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Development of a taxonomy of keywords for engineering education research^{1*}

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Joint Editors' Introduction to the Special Report 'Development of a Taxonomy of Keywords for Engineering Education Research'

As the engineering education literature has proliferated across disciplines and continents, the growing number of publications has become difficult to navigate. Recognizing the need to better find and organize publications, authors, and reviewers, Doctors Cindy Finelli and Maura Borrego led an inclusive effort to develop a taxonomy of engineering education terms from a United States perspective. They conducted workshops in several countries and drew on our expertise in an advisory capacity. The resulting taxonomy has the potential to connect engineering education scholarship worldwide. We are pleased to jointly publish this report on the development of the taxonomy, to reach all of our journals' audiences.

—Les Dawes, Editor, *Australasian Journal of Engineering Education*
—Jeffrey E. Froyd, Editor-in-Chief, *IEEE Transactions on Education*
—Erik de Graaff, Editor-in-Chief, *European Journal of Engineering Education*
—Ahmad Ibrahim, Editor, *International Journal of Engineering Education*
—Michael C. Loui, Editor, *Journal of Engineering Education*

ABSTRACT

The diversity of engineering education research provides an opportunity for cross-fertilisation of ideas and creativity, but it also can result in fragmentation of the field and duplication of effort. One solution is to establish a standardised taxonomy of engineering education terms to map the field and communicate and connect research initiatives. This report describes the process for developing such a taxonomy, the EER Taxonomy. Although the taxonomy focuses on engineering education research in the United States, inclusive efforts have engaged 266 individuals from 149 cities in 30 countries during one multiday workshop, seven conference sessions, and several other virtual and in-person activities. The resulting taxonomy comprises 455 terms arranged in 14 branches and six levels. This taxonomy was found to satisfy four criteria for validity and reliability: (1) keywords assigned to a set of abstracts were reproducible by multiple researchers, (2) the taxonomy comprised terms that could be selected as keywords to fully describe 243 articles in three journals, (3) the keywords for those 243 articles were evenly distributed across the branches of the taxonomy, and (4) the authors of 31 conference papers agreed with 90% of researcher-assigned keywords. This report also describes guidelines developed to help authors consistently assign keywords for their articles by encouraging them to choose terms from three categories: (1) context/focus/topic, (2) purpose/target/motivation, and (3) research approach.

KEYWORDS

Educational level; educational setting; outcomes; research approaches; theoretical frameworks

1. Introduction: the need for a taxonomy

Engineering education research is a broad-based, rapidly evolving, diverse, interdisciplinary, and highly international field. Exciting and innovative research is being conducted in a wide variety of educational and professional engineering settings, in countries around the world, and by researchers and practitioners in a range of disciplinary fields (for the range of research,

see Alpay and Jones 2012; Besterfield-Sacre et al. 2014; Borrego 2007; Borrego and Bernhard 2011; Case and Light 2011; de Graaff and Kolmos 2014; Froyd, Wankat, and Smith 2012; Heywood 2005; Jesiek, Newswander, and Borrego 2009). Although this diversity provides an opportunity for cross-fertilisation of ideas and creativity, it also can result in fragmentation of the field and duplication of effort.

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*The majority of text in this section is reprinted with permission, © 2014 American Society for Engineering Education (Finelli and Borrego 2014) This report differs from the conference papers cited within it, because it includes a complete description of all sessions as well as an expanded literature review and comprehensive analysis in the discussion and conclusion.

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One solution that would allow engineering education researchers and practitioners to best take advantage of this diversity is to establish a standardised terminology and organisational system – a taxonomy of terms – to map the field and to communicate and connect research initiatives. Such a taxonomy of terms for engineering education research could be useful for multiple audiences. It could serve as a framework for researchers and members of the engineering education research community to situate their individual research initiatives in the broader field, see connections and synthesise ideas, better access the research of others, and plan future work. It could be a source of terms to help novices understand the breadth of the field and conduct literature searches. The taxonomy could be a mechanism for journal editors to organise related authors and research areas, identify the alignment of submitted articles with a journal's mission, and categorise a reviewer database for more appropriate assignment of reviewers. And it could provide a method for funding agencies to classify research portfolios, identify areas for capacity building, frame solicitations, and recruit reviewers.

Others have noted the importance of organising research areas and publications in the field of engineering education research and have established systems for categorising the field and analysing entire bodies of work. Wankat (1999, 2004) and Whitin and Sheppard (2004) are frequently credited with the earliest efforts in analysing the field; each catalogued a set of articles published in the *Journal of Engineering Education*. Among other things, they studied each article's research topic, theoretical framework, and approaches to data collection. More recently, Jesiek et al. (2011) studied over 2000 publications in a variety of global engineering education journals and conferences over a three-year period, extracting 38 categories of terms; Malmi and collaborators (e.g. 2012, 2013) have categorised papers from the Société Européenne pour la Formation des Ingénieurs (European Society for Engineering Education [SEFI]) annual conferences and focused particularly on the research process; and Xian and Madhavan (2014) analysed over 24,000 papers from engineering education conferences and journals and used the taxonomy of education topics in the Education Resources Information Center (ERIC) database to characterise networks of collaboration among scholars.

Although different approaches such as these help identify a list of terms that might map the field of engineering education research, a standardised taxonomy would be more useful. It would guide researchers, journal editors, funding agencies, and other members of the community in creating the metadata that would enable deeper and more extensive analysis of research and publication trends.

In this report, we describe our process for creating a useful taxonomy and establishing an inclusive process

for doing so, and we offer evidence that the taxonomy is valid and reliable. Although this taxonomy does focus on engineering education research in the United States, we describe how we engaged a broad, international set of stakeholders in developing the taxonomy, and we hope the report informs and complements related efforts in the international community.

We also describe guidelines we developed for assigning keywords, and we hope those guidelines offer a useful framework for describing an author's work. The guidelines are not intended to constrain authors to using terms from the taxonomy for titles, abstracts, and the body of their manuscripts, and we expect journals, funders, and other organisations to set their own policies for using the taxonomy. Benefits of using standardised terms as we suggest include the ability to both connect related work and help others find engineering education research publications, and these benefits extend beyond the United States. And consistent with accepted taxonomy management practices, we propose that our field establish a committee of representatives from the journals jointly publishing this report to regularly maintain and update the taxonomy so it remains relevant and useful.

