AC 2009-1910: INTERNATIONALIZING ENGINEERING EDUCATION RESEARCH: MAPPING COUNTRIES AND KEYWORDS TO IDENTIFY NEW COLLABORATIVE HORIZONS

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Internationalizing Engineering Education Research: Mapping Countries and Keywords to Identify New Collaborative Horizons

Keywords: international, collaboration, engineering education research, bibliometrics

Abstract

What are the current levels of activity and leading subject areas of engineering education research, both worldwide and in specific national and regional contexts? And to what extent are engineering education researchers collaborating across countries? Building on prior theoretical and methodological insights from social studies of science and bibliometrics, we address these research questions by analyzing more than 2,000 journal articles and conference papers published from 2005 to 2008. Our findings are organized in three main parts. First, we describe how basic criteria for empirical research were used to select more than 800 qualifying articles for further analysis. We report on the number and percent of qualifying research papers appearing in each major publication outlet, providing insights about the research orientation of these outlets and recent trends in their respective orientations. Second, information about the institutional affiliations of authors for all qualifying papers allows us to report on publication activity by country and region. Some "enabling factors" are presented to explain particularly high levels of activity in certain countries and regions. Author affiliation data is also used to highlight current collaborative patterns in engineering education research, including trends related to co-authorship and multi-national research teams. Third and finally, a systematic examination of keywords allows us to categorize and count articles in a number of major topic areas. The paper concludes with a discussion of how our findings are being used to identify opportunities and strategies for building global capacity and developing cross-national collaborations in targeted research areas.

Introduction

In a growing number of countries and regions, engineering education is emerging as a vibrant research field. The European Society for Engineering Education (SEFI), for example, has formed a Working Group on Engineering Education Research (WG-EER) that met for the first time in February 2009.[1] The Australasian Association for Engineering Education (AAEE) is similarly developing its own Educational Research Methods (ERM) group.[2] Since 2001, a series of Global Colloquia on Engineering Education have been held by the American Society of Engineering Education (ASEE) and its partners in diverse locales, and the Society's *Journal of Engineering Education* (JEE) is now being distributed via professional societies in Australasia, the Caribbean, Europe, India, North America, Russia, and South America.[3] In many local contexts, engineering education research is being supported by a diverse and growing array of conferences and workshops, graduate courses and degree programs, university centers for faculty development and research, funding sources, and publication outlets.

But since engineering education research is a relatively new field, its international profile remains underdeveloped. Extensive networks are not currently in place to connect researchers from different countries who share an interest in similar topics and approaches. Further, we have not yet identified key research areas most likely to benefit from international collaboration, and we know relatively little about how various theories, methods, and findings might move – or fail to move – across national and cultural boundaries. As some scholars warn, fields that lack an international profile may not realize their full development potential, especially if isolated researchers are tackling similar problems and questions using rudimentary approaches.[4]

It is therefore worth noting recent initiatives intended to both increase the field's "global capacity" and encourage the formation of global networks of researchers. Perhaps most notably, in 2007 and 2008 *JEE* partnered with SEFI's *European Journal of Engineering Education* (EJEE) on an initiative titled Advancing the Global Capacity for Engineering Education Research (AGCEER).[5] At its core were ten AGCEER special sessions, held at engineering education conferences in Hungary, Turkey, Hong Kong, Australia, the U.S., Denmark, Russia, South Africa, Brazil, and India. Attendees discussed the current state and future trajectory of engineering education research, including needed expertise, existing and desired infrastructures, and leading research areas. In addition to encouraging networking among participants, data collected during these sessions was used to write a report on the global state and trajectory of engineering education as a research field.[6]

The present study was designed to compliment and supplement our analysis of the AGCEER initiative. By studying hundreds of conference papers and journal articles published from 2005 to 2008, we address the following research questions:

1. What quantity and types of engineering education research are currently being done, including 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 cross-national composition of research teams?

