identify those categories that are most isolated, connected to other categories, and/or clustered together.

The data used to generate this visualization included the name of each category, number of articles in each category, and strength of connec-

Table 3. Number of qualifying papers by source and year

Source and Year	Total No. of Papers	Qualifying Papers	Percent Qualifying
International Journal of Engineering Education (IJEE)			
2005	128	40	31%
2006	148	64	43%
2007	133	68	51%
2008	124	78	63%
European Journal of Engineering Education (EJEE)			
2005	45	14	31%
2006	64	20	31%
2007	62	19	31%
2008	51	31	61%
Australasian Journal of Engineering Education (AJEE)			
2006	2	2	100%
2007	9	7	78%
2008	10	8	80%
Proceedings of the SEFI Annual Conference			
2005	80	7	9%
2006	107	36	34%
2007	173	48	28%
2008	144	68	47%
Proceedings of the ASEE Global Colloquium on Engineering Education			
2005	193	69	36%
2006	172	54	31%
2007	118	30	25%
2008	143	63	44%
Proceedings of the AAEE Annual Conference			
2006	81	44	54%
2007	77	41	53%
2008	97	62	64%
Journal of Engineering Education (JEE)—non-US authors only			
2005–2008	12	12	100%
Totals for all papers			
2005–2008	**2173**	**885**	**41%**

tion between each category (measured by co-occurrence of articles). The sizes of the nodes and interconnecting lines in the visualization were linearly scaled by the GUESS software, with the radius of each node directly proportional to the number of articles in that category, and line thickness directly proportional to co-occurrence between categories. To make the diagram more useful and readable, a simple linear scaling formula was applied to determine whether co-occurrence between any given pair of categories was large enough to justify connecting them with a line (i.e. larger categories require a higher co-occurrence threshold before a line is drawn).

4. Findings and discussion

Our findings are presented in five major sections that analyze all qualifying empirical papers (n = 885) by:

1. source and year,
2. country and region,
3. collaborative patterns,

4. categories representing topics and contexts of research,
5. co-occurrence of articles by category.

4.1 Qualifying papers by source and year

As summarized in Table 3, 885 of 2,173 articles (or about 41%) in our dataset qualified as empirical papers based on the criteria described above. More specifically, papers published in *International Journal of Engineering Education (IJEE)* exhibited a consistent upward trend, with qualifying papers more than doubling from 31% in 2005 to 63% in 2008. During this period, it is notable that late *IJEE* editor Michael Wald explicitly discussed the journal's increasing emphasis on publishing "pioneering and research based ideas" and the importance of developing better criteria for evaluating engineering education research [5, 32]. He also questioned the relative value of publishing descriptive cases studies and best practice papers [33]. With *IJEE* accepting and publishing just 10–15% of submitted papers in recent years, the journal may in part be selecting manuscripts based on whether they have an empirical component [34, 35].

Empirical research papers represented a steady 31% of all papers published in *European Journal of Engineering Education (EJEE)* from 2005 to 2007, which appears largely consistent with Osorio and Osorio's findings for previous periods [14]. Yet in 2008 this percentage jumped to 61%. This increase is likely linked to other significant developments, including the appointment of four new Associate Editors in 2006 and the transition to a new Editor-in-Chief in 2008 [36]. Further, *EJEE* review criteria for papers were expanded in 2007 to include evaluation of the "originality and innovation potential" and "quality of the scientific evidence presented" [37]. A guest editorial in a 2007 special issue also noted that the featured papers were working at the "highest scientific level," while a special issue on "Educational Research Impacting Engineering Education" was published in 2009 [38, 39]. As indicated in Table 1, the number of empirical papers presented at SEFI's annual conference also increased from 9% in 2005 to 47% in 2008, and SEFI's new Working Group on Engineering Education Research (WG-EER) met for the first time in early 2009 [40]. These trends suggest that SEFI and its leadership are advocating engineering education research, including by developing a regional community and nurturing outlets for publishing and presenting this kind of work.