1.1. Basic taxonomy definitions and concepts

A *taxonomy*, a concept borrowed from biology, is a hierarchical classification scheme that makes categorising or finding terms within bodies of text easier for both indexers and searchers (Pack 2002). A taxonomy typically consists of a *controlled vocabulary*, or restricted list of terms for indexing, a set of *preferred terms* with the ways similar or related terms might be cross-referenced, and a *hierarchy*, which describes relationships among the vocabulary terms (Hedden 2010). A taxonomy, specifically the preferred terms, can help researchers search the literature by linking and suggesting related terms and by offering a hierarchical structure that aids in navigation (Hedden 2010). Most engineering databases, including IEEE, INSPEC, and Compendex, use controlled vocabularies, which assist users in locating related publications, sometimes without the users' conscious knowledge of the controlled vocabulary's existence. In other fields, some publications rely on databases that use controlled vocabularies (e.g. ERIC and IEEE Xplore) to assign keywords (Hedden 2010), but there is no such consistency in the field of engineering education research. A good taxonomy has uniform depth (level of detail), comprises distinct concepts represented by one preferred term, and uses the native language of the community it serves (Pack 2002).

Policy guidelines for applying a taxonomy can help researchers follow consistent procedures by establishing the proper level of detail for keywords, providing a framework of aspects to consider when selecting terms

for a document, and specifying how many terms to apply. Taxonomy developers typically generate terms by consulting subject matter experts and studying the corpus of literature in which a taxonomy will be applied (Hedden 2010). Then, a taxonomy should evolve through regular use – it should be flexible, easily updated, and constantly maintained (Levy 2004). Users who apply a taxonomy should be able to offer suggestions for adding new terms, removing old terms, clarifying existing terms, and making other updates. Similarly, individuals who maintain a taxonomy should monitor terms for overuse (which indicates the need to split one term into multiple terms), underuse (which suggests the need to delete or combine terms), and misuse (which highlights the need to clarify terms) (Hedden 2010). Taxonomies developed for academic fields can also be updated through a concerted effort of the broader community on a regular cycle, such as every five years (Marjorie Hlava, personal communication).

1.2. Taxonomy uses

A taxonomy can be used in many ways. For instance, it can serve as a source of keywords to describe a field of research, and it can provide a more precise approach for finding related documents than full-text searching does. As Levy (2004) noted, when using an indexed taxonomy as the framework for searching,

It's easy to get interesting synergies and to find items using new terms and jargon. A taxonomy is more reliable and standard, and it expresses the information architecture, providing context and grouping even when the words used are different. It makes search results more accurate and understandable, provides alternate access, uses different vocabulary, and crosses boundaries. (page 11)

Further, taxonomies and controlled vocabularies can help users focus on important sources from among literally millions of results, as noted by Hawkins, Larson, and Caton (2003):

When databases of information (particularly in full text) first became available on the Internet, many users felt that thesauri and subject classifications were no longer needed and would go the way of horseless carriages. After all, the theory ran, if everything is available on-line in full text, one would only need to enter the appropriate terms into a search engine, and the desired information would be retrieved. Inexperienced searchers quickly discovered the fallacy of this approach to information retrieval when they were faced with result sets numbering in the millions of hits, with the desired information buried somewhere in them. It was soon recognized that, far from fading away in the Web environment, subject classifications and thesauri have become more important than ever, and organizing information into subjects, or taxonomies, provided users with a significant improvement in retrieval. (page 772)

A taxonomy can also offer a structure to connect related research and enable visualisation of the relationships

between publications or other sources to which it is applied (Pack 2002). For example, products such as SciVal and Pivot use taxonomies and publication data from Scopus and ProQuest databases (respectively) to identify funding opportunities and potential collaborators. Elsevier also offers Reviewer Finder to find reviewers and expand a reviewer network, and the Deep Insights Anytime, Anywhere project creates user-friendly interfaces for searching and visualising the database of grant projects and investigators of the Transforming Undergraduate Education in STEM programme of the United States National Science Foundation (Liu et al. 2013).

After the initial data-set is hand-coded and decisions about terminology and relevant category names are made by humans, a taxonomy can serve as the basis for automated algorithms that organise content (including web content) to find and categorise information (Pack 2002). In engineering education, for instance, Xian and Madhavan (2014) created a machine-assigned method for analysing the topics of engineering education publications using the human-generated taxonomy of education topics in the ERIC database.

1.3. Taxonomies in other fields

Other fields have applied taxonomies for better defining their scope and boundaries, assigning reviewers, and organising biological data. For example, Ulrich and Dash (2011) developed a taxonomy for the *Journal of Research Practice* to strengthen the profile and visibility of its transdisciplinary content, to communicate more precisely to potential authors about the 'fit' of their submission within the journal's scope, and to allow potential readers to judge their interest in the journal (and to recommend it to others). Their taxonomy is organised using three distinct categories: (1) focus areas (broad theme of importance to the journal), (2) subject areas, and (3) keywords. Ulrich and Dash (2011) noted,

Basically, we believe that defining focus areas is a useful way to clarify and explain to our readers and authors those topics of particular interest in which the journal aims to excel, that is, to achieve a high standard of quality, originality, and practical relevance. (page 3)

In the field of computer science and information systems, Kalmukov (2012) described how automated computer algorithms could use a taxonomy of terms and information from individual editors or programme chairs to assign peer reviewers with overlapping but nonidentical keyword profiles. He conducted an experiment in which conference papers were assigned a set of keywords, potential reviewers self-identified their expertise, and reviewers then bid on willingness to review specific papers according to the perceived match with their expertise. The experiment, though, resulted in poor matches between the automated assignments, and Kalmukov identified several reasons for these

Table 1. Project activities, conference details, and participant demographics.