Our analysis helps reveal the evolving character and trajectory of engineering education as a research field, in both local and global contexts. For example, we identify key recent changes in the orientation of a number of journals and conferences, and we propose a number of "enabling factors" that may help explain particularly high levels of research activity in certain locales. We intend that such findings will prove relevant for other researchers and stakeholders, especially as they develop strategies for expanding both the international profile and cross-national networks of engineering education research. As an example of a specific initiative that grows out of this work, the authors are using the database described in this paper to identify specific research areas most likely to benefit from targeted international collaborations. The results will be used to organize a series of multi-national workshops that are focused on one or more of the identified topical areas.

Literature Review

Previous attempts have been made to quantify and characterize the breadth and depth of engineering education research, particularly in the U.S. Wankat, for example, analyzed *Journal of Engineering Education* articles from 1993-1997 (n = 230) and 1993-2002 (n = 597).[7-8] Since the journal did not use author-defined keywords during these periods, the author generated the following list of categories and assigned up to four categories to each article:

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

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

Wankat provided little explanation about his categorization procedures, but he acknowledged the subjective judgment inherent in assigning keywords, and suggested a panel would be more reliable than a single researcher. [8] He also analyzed whether or not articles were discipline specific, which reduced the need to categorize by engineering sub-discipline. In addition, he tracked trends over time and conducted analyses to assess the research orientation of the journal, observing increases over time in research funding, the use of theory, and number of citations.

In 2004, Whitin and Sheppard published a similar analysis of *Journal of Engineering Education* articles from 1996-2001 (n = 398).[9] They assigned only one keyword to each article, describing their approach as “different and complementary” to Wankat’s. Their categories were: Students (12% of articles), Faculty (23%), Practitioners and Alumni (5%), Courses and Programs (34%), Assessment and Evaluation (20%), and General/Miscellaneous (6%). To address the validity and reliability of the categorization procedure, the authors based their categories on Wankat’s prior work. One researcher coded all papers and two researchers verified the consistency of the coding on a subset of the papers. Whitin and Sheppard identified trends similar to those noted by Wankat, and consistent with the journal’s increasing focus on research.

In 2007, Borrego examined archival publications of four U.S. National Science Foundation funded Engineering Education Coalitions from 1990-2005 (n = 700).[10] This analysis employed a theoretical framework of disciplinary development and a more complex, hierarchical categorization along three orthogonal dimensions:

1. Population: Who is the principal group being studied or benefiting from the change (e.g., freshmen, faculty, senior design students, women/minorities)?
2. Methodology: What was the intervention or change that 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 is the change being communicated or transferred (e.g., web site, instructional module, survey tool, article simply describing the experience)?

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

Taken collectively, these three analyses indicate that the long-term, historical trajectory of engineering education tends toward more systematic, evidence-based research. Given the similarities of findings in all three cases, 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 changes, including changing definitions of engineering and the continued impacts of technology, communication over distance, globalization, and sustainability concerns.

The Engineering Education Research Colloquies represent a more forward-looking approach to characterizing the landscape of engineering education research.[11-12] More specifically, they "were designed to collaboratively develop a national research framework and agenda to conduct rigorous engineering education research." [11] Various strategies were used to organize and synthesize the views of more than seventy participants, leading to the identification of five main research clusters: Engineering Epistemologies, Engineering Learning Mechanisms, Engineering Learning Systems, Engineering Diversity and Inclusiveness, and Engineering Assessment.

While these five research areas have not yet 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 research topics considered the core of engineering education research. Previously, legitimate engineering education research topics focused narrowly on the undergraduate classroom, or "how people learn engineering."[13] Now more attention is being paid to the systems (governments, policies, institutions), faculty, and ways of knowing that directly impact engineering students and learning.