The Australasian conference and journal had consistently high ratios of qualifying papers, for reasons we discuss below. Qualifying papers at the

Table 4. Number of qualifying papers by author country of origin

Author Country[1]	No. of Papers	Author Country[1]	No. of Papers	Author Country[1]	No. of Papers
United States	317	Israel	7	Korea	2
Total—EU	260	Malaysia	7	Latvia	2
Australia	205	Hong Kong	5	Palestine	2
UK/Ireland	57	India	5	Poland	2
Spain	37	Japan	5	Slovenia	2
Germany	28	Brazil	4	UAE	2
Netherlands	28	Colombia	4	Czech Republic	1
Turkey	23	Greece	4	Iran	1
New Zealand	22	Norway	4	Nigeria	1
South Africa	22	Romania	4	Oman	1
Sweden	21	Thailand	4	Pakistan	1
Denmark	20	Chile	3	Puerto Rico	1
Finland	19	Italy	3	Qatar	1
Canada	17	Kuwait	3	Saudi Arabia	1
Belgium	10	Lebanon	3	Sierra Leone	1
France	9	Russia	3	Trinidad & Tobago	1
Mexico	8	Singapore	3	Ukraine	1
Portugal	8	Slovakia	3	Zimbabwe	1
Taiwan	8	Hungary	2	**Total—All Data**	**956**[2]

[1] Shaded cells indicate European Union (EU) member countries.
[2] Total larger than total number of papers (n= 885) due to double counting of multi-authored papers.

ASEE Global Colloquium, on the other hand, ranged from a low of 25% in 2007 to a high of 44% in 2008. These variations likely reflect yearly changes in the location, thematic focus, and organizers of this conference series. All of the *Journal of Engineering Education (JEE)* articles we analyzed qualified as empirical research, which is consistent with the journal's scope and objectives for the period in question [3].

4.2 Qualifying papers by country and region

Country-of-origin information for all 885 qualifying papers is presented in Table 4. As indicated, 317 papers (or 36%) included one or more authors affiliated with institutions in the US. Authors or co-authors affiliated with institutions in member countries of the European Union (EU) were listed on 260 (or about 29%) of all qualifying articles. Top author locations in the EU were the United Kingdom/Ireland (57 papers), Spain (37), Germany (28), and the Netherlands (28). Australia was the second highest ranked country of author origin, with 205 total papers.

These data clearly reflect increasing activity and support for engineering education research in the US, a trend with origins in the late 1990s and early 2000s [1]. Collectively, the EU also has a notable profile in our dataset, reflecting both increasing support for engineering education research in Europe and our inclusion of EU-based publications and conferences. As we report elsewhere, research activity in Australia has been bolstered by vibrant professional groups, conferences, and publication outlets; the development of a cohesive and well-connected regional community of researchers; and funding for research from sources such as the Carrick Institute (now the Australian Learning and Teaching Council, or ALTC) [2].

We are also now working to develop explanations for high levels of research activity in other specific countries. Evidence suggests, for example, that engineering education research has been encouraged in Spain through the founding of government-supported engineering education innovation centers [41]. In the UK, the field has been bolstered by subject centers funded by the Higher Education Academy, especially the Engineering Subject Centre at Loughborough University [2].