	Participants		
	US	Non-US	Total
Refining the taxonomy			
Advisory board meetings, 2013–2014	7	2	9
Commissioned outlines, April 2013	3	3	6
Mapping the Field, 20–21 May 2013, Ann Arbor, Michigan, USA	39	9	48
2013 ASEE, 25 June 2013, Atlanta, Georgia, USA	35	6	41
2013 REES, 6 July 2013, Kuala Lumpur, Malaysia	12	48	60
Virtual workshop for graduate students, August 2013	8	1	9
2013 SEFI, 20 September 2013, Leuven, Belgium	3	54	57
2013 FIE, 25 October 2013, Oklahoma City, Oklahoma, USA	29	7	36
Evaluating validity and reliability			
2014 ASEE, June 2014, Indianapolis, Indiana, USA	27	3	30
Developing guidelines for assigning keywords			
2014 FIE, 22 October 2014, Madrid, Spain	6	3	9
Total unique participants ^a	137	129	266

^aSome individuals participated in more than one activity, so the number of unique participants is not a summation of the overall participant count.

mismatches. He found that reviewers did not select enough keywords to cover their entire range of reviewing competency areas, reviewers often used keywords that were too general to describe the specific papers, the taxonomy had duplicate terms in multiple areas, and many papers lacked sufficient keywords to describe their complete interdisciplinary scope.

The Gene Ontology Consortium is a virtual community of volunteer editors who since 1996 have maintained structured, controlled vocabularies of gene product function information (Mayor and Robinson 2014). The ontology provides additional uniformity to the way that biologists apply the conventions of naming and describing the functions of genes. Although the ontology does not focus on keywords that would be assigned to publications or authors, its effectiveness can still be tracked through bibliometric analysis of publications. Mayor and Robinson (2014) found that publications using the ontology are numerous, increasing in number, and represent a global research community. That the papers using the ontology are published in a wide range of journals and are cited frequently attest to the usefulness of the ontology. These results suggest a vision for widespread use of the engineering education research taxonomy described here.

2. Evolution of the taxonomy: a design-based research approach

To meet the need for a taxonomy in engineering education research, we applied the integrative learning design framework from design-based research in education (Kelly 2014). Specifically, we developed an initial draft taxonomy and then simultaneously refined and tested draft versions of the taxonomy by engaging various stakeholders through multiple iterations of deployment and improvement, resulting in the final taxonomy, EER Taxonomy Version 1.0 (Finelli and Borrego 2015). We evaluated the validity and reliability of the taxonomy and developed guidelines for using it. For our work, we had two specific goals:

Create a useful taxonomy We aimed to create a concise and comprehensive map for the field that would be complete enough to allow any research initiative to be described using four to six keywords but that would not be an exhaustive list of every possible term. We also intended for the taxonomy to be a useful tool for multiple audiences, including researchers and other community members in the field, journal editors, and funding agencies. We worked to achieve this goal through a process of continuous improvement by seeking feedback and advice from an advisory board of journal editors and other recognized experts in engineering education, conducting several iterative refinements of the taxonomy, hearing from multiple and varied voices at all stages of the process, and seeking out a professional taxonomist early in the project with whom we partnered through the entire process.

Establish an inclusive process Although this taxonomy project was funded by the U.S. National Science Foundation, we employed a process that aimed to be inclusive of the diverse global community of engineering education research. Thus, we included international participation of faculty, administrators, and graduate students from across the world through our advisory board, invited workshops, and presentations at international conferences. Many of our design decisions were guided by this purpose of inclusiveness. We advertised opportunities for involvement broadly through national and international venues. When space for participation was limited, we used transparent selection processes and criteria that encouraged diversity. At workshops and conference sessions, we implemented activities that de-emphasized hierarchy and privilege of particular research areas, and we adapted activities to be relevant in the local context for engineering education research. Ultimately however, due to time and funding constraints, the taxonomy focuses on engineering education research in the United States.

Our approach included proactive and retroactive analysis of data and other feedback from multiple members of the community, collected through one workshop, seven conference sessions, and other activities. Table 1 provides details about those individuals, and Figure 1 maps their home institutions. Altogether, there were 266 unique participants, representing 149 cities in 30 countries, who engaged in a series of activities that involved:



Figure 1. Location of home institution for 266 unique participants.

Table 2. Details of taxonomy versions.

	Date created	No. of terms ^a	No. of branches	No. of levels
Version 0.1	05/05/13	1257	13	7
Version 0.2	06/21/13	969	14	6
Version 0.3	07/01/13	1012	14	6
Version 0.4	09/13/13	1057	17	6
Version 0.5	10/17/13	1052	17	6
Version 0.6	11/08/13	452	14	6
Version 1.0	09/23/14	455	14	6

^aThe branch names are included in the counts for 'number of terms.'

(1) refining draft versions of the taxonomy, (2) evaluating validity and reliability of the taxonomy and (3) developing a set of guidelines for assigning keywords from the taxonomy. Each step is described in detail below.

2.1. Refining the taxonomy*

The diverse range of community members who assisted in developing and refining our taxonomy included experts from Access Innovations, an information management firm that regularly creates and maintains taxonomies. We developed an initial draft taxonomy from three commissioned outlines, participants refined the draft prototype at a two-day Mapping the Field Conference, and stakeholders developed and refined draft versions at a series of five subsequent workshops: the 2013 American Society for Engineering Education Annual Conference, the 2013 Research in Engineering Education Symposium, a virtual workshop that engaged nine graduate students, the 2013 European Society for Engineering Education Annual Conference, and the

2013 Frontiers in Education Annual Conference. At each iteration, we allowed stakeholders to practice on a diverse set of articles (Hedden 2010), and we followed ANSI/NISO Z39.19 standard in carefully considering which distinct terms to include and which compound words warranted a unique term (Hedden 2010). Details about the six draft versions of the taxonomy (versions 0.1 through 0.6), as well as the final taxonomy (EER Taxonomy Version 1.0), are included in Table 2.