Casting a wider net reveals a range of ongoing efforts to develop categorization schemes and perform analysis of publications in other fields. Studies of computing education run most closely parallel to our own work, especially because of topical and community overlaps with engineering education. Simon, for example, reviews prior efforts to classify publications in the field of computing education, including by types of papers, methodologies employed, and subject area.[14] He also develops a more comprehensive classification system based on research topic, context of study, and nature of paper (position, report, analysis, and experiment). Finally, he categorizes all computing education papers (n=175) from seven Australasian Computing Education (ACE) and National Advisory Committee on Computing Qualifications (NACCQ) conferences. Simon concludes that practice-oriented "reports" remain dominant in this body of literature, computer programming is the most common context for studies, and teaching/learning techniques is the most prevalent research topic, followed by curriculum and teaching/learning tools.

In a follow-up study, Simon et al. use the same system to categorize papers (n=43) from a series of International Computing Education Research (ICER) workshops held 2005-2007.[15] In addition to placing significant emphasis on developing methods for improving the reliability of classification among multiple researchers, the authors report a relatively high percentage of "research" papers (88%) and multi-institutional studies (33%) in their data set. Fincher, on the other hand, examines multi-institutional and multi-national trends as potential markers for the development of Computer Science Education (CSEd) as a research discipline, but uses a more descriptive, case study approach to closely examine a small number of specific projects.[16]

Theory

Our study takes theoretical insights from the sociology of science, which helps us understand how large-scale patterns of scientific and technical research are related to the more localized practices and activities of researchers and research groups.[17] Fujigaki more specifically argues that performing large-scale studies of journal articles and conference papers is especially helpful in illuminating these kinds of local-global links, including across time and geography.[18] Fujigaki's work also shows the value of using systems theory to conceptualize how networks of scientific researchers, publications, and publication outlets form, develop, and interrelate.

Methodology

The present study uses a mixed methods approach that brings together scientometric and qualitative methods. Scientometrics is quantitative in character, and involves the use of statistical and mathematical methods to study the development of science and scientific fields.[19] As in our previous analysis of a smaller data set, we use basic scientometric analyses to identify relevant patterns and trends in our bibliographic database.[20] We also use qualitative approaches to examine select articles in our database, along with related editorials and other supplemental materials, giving our analysis additional texture and revealing underlying reasons for specific trends. For example, author affiliation data allows us to infer the number and size of cross-national research collaborations, while the content of articles (including background details and author biographies) provides novel insights about the origin and character of such collaborations.

Data Sources

This study analyzed more than 2000 articles and conference papers published 2005-2008 in: *International Journal of Engineering Education (IJEE)*, *European Journal of Engineering Education (EJEE)*, *Australasian Journal of Engineering Education (AJEE)*, *Proceedings of the SEFI Annual Conference*, *Proceedings of the ASEE Global Colloquium Annual Conference, Proceedings of the AAEE Annual Conference*, and *Journal of Engineering Education*. These publication outlets were selected because of both their geographic diversity and explicit focus on engineering education. Papers published during 2008 in *AJEE* and *Proceedings of the AAEE Annual Conference* have not yet been obtained, but will be analyzed in future work. We only examined *JEE* papers with non-U.S. authors since we found that the other publication outlets already included in our database feature a large and representative sample of research from U.S.-based authors. Our qualitative analysis extended beyond this data set to include relevant editorials published in the journals listed above, coupled with supplemental archival research and publication analysis using a variety of other sources and databases.

Data Analysis

The first stage of our analysis involved systematically reviewing all articles to determine which qualified as systematic research publications, which by definition is the focus of our study. Given the difficulties inherent in using complex criteria to determine what counts as scientific research, we simplified our procedure by identifying all papers that presented and discussed empirical data or evidence, most often in the form of surveys or learning assessments. This excluded purely descriptive papers, such as those that discussed the development and/or content of modules, labs, courses, and/or curricula. Papers that presented only technical data or results were also excluded.