Our research also lends support to the argument that coming to agreement about desirable attributes for engineering graduates can encourage engineering education research in a given nation or region [42]. Once such attributes have been codified and institutionalized, including via outcomes-based assessment and accreditation systems, researchers can focus on studying rather than debating desirable attributes for graduate engineers. Indeed, our data demonstrate that the most productive countries in the realm of engineering education research have established specific outcomes: Australia starting in 1996 [43], the United States beginning in 1998 with ABET EC2000 [44], and the United Kingdom in 2004 with UK-SPEC [45, 46]. Other movements to normalize higher education and establish desirable graduate attributes (such as via the Bologna Declaration and so-called "Dublin Descriptors") may also be encouraging engineering education research in the EU, both within and across countries [47, 48].
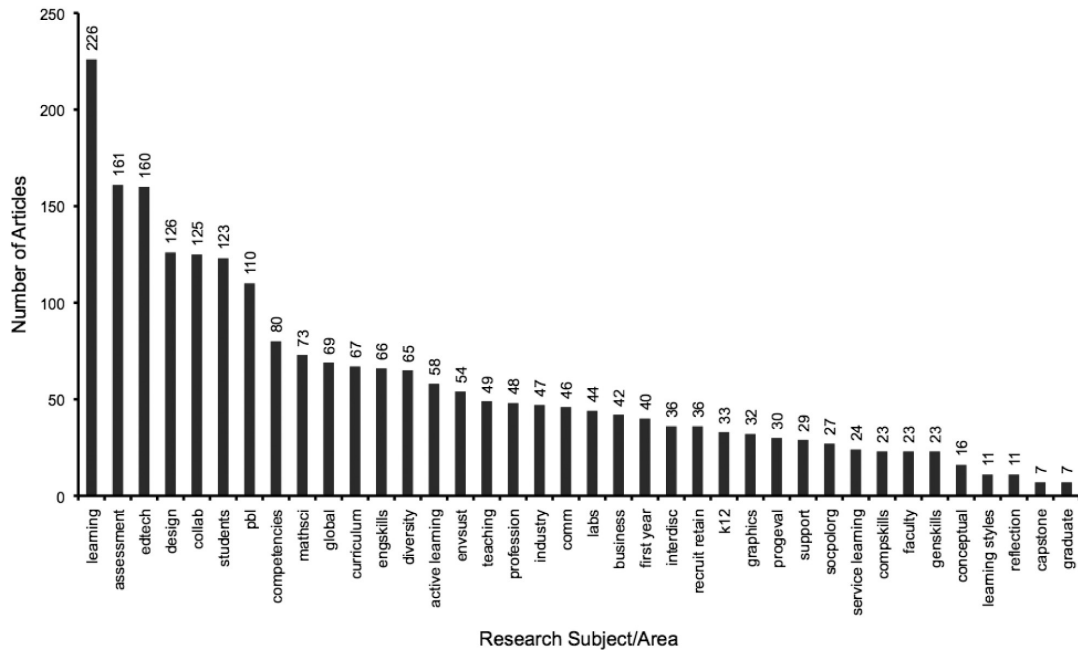
Fig. 1. Number of articles by category.

4.3 Collaborative patterns

Given our interest in tracking and promoting collaborations in engineering education research, we examined a number of related metrics. For all articles in our database, the average number of authors per paper was 2.6. In addition, 189 of 885 papers (or about 21%) were authored by a single individual, 295 were co-authored, 208 had three authors, and 193 had four or more authors, up to a maximum of twelve authors. These statistics suggest that engineering education research is not typically a solitary activity, and instead often involves 2–3 researchers. These findings also appear to reflect a longer historical decline in the number of single author papers. Wankat, for instance, found that the number of *JEE* papers with only one author was 37% for 1993–1997, falling to 27% for 1998–2002 [12]. Wankat also noted increasing acknowledgment of external funding in papers published during these periods, and suggested this might explain the trend toward larger research teams and hence more co-authors. While we agree that expanded funding remains an important factor in encouraging larger collaborative projects, we suggest that the more general growth of the field, coupled with the establishment of identifiable academic centers of engineering education research in many countries and regions, have further boosted co-authorship rates in recent years.

As evidence of multi-national collaborations, we found that 67 of 885 papers (or 8%) had co-authors affiliated with institutions in two or more countries. Of these, 59 articles involved authors from two countries, seven included authors from three countries, and one paper had authors affiliated with institutions in four countries. The countries represented most often in these collaborations were the US (35 of 67 papers), UK/Ireland (15 papers), Australia (14 papers), and Germany (11 papers). The most common pairs of collaborating countries were Australia and UK/Ireland (six papers, including one with the Netherlands), Taiwan and the US (five papers), and UK/Ireland and US (four papers, including one with New Zealand).

4.4 Qualifying papers by category

Figure 1 presents the number of articles associated with each of 38 major categories, based on the algorithm already described. Table 2, presented above, gives a brief description of each category, sorted in descending order of occurrence and including a representative list of keyword terms. This analysis leads to a number of specific observations. First, we conclude that a number of leading research areas have remained prominent for more than a decade. For example, our *assessment* category was ranked second with 161 articles, while *design* ranked fourth with 126 articles and collaborative learning (or *collab*) fifth with 125 articles. These results largely match Wankat's analysis, which respectively identified *Design*, *Assessment*, and *Groups/Teams* as the third, fourth, and fifth most prevalent research areas for papers published in *JEE*, 1993–2002 [12].