2.1.1. Advisory board meetings

To guide our project efforts, we established a 10-member advisory board comprising leaders in engineering education. The board included the chairs of two departments of engineering education (Purdue University and Virginia Polytechnic Institute and State University), the past or present editors of five journals in the field (*Australasian Journal of Engineering Education*, *European Journal of Engineering Education*, *Journal of Engineering Education*, *IEEE Transactions on Education*, and *International Journal of Engineering Education*), and

Table 3. Advisory board members.

Stephanie Adams	Department Head and Professor, Engineering Education, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA
Cindy Atman	Director, Center for Engineering Learning & Teaching and Professor and Mitchell T. and Lella Blanche Bowie Endowed Chair, Human Centered Design and Engineering, University of Washington, Seattle, Washington, USA
Erik de Graaff	Editor-in-Chief, <i>European Journal of Engineering Education</i> and Professor, Aalborg University, Aalborg, Denmark
Jeffrey Froyd	Editor-in-Chief, <i>IEEE Transactions on Education</i> and Director, Faculty Climate and Development and TEES Research Professor, Texas A&M University, College Station, Texas, USA
Ahmad Ibrahim	Editor, <i>International Journal of Engineering Education</i> and Professor, RCC Institute of Technology Yorkville University, Toronto, Ontario, Canada
Euan Lindsay	Past co-editor, <i>Australasian Journal of Engineering Education</i> and Foundation Professor of Engineering, Charles Sturt University, Bathurst, New South Wales, Australia
Thomas Litzinger	Director, Leonhard Center and Professor, Mechanical Engineering, The Pennsylvania State University, University Park, Pennsylvania, USA
David Radcliffe	Kamyar Haghighi Head and Epistemology Professor, Engineering Education, Purdue University, West Lafayette, Indiana, USA
Michael Loui	Editor, <i>Journal of Engineering Education</i> and Dale and Suzi Gallagher Professor, Engineering Education, Purdue University, West Lafayette, Indiana, USA and Professor Emeritus, Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Illinois, USA
Sheri Sheppard	Co-Director, Center for Design Research and Professor, Mechanical Engineering, Stanford University, Stanford, California, USA

other recognised world leaders in engineering education research. Members of the advisory board are listed in Table 3.

We consulted with our advisory board at two in-person meetings (one immediately following the Mapping the Field Conference in Ann Arbor and one during the 2013 American Society of Engineering Education Annual Conference), at multiple virtual meetings, and through individual phone conversations. At each phase, we reviewed the process for engaging the community in refining the taxonomy, considered whether the goals and focus (with respect to research vs. practice and national vs. international) were appropriate and achievable, and discussed strategies for ensuring access and use of the final taxonomy. The advisory board was particularly helpful in thinking strategically about the long-term impact of the project.

2.1.2. Commissioned outlines

2.1.2.1. Participant selection. We began the project by commissioning three outlines to synthesise related efforts already underway. We issued an international, open call and received six proposals for initial outlines. From the proposals submitted, we commissioned three teams (six individuals) to provide outlines as the basis for the initial taxonomy.

2.1.2.2. Outline details. The three outlines, each consisting of terms arranged in a two-level outline, were developed using different approaches and source materials. For the first outline, its authors began by analysing bibliographic data (i.e. title, abstract, and keyword list) for nearly 900 international journal articles and conference papers from 2005 to 2008. They iteratively created a set of first-level terms (each having a clearly identifiable research area) and second-level terms. Next, from over 500 relevant journal articles and conference proceedings, the authors expanded

their analysis by creating a more comprehensive set of terms for the diversity category. Their resulting outline contained 1242 terms categorised into 38 branches.

The second outline was based on 2216 peer-reviewed journal articles in five international engineering education journals from 1959 to 2012. The authors of the outline studied the titles to determine an initial set of keywords for each article, and then they applied network analysis to identify underlying themes and relationships among the keywords. The two-level outline included 256 terms categorised into 46 branches, as well as a time dimension and an indication of the level of connectedness.

The third outline involved analyses of three separate sources: (1) the full text of 35 journal articles published in the United Kingdom during 2006–2012, 86 conference papers during 2008–2012, and a pedagogic research statement for the field; (2) the authors' personal reflections on three related conferences and a study of relevant PhD theses; and (3) meeting notes of the United Kingdom Engineering Education Research Special Interest Group from 2009 to 2013. The two-level outline included 56 terms categorised into 13 branches.

2.1.2.3. Outcome. From the three commissioned outlines, Access Innovations created a draft taxonomy. The company integrated and refined the outlines, normalised the terms, and worked to consolidate the two-level structure into a more hierarchical one. The resulting draft taxonomy (version 0.1) included 1257 terms arranged in 13 branches and seven levels.

2.1.3. Mapping the Field Conference

2.1.3.1. Participant selection. The Mapping the Field Conference was a two-day workshop to refine the draft taxonomy and its accompanying organising structure. We sent email invitations to several groups, including the Research in Engineering Education Network, the

Global Engineering Deans Council of the International Federation of Engineering Education Societies, the Educational Research and Methods Division of the American Society of Engineering Education, and the Engineering Libraries Division of the American Society of Engineering Education. The invitation included a link to a brief application, which requested individuals to list keywords to describe their main research area and to answer two questions: What areas of engineering education are in most pressing need of additional research? How will you contribute to diversity of perspectives at this workshop?

We aimed to be as inclusive of the international community as possible, and we selected a group of researchers and other stakeholders according to a variety of factors, including diversity of experience and history in the field; diversity of research area and understanding of the field based on application responses; and diversity of perspectives, especially as related to international backgrounds. Altogether, we selected 48 conference participants from 96 applicants. The participants comprised 39 individuals from the United States and nine colleagues from other countries and who represented 40 distinct institutions from across the world. They had broad experience levels and ranged from current graduate students and faculty new to the field, to seasoned veterans with extensive experience.

2.1.3.2. Conference details. The Mapping the Field Conference was held in Ann Arbor, Michigan, on 20–21 May 2013. Participants reviewed subsections of the initial draft taxonomy in advance of the conference and worked to further refine version 0.1 of the draft taxonomy. At the conference, a professional taxonomist from Access Innovations presented an introduction to taxonomies and an overview about using and maintaining taxonomies. Participants engaged in multiple breakout sessions where they discussed subsections of the taxonomy, suggested term-by-term revisions, and made high-level revisions to the overall taxonomy.