Three researchers used these criteria to evaluate a large initial set of articles. All articles that were not unanimously qualified or disqualified were reviewed and discussed until consensus was reached. As the rate of discrepancies dropped, one researcher took over the evaluation of the remaining articles, and asked the other researchers to review borderline cases on an as-needed basis. Each paper meeting our broad definition for empirical research was then entered into an EndNote database. Institutional affiliations of authors were used to record country (or countries) of origin for each article. Author-identified keywords were also added, and papers without keywords were given researcher-generated keywords based on their titles and abstracts.

Finally, one researcher assigned keywords to one or two of 40 major topical categories, many of which are similar to those used by Wankat and Simon.[7-8,14] This categorization was revised twice following careful review by a second researcher. Paper titles and abstracts were often examined to develop a better sense for how specific keywords were being used by authors. Of more than 1800 unique keywords, approximately 70% (or 1260) were assigned to one or two categories. About 10% of these keywords were assigned to two categories. The researchers did not categorize keywords associated with specific engineering disciplines, sub-disciplines, and technical topics, but plan to do so in future analysis.

Findings and Discussion

Number of Qualifying Papers by Source and Year

As summarized in Table 1, 815 of 2054 articles (or about 40%) in our data set qualified as research papers according to the criteria described above. Papers published in *IJEE* exhibit a consistent upward trend, with the percentage of qualifying papers more than doubling from 31% in 2005 to 63%. In a preliminary analysis of a smaller subset of our data, we note that *IJEE* editor Michael Wald has explicitly discussed both the journal's increasing emphasis on publishing "pioneering and research based ideas" and the importance of developing criteria to evaluate engineering education research, and he has also questioned the relative value of publishing descriptive cases studies and best practice papers.[20-22] With *IJEE* now receiving more than 1,000 papers per year but publishing fewer than 150, the evidence presented here suggests that the journal and its editors are favoring articles that present and discuss empirical data.

EJEE, on the other hand, saw its percentage of research papers jump to 61% in 2008, up from a steady rate of 31% during the previous three years. This change correlates with other recent developments, including a new editor and editorial board. Other evidence also reveals the journal's changing profile. Around early 2007, for example, *EJEE* review criteria for papers were expanded to emphasize the "originality and innovation potential" and "quality of the scientific evidence presented."[23] Further, a guest editorial in a 2007 special issue noted that the included papers were working at the "highest scientific level," while another special issue on "Educational Research Impacting Engineering Education" was planned for 2009.[24-25]

Table 1. 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	N/A	N/A	N/A
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 Annual Conference			
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	N/A	N/A	N/A
Journal of Engineering Education (JEE) – non-U.S. authors only			
2005-2008	12	12	100%
Totals for all papers			
2005-2008	**2054**	**815**	**40%**

The number of research papers presented at SEFI's annual conference also increased from 9% in 2005 to 47% in 2008, suggesting that SEFI and its leadership are more generally emphasizing and supporting engineering education research. These developments parallel a number of other, broader trends, including efforts to promote engineering education research by the European Union's thematic network on Teaching and Research in Engineering in Europe (TREE).

The Australasian conference and journal had consistently high ratios of qualifying papers. Due to reasons discussed in more detail below, we expect these trends to continue into 2008. Qualifying papers at the 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 organization of this conference series.

Research Activity by Country

Country-of-origin information for all 815 qualifying papers is presented in Table 2. As indicated, 315 papers (or 39%) included one or more authors affiliated with institutions located in the United States. Authors or co-authors affiliated with institutions in member countries of the European Union (EU) were listed on 257 (or about 32%) of all qualifying articles. Top author locations in the EU were the United Kingdom (54 papers), Spain (37), Germany (28), and the Netherlands (28). Australia was the second most represented country of origin, with 154 papers.