Fig. 2. Diagram of article co-occurrence by category.

Interest in educational/instructional technologies has also remained strong. In fact, this research area (*edtech*) ranked third in our dataset with 161 articles. If Wankat's *Computers*, *Internet/Web*, and *Distance Education* categories were combined, they would have a similar ranking for *JEE* articles published 1998–2002 [12]. Osorio and Osorio's similar *Technology* category was also ranked highly [14]. We propose that the prominence of this research area derives from many engineers' comfort and familiarity with technology generally and computer technology specifically, coupled with reasonably high availability of funding for technology-supported educational interventions [49].

Our analysis also reveals some new trends. For example, *learning* was the most common category in our dataset, with 226 articles. Another 123 articles were concerned with *students* (including attitudes, perceptions, characteristics, etc.), while 58 papers discussed *active learning* and allied subjects. In contrast, Wankat concluded that *Teaching* was consistently the top category for articles published in *JEE* from 1993 to 2002, while *Learning* ranked fifth for 1993–1997 and seventh for 1998–2002 [12]. Wankat's *Experiential/Hands On* designation—roughly equivalent to

our *active learning* category—included just 9 articles. Osorio and Osorio similarly had more papers in their *Teaching* category and fewer in *Learning*, albeit by a smaller margin [14]. We propose this shift reflects an ongoing movement away from a traditional paradigm of engineering teaching that involves one-way delivery of material to passive, isolated learners, and toward newer and more student-centered approaches that support learning through increasingly active and collaborative means [50]. More research is needed, however, to confirm the extent to which pedagogical practice in engineering education is undergoing this kind of transformation.

Our data also reveal a number of research subjects that appear to be growing in prominence. Problem- and project-based learning (*pbl*), for example, was ranked seventh with 110 articles. It is notable that neither Wankat nor Osorio and Osorio had comparable categories, suggesting that the visibility of PBL has historically been low, especially in the US context. However, a growing body of evidence indicates that PBL is gaining momentum and attention among engineering education researchers, both in the US and abroad [51, 52].

Further, we propose that an ongoing shift to outcomes-based accreditation in many countries and regions (including the US, Australia, and parts of the EU) has been paralleled by a rise in research on graduate attributes, outcomes, and competencies, as evidenced by our eighth ranked *competencies* category with 80 articles and twelfth ranked engineering skills (*engskills*) category with 66 articles. Against the backdrop of accelerating globalization trends, including increasing emphasis on global competency, education, and professional practice [53], we also identified 69 articles in *global*, our tenth-ranked category.

The 73 papers in the *mathsci* category, on the other hand, suggest significant crosstalk between engineering education and other STEM education research fields. The partially overlapping categories of *diversity* (65 articles) and *recruit-retain* (36 articles) also have notable profiles, as does research on cooperative/industry-based education (category *industry*) with 47 articles. And while we follow others in observing that the main focus of much engineering education research remains at the undergraduate/baccalaureate level, we find a notable number of papers focused on other study contexts and populations, including professional practice and continuing education (*profession* with 48 articles), pre-college (*k12* with 33 articles), faculty/staff characteristics and training (*faculty* with 23 articles), and (post)graduate engineering education (*graduate* with seven articles). Along similar lines, our other recent analyses of global trends in engineering education research have suggested growing interest in studies of policy and professional practice [9].

4.5 Co-occurrence of articles by category

Figure 2 provides a circular diagram of all 38 categories. As described above, the size of each category (or node in the figure) represents the number of articles in that category, while the existence and sizes of lines reflect the number of articles co-occurring between categories. Not surprisingly, this diagram shows that categories with more articles (e.g. *learning*, *assessment*, *edtech*) are more densely connected to other categories, and especially other large categories. However, this representation also reveals clusters of related research areas. For example, *pbl* is strongly linked to *collab*, which is not surprising given that PBL often involves team/group-based learning. Similarly, we find *pbl* linked to *first year* and *capstone*, both of which are common contexts for the application of problem- and project-based learning in engineering. We find another notable cluster of activity around *assessment* (of student performance), *progeval* (program evaluation), and

competencies, as well as links to other relevant clusters of specific skills/attributes (*engskills* and *genskills*).