2.1.3.3. Outcome. Access Innovations worked with the documents produced at the conference, and through an iterative process, we produced version 0.2 of the draft taxonomy. It included 969 total terms, arranged in 14 branches and six levels.

2.1.4. 2013 American Society of Engineering Education Annual Conference

2.1.4.1. Workshop details. We held a free workshop at the 2013 American Society of Engineering Education (ASEE) Annual Conference in Atlanta, Georgia, on 25 June 2013 (Finelli and Borrego 2013). This pre-conference workshop was advertised to all conference attendees by means of an abstract printed in the conference programme. The abstract included specific welcoming statements to indicate the inclusive nature

of the workshop. During the three-hour workshop, 41 participants reviewed version 0.2 of the draft taxonomy and used and revised it during two activities.

For the first activity, we compiled six sets of five abstracts, selected from papers published in the *Proceedings of the 2012 ASEE Annual Conference* and in recent issues of *Advances in Engineering Education*, the *International Journal of Engineering Education*, and the *Journal of Engineering Education*. Working individually, then in small groups, participants applied the draft taxonomy to abstracts in one of the sets by identifying four to six keywords to describe each abstract. They also identified terms missing from the taxonomy and offered suggestions for making the taxonomy easier to use. Then, for the second activity, participants assisted in refining the taxonomy by working in groups to make detailed, term-by-term revisions to selected branches of the draft taxonomy.

2.1.4.2. Outcome. Following the 2013 ASEE Annual Conference, we integrated participant feedback to produce version 0.3 of the draft taxonomy. It included 1012 total terms, arranged in 14 branches and six levels.

2.1.5. 2013 Research in Engineering Education Symposium

2.1.5.1. Workshop details. To solicit insights representing a global set of perspectives about the taxonomy, we held a free workshop at the 2013 Research in Engineering Education (REE) Symposium in Kuala Lumpur, Malaysia, on 6 July 2013. We advertised the workshop to all symposium attendees through an inclusively worded abstract printed in the conference programme, and 59 participants reviewed version 0.3 of the draft taxonomy during a 90-min post-conference session. As at the previous conference, participants began by using the draft taxonomy to identify keywords for a set of abstracts. To be relevant to the context of the symposium, the activity involved five sets of four abstracts, chosen from papers published in the *Proceedings of the 2011 REE Symposium*, in the *Proceedings of the 2012 REE Symposium*, and in recent issues of the *International Journal of Engineering Education*. Participants then engaged in a broader discussion about making the taxonomy more globally relevant and ensuring its widespread use.

2.1.5.2. Outcome. Several suggestions for refining the taxonomy resulted from the workshop activities. Rather than create an updated taxonomy, we used these suggestions to inform a virtual workshop for graduate students.

2.1.6. Virtual workshop for graduate students

2.1.6.1. Participant selection. To further refine the taxonomy over a longer period of time than a conference workshop, we invited graduate students to apply to

participate in a virtual workshop through a series of broadly distributed email messages. We asked applicants to complete a keyword activity and respond to questions about transformative research in engineering education and about how they would contribute to diversity in the group. Drawing on their responses, we selected nine students to participate.

2.1.6.2. Workshop details. Over a one-month period, the graduate students reviewed version 0.3 of the draft taxonomy and completed three activities. They worked individually to use and apply the taxonomy to identify keywords for five abstracts of their choosing, participated in virtual group work (in teams of three) to revise an assigned portion of the draft taxonomy using feedback generated from the 2013 REE Symposium, and worked in virtual groups to make holistic revisions to a new version of the taxonomy.

2.1.6.3. Outcome. We incorporated feedback from these activities to develop version 0.4 of the draft taxonomy. It included 1057 total terms, arranged in 17 branches and six levels.

2.1.7. 2013 European Society for Engineering Education Annual Conference

2.1.7.1. Workshop details. To again collect insights representing a broad, international perspective on the taxonomy, we held a workshop at the 2013 European Society for Engineering Education (SEFI) Annual Conference in Leuven, Belgium, on 20 September 2013 (Borrego 2013). This workshop was advertised to all conference attendees, and the SEFI Engineering Education Research Working Group members were especially encouraged to attend. Fifty-seven participants reviewed version 0.4 of the draft taxonomy during the four-hour post-conference workshop, and they engaged in one activity to use the taxonomy and a second activity to refine it. Abstracts for applying the taxonomy activity were chosen from papers published in the *Proceedings of the 2011 SEFI Annual Conference*, in the *Proceedings of the 2012 SEFI Annual Conference*, and in the 2013 volume of the *European Journal of Engineering Education*. Participants also offered suggestions for higher level revisions to the taxonomy.

2.1.7.2. Outcome. Following the 2013 SEFI Annual Conference, we integrated participant feedback and produced version 0.5 of the draft taxonomy. It included 1052 terms, arranged in 17 branches and six levels.

2.1.8. 2013 Frontiers in Education Annual Conference

2.1.8.1. Workshop details. We conducted a free workshop at the 2013 Frontiers in Education (FIE) Annual Conference in Oklahoma City, Oklahoma, on 23 October 2013 (Finelli 2013). The workshop was advertised to all conference attendees through the

conference programme. During the three-hour, pre-conference session, 35 participants reviewed version 0.5 of the draft taxonomy and engaged in two activities. The first activity involved using the taxonomy to identify keywords for four abstracts selected from papers published in the *Proceedings of the 2011 FIE Annual Conference* and in the *Proceedings of the 2012 FIE Annual Conference*. In a second activity, smaller groups revised one of six branches of the taxonomy.

2.1.8.2. Outcome. Following the 2013 FIE Annual Conference, we integrated feedback from participants to develop version 0.6 of the draft taxonomy. It was a significantly streamlined version, which included just 452 terms organised in 14 branches and six levels. As suggested by workshop participants, these changes were made for two reasons: to achieve a consistent level of detail across all of the taxonomy branches, and to focus the taxonomy more on existing work than aspirational or future directions.