Table 2. 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	315	Israel	7	Korea	2
Total – EU	257	Hong Kong	5	Latvia	2
Australia	154	Japan	5	Palestine	2
United Kingdom	54	Malaysia	5	Poland	2
Spain	37	Brazil	4	Slovenia	2
Germany	28	Colombia	4	UAE	2
Netherlands	28	India	4	Czech Republic	1
Turkey	23	Greece	4	Iran	1
South Africa	22	Norway	4	Nigeria	1
Sweden	21	Romania	4	Oman	1
Denmark	20	Thailand	4	Pakistan	1
Finland	19	Chile	3	Puerto Rico	1
Canada	17	Italy	3	Qatar	1
Belgium	10	Kuwait	3	Saudi Arabia	1
New Zealand	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**	**888** [2]

[1] Shaded cells indicate European Union (EU) member countries.
[2] Total is larger than total papers (n= 815) due to double counting of multi-authored papers.

These data reveal a number of relevant trends. First, they clearly reflect increasing activity and support for engineering education research in the U.S., a trend with origins in the late 1990s and early 2000s.[26] The continued efforts of U.S. researchers to present and publish internationally may also be encouraged by the limited number of U.S.-based journals dedicated to engineering education research. When viewed collectively, the EU also has a notable profile in our data set, likely reflecting both increasing support for engineering education research in Europe and our focus on EU-based publications and conferences.

We are now working to develop explanations for high levels of research activity in a number of other specific countries. Evidence suggests, for example, that engineering education research is being encouraged in Spain through the founding of government-supported engineering education innovation centers.[27] In the UK, on the other hand, engineering education research activities are in part being supported and nurtured by some of the subject centers funded by the Higher Education Academy, especially the Engineering Subject Centre at Loughborough University.[28] And in Australia, EER is being bolstered by: vibrant professional groups, conferences and publication outlets; the development of a cohesive and well-connected regional community of researchers; and funding from sources such as the Carrick Institute (now the Australian Learning and Teaching Council, or ALTC).

Our research also provides additional support for an argument, originally developed by Lucena, Downey, Jesiek, and Ruff, that coming to agreement about desired competencies (or graduate attributes) for engineering graduates can serve as an important enabling factor for developing engineering education research in a given nation or region.[29] When such agreement is reached, researchers can focus on studying rather than debating desired competencies and attributes. In line with this argument, the present study reveals that the highest levels of engineering education research activity are occurring in countries and regions where desired competencies have been established or are well on their way to being established.

In the United States, the development and implementation of ABET EC2000 accreditation criteria in the late 1990s and early 2000s helped standardize competencies, relate them to accreditation procedures and curricular reform, and promote related research.[30] During roughly the same period, Australia's Institute of Engineers (now Engineers Australia) developed and rolled out its own set of competency standards for engineers.[31] And while the story in Europe remains somewhat more complex and diverse, the Bologna Declaration and so-called "Dublin Descriptors" have similarly encouraged more widespread agreement about desired graduate attributes, especially to help improve the mobility of engineering graduates across European borders.[32] As a further reflection of this trend, a special issue of *EJEE* published in 2006 featured a series of research papers on competency and assessment in engineering education.

Collaboration Patterns

For our entire data set, the average number of authors per paper was 2.7. In addition, 169 of 815 papers (or about 21%) were single authored, 271 were co-authored, 190 had three authors, and the remainder had four or more authors, up to a maximum of twelve. Such statistics suggest that engineering education research is not typically a solitary activity, and instead often involves 2-3 researchers. Additional analysis is needed, however, to better understand the character of these collaborations.

We also found that 66 of 815 papers (or 8%) had co-authors affiliated with institutions in two or more countries. Of these, 58 articles involved authors from two different countries, 7 included authors from three countries, and one paper had authors affiliated with 4 countries. The countries represented most often in these collaborations were the United States (34 of 66 papers), United Kingdom (15 of 66), Australia (13 of 66), and Germany (11 of 66). The most common pairs of collaborating countries were Australia and the UK (6 papers, including 1 with the Netherlands), Taiwan and the US (5), and the UK and US (4, including 1 with New Zealand).