Conversely, we observe that a number of emerging research areas—including industry-related education and training (*industry*), social, organizational, philosophical, and political studies of engineers and engineering (*socpolorg*), and studies of the engineering profession (*profession*)—appear relatively isolated from other areas. We hope our analysis will help others think about the scope of engineering education as a field, including to identify untapped opportunities for research, both at the intersection of existing areas and in new areas.

5. Conclusions and recommendations

This paper confirms and builds on prior research results by documenting increasing worldwide emphasis on more systematic and evidence-based forms of engineering education research. The paper also identifies Australia, the EU, and US as particularly active in engineering education research. Regarding specific research areas, we find continued strong interest in many subjects long viewed as central facets of engineering education, including assessment, collaborative/team learning, design, and educational/instructional technologies. Further, we observe an historical shift away from research explicitly focused on teaching and toward studies that examine students and learning, global engineering education, problem- and project-based learning, and graduate outcomes/attributes. We also note growing interest in research outside traditional undergraduate/baccalaureate contexts, including cooperative and continuing education, the engineering workplace, pre-engineering education, and policy settings.

These findings largely resonate with other recent trends in the US and abroad, as evidenced by the Engineering Education Research Colloquies agenda and findings from AGCEER conference sessions [9, 21]. However, nurturing research in these emerging areas and alternative contexts will require proactive steps to cultivate new research communities and sub-communities. Some possible strategies and mechanisms include themed conference sessions and workshops, special issues of journals or even new journals, detailed research agendas focused on emerging areas, relevant graduate-level courses and seminars, and explicit efforts to relate research to practical outcomes and interventions. We posit that many of these areas can especially benefit from cross-national collaborations. For example, authors Jesiek, Borrego, and Beddoes organized international

workshops in 2009 on problem- and project-based learning (PBL), gender and diversity, and e-learning. Additional information about the selection of meeting topics and locations, along with specific findings from the workshops, are reported elsewhere [54–56].

Finally, our analysis leads us to three very practical recommendations that can help develop global capacity and community in engineering education research.

First, journal editors and conference organizers should require detailed, high-quality abstracts for all submitted papers. More specifically, authors should clearly indicate their theoretical frameworks, research methods, focal subjects/objects of inquiry, research settings, and disciplinary area(s). The recent transition of *JEE* to a structured abstract format suggests one way to address this issue [57].

Second, keywords and categorization schemes should be improved. All journals and conference proceedings should require at least 4–5 keywords for all published papers, and editors should closely monitor author-generated keywords to ensure they accurately and completely represent the content of papers. Trivial or obvious keywords like "engineering education" should be omitted. Journals that require or suggest pre-defined keywords should frequently review and revise these lists to maintain their quality. It may also be feasible to develop a controlled vocabulary or standard ontology for the field, and/or encourage authors to position their work in relation to current research agendas [e.g. 21]. However, such efforts must also respect the field's diversity, including differences in terminology across disciplinary and geographical boundaries.

Third, access to diverse bodies of literature must be improved. We spent many months collecting the sources for this research, with some conference proceedings proving very difficult to obtain. Further, joining relevant professional organizations and accessing their publications was often a slow, cumbersome, and expensive process, especially when working across countries and regions. The large number of engineering education research papers not published in English only compounds these challenges. To improve access to such literature, publishers and editors could present paper titles and abstracts in multiple languages, and/or provide readers with easy access to web-based translation tools (e.g. Google Translate).

Even more generally, searching the global research literature now requires visits to numerous search engines and databases. We conclude that there is an urgent need for enhanced aggregation, search, and analysis capabilities for engineering education research. In part, this challenge is being addressed under the auspices of Interactive Knowledge Networks for Engineering Education Research (iKNEER), a comprehensive knowledge management platform and suite of analytic tools designed for the field of engineering education research [58, 59]. As our analysis indicates, such infrastructures are sorely needed to help researchers, scholars, and teachers more easily explore the engineering education literature, identify future directions for research, and find prospective collaborators.

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