In summary, we conducted several in-person and virtual workshops, integrated feedback from our advisory board, and worked with a taxonomy creation firm to develop and refine draft versions of the taxonomy. Our use of inclusive activities to solicit a broad range of global perspectives produced a draft taxonomy that we assessed for validity and reliability.

2.2. Evaluating validity and reliability

To evaluate the validity and reliability of the taxonomy, we adapted the procedures Hawkins, Larson, and Caton (2003) used to validate their information science taxonomy. In this procedure, multiple researchers assigned keywords to a set of publication abstracts, studying the resulting keywords, and (because they did not involve their community in many iterations of developing the taxonomy) refining the taxonomy by adding some terms and removing others that were unused or duplicated. Since we extensively involved our community in refining the taxonomy, we went beyond these efforts by adding a procedure, related to reliability, which assessed the extent to which authors agreed with keywords we assigned to describe their publications. Overall, through a series of activities involving conference papers and journal articles, we evaluated the validity and reliability of our taxonomy using four criteria:

- (1) Keywords assigned from the taxonomy are reproducible by different researchers.
- (2) The field of engineering education research, as represented by a sample of journal articles, is encompassed by terms in the taxonomy.
- (3) Keywords assigned from the taxonomy to the same journal articles are evenly distributed across the branches.

Table 4. Papers published and abstracts reviewed for evaluating validity and reliability.

	No. papers published				No. abstracts reviewed			
	2011	2012	2013	Total	2011	2012	2013	Total
<i>Journal of Engineering Education</i>	30	29	22	81	30	29	22	81
<i>IEEE Transactions on Education</i>	82	73	60	215	30	29	22	81
<i>International Journal of Engineering Education</i>	130	112	142	374	30	29	22	81
Total	242	214	224	680	90	87	66	243

- (4) Keywords assigned from the taxonomy to a set of conference papers representative of the field are reliable.

2.2.1. Norming exercise

2.2.1.1. Activity details. We completed a norming exercise to provide a consistent, objective approach for selecting keywords and to identify the extent to which keywords were reproducible by multiple researchers. After developing a set of working guidelines for assigning keywords, two of us independently assigned keywords from version 0.6 of the draft taxonomy to the same 30 abstracts used at the 2013 ASEE Annual Conference workshop. Then we compared the keywords. We also refined the working guidelines for assigning keywords to ensure even more consistency for subsequent activities.

2.2.1.2. Outcome. We found extensive overlap between the keywords assigned by the two of us. There were a few disagreements, but those were easy to resolve. Because there was a high level of reproducibility in assigning keywords, the taxonomy satisfied our first criterion for validity and reliability.

2.2.2. Keyword frequency analysis

2.2.2.1. Activity details. Next, we selected a set of articles as a representative sample for the field of engineering education research in the United States, and we assigned and analysed keywords for those articles. The set included 243 articles published during 2011, 2012, and 2013 in three journals: the *Journal of Engineering Education*, *IEEE Transactions on Education*, and the *International Journal of Engineering Education*. Although the number of articles published in these journals varied significantly, we analysed the same number of articles from each journal to provide equal representation. Specifically, because the *Journal of Engineering Education* published the fewest number of articles each year, we included every article published in that journal but chose a random sample of articles in the other two journals each year. In total, of the 680 articles published in these three journals in 2011, 2012, and 2013, we analysed 243 journal articles (see Table 4).

For each abstract of the 243 journal articles, the same two of us who completed the previous norming exercise used the working guidelines we had developed to select three to six keywords from version 0.6 of the draft

taxonomy. (Although some of the articles had author-assigned keywords, we intentionally did not use them in our analysis, because the keywords were not drawn from a common set of terms and because not every article had them.) We conducted a frequency analysis of the keywords to study the distribution of the keywords across the taxonomy.

2.2.2.2. Outcome. Altogether, from the 438 available terms of version 0.6 of the draft taxonomy (we chose not to use any of the 14 branch names as keywords), we successfully identified relevant keywords for all 243 articles. In total we assigned 1176 keywords, distributed across all 14 taxonomy branches (Table 5). Thus, because the set of articles we selected to represent the field of engineering education research could be adequately described by terms in the taxonomy, the taxonomy satisfied our second criterion for validity and reliability.

For this set of articles and using version 0.6 of the taxonomy, Figure 2 provides a visual representation of the keyword frequency analysis, and Figure 3 displays the analysis as a word cloud. In our analysis, 168 of the taxonomy terms were never selected as keywords, and the remaining 270 terms were assigned as keywords an average of 4.4 times (maximum = 39, median = 2). The three most frequently used taxonomy terms were 'survey,' 'case study,' and 'undergraduate.' The keywords for the abstracts were distributed in a fairly even way, so the taxonomy satisfied our third criterion for validity and reliability.

Because we had involved the broader community in refining the taxonomy at several workshops, and because the purpose of the keyword frequency analysis was to validate the taxonomy, we chose not to make significant adjustments based on our frequency analysis. However, the taxonomy terms that were not chosen as keywords for this set of journal articles will serve as candidates for removal as the taxonomy is further refined through actual use.

2.2.3 2014 American Society of Engineering Education Annual Conference

2.2.3.1. Activity details. Finally, we applied version 0.6 of the draft taxonomy to papers accepted for presentation at the 2014 ASEE Annual Conference by the Educational Research and Methods Division (ERM) of ASEE, and we asked authors to confirm whether keywords we assigned were appropriate to represent their papers. We restricted our analysis to papers published by the ERM Division

Table 5. Distribution of keywords across the taxonomy branches.