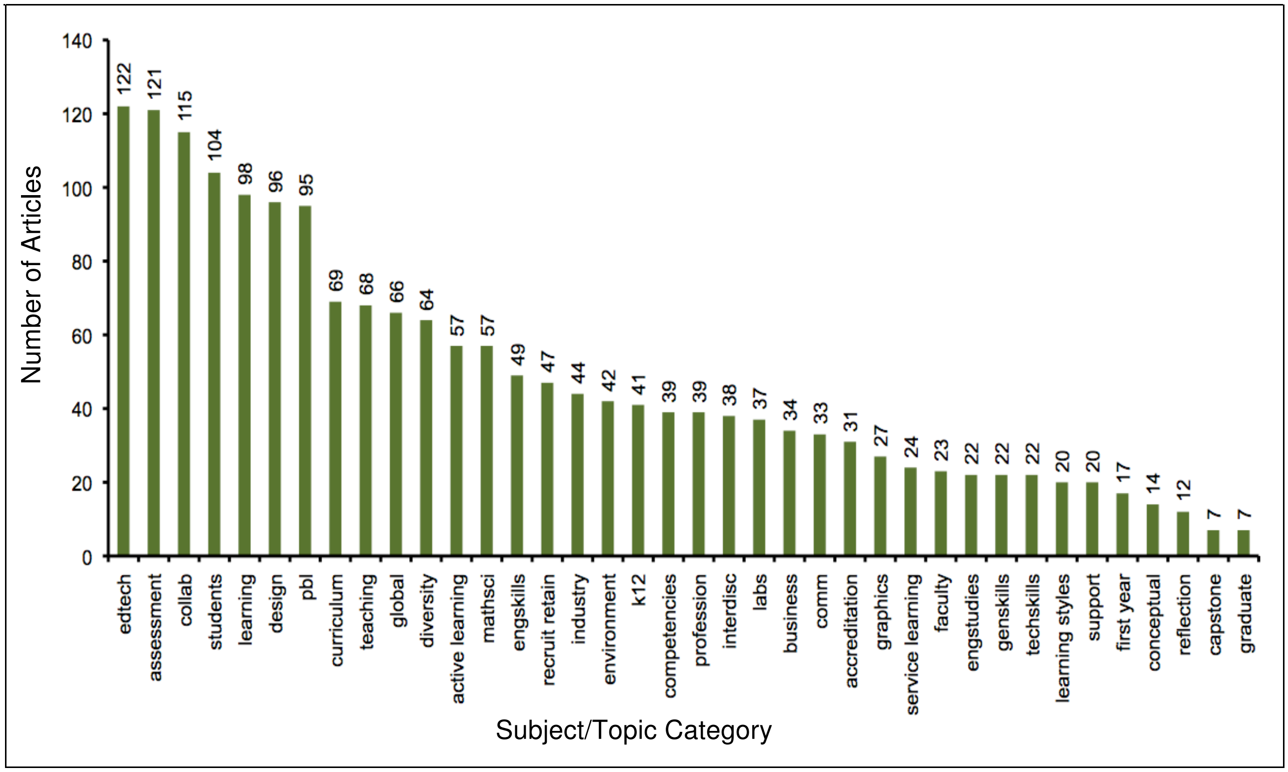
As these data suggest, former colonial relationships and shared native language often seem to encourage collaboration. Further analysis of the content of multi-national papers, including an examination of relevant background information and author biographies, also suggests that collaborations frequently grow out of pre-existing individual and institutional relationships. For example, researchers who move to another country may continue to collaborate and publish with peers and partners at their former institution(s). In other cases, cross-national collaborations involve visiting professorships, post-doc appointments, Fulbright exchanges, and advisee-student relationships that cross national boundaries. International initiatives undertaken by universities, including partnerships with foreign institutions, also seem to encourage research collaborations.

Keyword and Category Analysis

Figure 1 presents total number of articles in each of 38 major categories, based on keyword analysis. As noted above, an article could fall into multiple categories because of its associated keywords. Out of 815 articles, 796 (or 98%) were successfully placed in at least one category. Table 3 gives a brief description of each category, sorted in descending order of occurrence, and including a representative (but not complete) list of associated keywords and keyword clusters.