Taxonomy branch	References
1. Assessment	106
2. Design	24
3. Diversity	53
4. Educational level	31
5. Educational setting	115
6. Educational technology	108
7. Instruction	88
8. Outcomes	59
9. Professional practice	172
10. Recruitment and retention	121
11. Related fields	16
12. Research approach	29
13. Theoretical frameworks	225
14. Teams	29

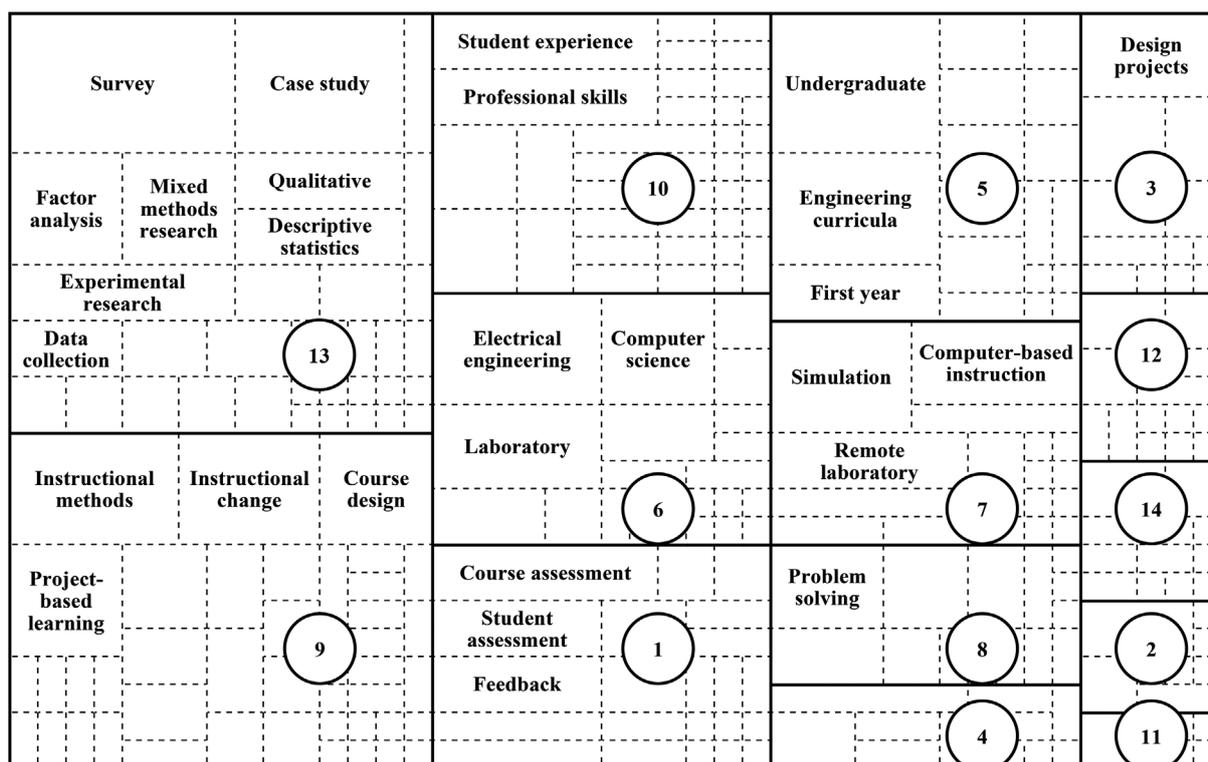


Figure 2. Keyword frequency analysis. The 270 taxonomy terms that are used at least once in the frequency analysis are each represented by an individual rectangular box, and the size of the box is proportional to the number of times a term was used. Terms that are used at least 10 times are listed. The dark borders separate terms in the 14 taxonomy branches, and those branches are identified by circled numbers.

for three reasons. First, the taxonomy focused on engineering education research, and the ERM Division aligns most explicitly with this area. Second, limiting our analysis to these papers provided a manageable sample size. Third, we suspected that ERM members would be more likely to respond to requests related to taxonomy development than randomly selected authors.

In advance of the conference, we invited authors of all 70 ERM Division papers listed in the conference programme to send the final version of their paper that would appear in the *Proceedings of the 2014 ASEE Annual Conference*. We received 36 papers, and we assigned five keywords (using the working guidelines we had established) to each. Next, we forwarded our set of keywords, along with our working guidelines for

assigning them, to authors and requested feedback from the authors about how well they believed each of keyword suited their paper. Authors were invited to offer alternative keywords if they disagreed with our selection. Thirty-one of the authors replied to our request.

2.2.3.2. Outcome. The authors' level of agreement with the 155 keywords we assigned (five for each of the 31 papers) was quite high. Authors agreed or strongly agreed with 140 (90%) of the keywords we selected and disagreed or strongly disagreed with 15 (10%). This high author agreement suggested that the taxonomy will be usable in the future for authors to assign their own keywords when submitting abstracts and papers for peer review. Further, the strong agreement suggested



Figure 3. Word cloud for keyword frequency analysis. The 26 terms used at least 10 times in the keyword frequency analysis are illustrated here, and terms with larger font sizes were used more often.

that our approach was reliable and that the taxonomy satisfied our fourth criterion for validity and reliability.

In summary, our analyses showed that version 0.6 of the draft taxonomy satisfied all four of the criteria we established for validity and reliability. Multiple researchers selected reproducible keywords for a set of abstracts (Criterion 1), the taxonomy comprised terms that could describe every article in a representative sample from the field of engineering education research in the United States (Criterion 2), keywords selected for the sample were evenly distributed across the branches of the taxonomy (Criterion 3), and the strong agreement by authors with our researcher-assigned keywords indicated the reliability of keywords (Criterion 4). Following the validity and reliability testing, we made minor updates to version 0.6 of the draft taxonomy by removing duplicate terms, combining similar terms, renaming terms, and adding terms. The resulting version of the taxonomy, EER Taxonomy Version 1.0 (Finelli and Borrego 2015), has 454 terms arranged in 14 branches and six levels. It is our final one.

2.3. Developing guidelines for assigning keywords

As we proposed previously, one primary use of this taxonomy for engineering education research is for selecting keywords that describe conference papers and journal articles. Providing keywords allows a researcher to describe scholarly work to a broader community, position the work in the existing field, interest potential readers, and aligns current work with other useful research. Modern taxonomies often provide application guidelines for assigning keywords that address both content-related items, such as the type of keywords to assign (Levy 2004), as well as broader guidelines, such as the total number of keywords to assign (Hedden 2010).