Our analysis reveals significant worldwide activity around a number of major research areas, many of which have longer histories. To begin, educational/instructional technologies (or *edtech*) was the most common category in our data set, with 122 articles. Taken together, the Computers, Internet/Web, and Distance Education categories would have had a similar ranking in Wankat's analysis of *JEE* articles published 1998-2002. Our *assessment* category was ranked second (121 articles), followed by *collaborative* learning (115 articles). For *JEE* articles published 1998-2002, Wankat found that *assessment* and *groups/teams* were respectively ranked fourth and fifth in his data set. Articles falling in the *design* category ranked sixth in our study (96 articles), and those related to problem/ project-based learning (or *pbl*) were ranked seventh (97 articles). By comparison, Wankat's *design* category was ranked second for 1993-1997 and third for 1998-2002. He did not isolate problem/ project-based learning in his analysis.

Figure 1. Number of Articles by Subject/Topic Category



Wankat also found that *teaching* was consistently the top-ranked category for *JEE* articles published 1993-2002, while *learning* ranked fifth for 1993-1997 and seventh for 1998-2002. Our findings suggest a reversal of this trend, with *learning* ranked fifth in our study (with 98 articles, or 12% of our data set) and *teaching* falling to ninth (68 articles). We hypothesize that these findings reflect a more general paradigm shift in engineering education as teacher-centered pedagogies and assumptions about passive students are gradually replaced by new ideas about student-centered teaching and new images of students as active, independent, and contextual knowers.[33] As further evidence for expanding interest in students and student-centered teaching, we found a very large number of articles (104) concerned with *students* (including attitudes, perceptions, characteristics, etc.). We also identified a notable number of papers (57) on *active-learning* and closely related topics, making it the twelfth ranked category in our study. Wankat's *Experiential/Hands On* category, by contrast, was ranked sixteenth for 1998-2002. However, additional analysis is needed to verify and explain these trends.

Our data also reveals a number of EER topics that appear to be growing in prominence. These include global engineering education and related subjects (category *global*) with 66 articles, and environmental issues and sustainability (*environment*) with 42 articles. The partially overlapping categories of diversity (64 articles) and recruit-retain (47 articles) also have notable profiles, as does research on work-based and cooperative education (category *industry*) with 44 articles.

Table 3. Category Codes and Descriptions (descending order of occurrence)

Category Code	Description
edtech	Educational/Instructional Technologies, inc. Online, Distance, Web-based Learning
assessment	Assessment, Evaluation, Grading, Outcomes, Quizzes, and Tests
collab	Collaborative, Group, and Team Learning and Skills
students	Student Attitudes, Characteristics, Identity, Motivations, Perceptions, Personalities
learning	General Learning Topics, inc. Deep, Enhanced, Inclusive, Informal, Lifelong
design	Design Education, Methods, Practices, Processes, Projects, Skills, and Thinking
Pbl	Problem- and Project-Based Learning
curriculum	Design, Reform, and Development of Courses and Curricula
teaching	Teaching, inc. Pedagogy, Methods, Modes, Skills, Strategies, and Teacher Training
global	Global Competence and Education, Intercultural Skills, Foreign Language, Mobility
diversity	Diversity, inc. Gender, Masculinity, Minority, Race, Women
active-learning	Active, Experiential, Hands-on, Inquiry-based, and Interactive Learning
mathsci	Math and Science Education, Scientific Literacy, Scientific Thinking
engskills	Engineering Skills, inc. Creativity, Innovation, Problem-Definition/Solution, Systems
recruit-retain	Recruitment and Retention, inc. Attrition, Pipeline
industry	Industry-Related Education and Training, inc. Cooperative, Vocational, Work-Based
environment	Environment, Ethics, Sustainability, and Social Responsibility
k12	K-12, Middle School, Pre-College, and Pre-Engineering
competencies	Attributes, Capabilities, Competencies, and Skills (general/unspecified)
profession	Studies of Alumni, Careers, Continuing Education, Employment, Postgraduates
interdisciplinary	Interdisciplinary, Cross-Disciplinary, and Multi-Disciplinary Education and Learning
Labs	Labs, Laboratories, Lab Work, Remote Labs, Studio Learning, and Virtual Labs
business	Business, Management, Entrepreneurial, and Leadership, inc. Skills, Experiences
comm	Communication, Interpersonal, Presentation, Rhetorical, and Writing Skills
accreditation	Accreditation, inc. ABET, EC2000, Educational Quality
graphics	Engineering Drawing and Graphics, inc. CAD, Spatial Abilities, and Visualization
service-learning	Service Learning, Community-Based Learning, Engineering Outreach
faculty	Faculty Attitudes, Perspectives, Scholarship, Training, and Development
engstudies	Engineering Studies, inc. Culture, Discipline Formation, Epistemology, Policy, STS
genskills	General Skills, inc. Cognitive, Critical Thinking, Information Literacy, Logic, Reason
techskills	Technology Skills, inc. Excel, MATLAB, Programming, and Software Design
learning-styles	Learning Profiles, Styles, Types
support	Academic Advising and Support, inc. Coaching, Mentoring, Study Groups, Tutoring
first-year	First Year, Freshman, and Foundation Year, inc. Experiences, Programs, Students
conceptual	Conceptual Understanding, inc. Concept Inventories, Learning, Mapping, and Tests
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

The 57 papers in the *mathsci* category, on the other hand, suggest significant overlap and crosstalk between EER and other STEM education research fields. And while the main focus of much engineering education research remains at the undergraduate/baccalaureate level, we find that notable numbers of researchers are also now performing research on, or relevant to, other contexts, including pre-engineering or *k12* (41 articles), *professional* (39 articles), *faculty* (23 articles), and *graduate education* (7 articles).

Conclusions and Future Work

This paper confirms and builds on prior research results by documenting growing worldwide emphasis on more systematic and evidence-based forms of engineering education research. The paper also reveals that U.S.-based researchers continue to have both high levels of activity and an expanding international profile, while Australia and the EU are rising in prominence as centers of much engineering education research. In terms of our category and keyword analysis, we find continued strong interest in some areas that have long been viewed as central facets of engineering education, including assessment, collaborative learning, and design. Yet we also observe a historical shift away from research on teaching and toward studies of students and learning, along with more research related to global engineering education, sustainability and environmental concerns, diversity issues, work-based learning, pre-engineering, and professional practice. We posit that these topics and areas represent important emerging frontiers for engineering education research that may especially benefit from cross-national research collaborations. We are continuing to build on these insights, including through our efforts to organize a series of multi-national workshops that will bring together researchers around one or more targeted research topics.

On an even more practical level, the present project leads us to a number of specific and more practical recommendations that can help develop global capacity and community in engineering education research. For instance, journal editors and conference organizers should require some minimum number of keywords for all published papers, along with high-quality abstracts. The quality and consistency of keywords and abstracts should also be improved, such as by asking authors to provide information along multiple, orthogonal dimensions. Systematically recording information related to each paper's theoretical framework, research methods, focal subjects/objects of inquiry, research setting, and disciplinary area(s) would not only improve the types of analysis presented here, it would also make research results more accessible to what remains a diverse and widely distributed community. It might also be possible and feasible to begin developing controlled vocabularies or standardized ontologies for the field. Yet such efforts could have undesirable normalizing or homogenizing effects, especially by failing to acknowledge significant disciplinary and cross-national variations in EER.

We continue to analyze the present data set, including by more closely examining paper titles and abstracts to help verify and validate our keyword-category map. We are also performing co-occurrence analysis to better understand how categories are related to one another and help generate a two-dimensional map of our keyword and category data. Finally, we are exploring how co-word mapping and citation analysis can generate other new insights from this database, and we are making plans to post our data online for use by the entire EER community.

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