During our interactions with multiple stakeholders in the development of the draft taxonomy, we identified multiple reasons for providing clear direction on assigning keywords. We found that, without guidance, authors often choose keywords that lack a uniform level of detail – the words are overly general or too specific. Similarly, authors use jargon or other terms that are not familiar to a broad range of researcher (rather than choosing preferred terms), and they use terms that sometimes have different meanings in different research contexts. We found that authors often select keywords that describe only a limited part of a project (e.g. the population and intervention but not the methods or evidence), and they have difficulty gauging how many terms to apply.

Thus, concurrent with activities to develop and refine the taxonomy and assess its validity and reliability, we developed a set of guidelines to assist authors in assigning keywords to their publications. We reviewed author instructions for five journals targeted to engineering education research (*Australasian Journal of Engineering Education*, *European Journal for Engineering Education*, *Journal of Engineering Education*, *IEEE Transactions on Education*, and *International Journal of Engineering Education*) and summarised guidelines they provide for assigning keywords (Table 6). Then we drafted an initial set of guidelines that suggested that one or two keywords be assigned from each of three keyword categories: context/focus/topic, purpose/target/motivation, and research approach.

2.3.1. 2014 *Frontiers in Education Annual Conference*

2.3.1.1. Workshop details. We solicited feedback about our initial guidelines during a free workshop at the 2014 *Frontiers in Education (FIE) Annual Conference*

Table 6. Summary of journal instructions for authors.

Australasian Journal of Engineering Education

www.editorialmanager.com/eatj/default.aspx

Authors are instructed that each submission should include keywords, but no guidance is offered

European Journal of Engineering Education

www.tandfonline.com/action/authorSubmission?journalCode=ceee20&page=instructions&#.VJB3zCvF9PO

Instructions for authors note that 'each manuscript should have 3 to 6 keywords,' and they provide hyperlinks to generic guidelines that encourage authors to refer to an 'established common indexing standard in a particular discipline (e.g. GeoRef, ERIC Thesaurus, PsycInfo, ChemWeb, and so on)'. However, specific advice about keywords is not given

Journal of Engineering Education

onlinelibrary.wiley.com/journal/10.1002/%28ISSN%292168-9830/homepage/ForAuthors.html

When submitting the structured abstract that accompanies each manuscript, authors are instructed to 'list three keywords,' but no further guidance is provided

IEEE Transactions on Education

www.ieee.org/publications_standards/publications/authors/authors_journals.html

The journal provides a taxonomy of suggested keywords and encourages authors to select terms from the list (or to add their own terms if they cannot find appropriate ones). The list comprises 'the first three hierarchical levels under each branch that is formed from the top-most terms of the IEEE Thesaurus.' The 2014 IEEE Taxonomy, however, frequently does not include education-related terms (e.g. it does not include the terms 'gender,' 'pedagogy,' 'focus group,' or 'design project'), so it is only of limited use. There are no other guidelines for assigning keywords

International Journal of Engineering Education

www.ijee.ie/authors/Guide_to_Authors.html

Instructions for assigning keywords are limited to 'include keywords such as: keyword1; keyword2; keyword3; keyword4'

in Madrid, Spain, on 22 October 2014 (Finelli and Rasoulifar 2014). The abstract of the workshop printed in the conference programme included an open invitation for all conference participants to attend. During the three-hour, pre-conference workshop, participants used the final taxonomy to choose keywords for four abstracts selected from papers published in the *Proceedings of the 2011 FIE Annual Conference* and in the *Proceedings of the 2012 FIE Annual Conference*, and they reflected on the approach they used for assigning keywords. Then, we introduced our initial set of guidelines, and participants repeated the keyword exercise; this time they compared keywords from the two activities and suggested improvements to the guidelines. Finally, workshop participants discussed, in small groups, ways to encourage other researchers and community members to use the taxonomy and ways to make it a more useful tool.

2.3.1.2. Outcome. Participants found the guidelines helpful and easy to use, and they suggested updates that we incorporated into a final set of guidelines. The final guidelines are defined in Table 7 and mapped to related branches of the taxonomy from which keywords might be chosen. Table 8 gives an example of how the guidelines can be applied to assign keywords for an abstract.

To encourage more widespread use of the taxonomy, workshop participants suggested that (1) journal editors and conferences should begin requiring its use, (2) the taxonomy should be used to index conference proceedings and other collections and to cluster papers according to related keywords, and (3) a marketing campaign should be undertaken to illustrate the utility of the taxonomy. Finally, on the basis of their interactions with different electronic and paper versions of the taxonomy, participants suggested the taxonomy should be packaged

as a free iPhone app or a mobile website to make it a more useful tool. We have responded by developing both tools.

In summary, using these guidelines can ensure that the keywords are assigned to identify important concepts and are chosen in a consistent way. And although they were developed to assist authors in assigning keywords to their publications, the guidelines might also assist reviewers in describing their own research expertise.

3. The final taxonomy

The final taxonomy, EER Taxonomy Version 1.0 (Finelli and Borrego 2015), comprises 455 terms arranged in 14 branches and six levels. It is copyrighted under a Creative Commons Attribution-Share Alike 4.0 International License and is available to use and adapt for free with attribution to the original source. This final version was developed in concert with a professional taxonomist, and the full taxonomy is archived and is accessible from the institutional repositories for the first author's current institution (the University of Michigan at Ann Arbor).

An iPhone app, EER Taxonomy (Finelli 2015), is built for iOS 8 and provides an easy-to-use interface for the taxonomy. The application automatically updates the taxonomy from a remote server (obviating the need for a user to download updates), and it includes a brief user's guide. The app provides functionality to interactively browse the taxonomy in a multi-level environment to reflect the outline structure of the taxonomy. As well, users can conduct an instant search, and the location of the resulting keyword is indicated through a combination of breadcrumb navigation and expandable terms. Users may create, edit, delete, and export customised lists of favourite or commonly used keywords. The app, which allows users to send feedback to the research team and which links to a Creative Commons licence, may be

Table 7. Guidelines for selecting keywords.

Keyword category (select one or two keywords from each of the following three categories)	Related taxonomy branches
Context/focus/topic Focus of study Educational level (e.g. pre-college, graduate student, practicing engineer) Field of engineering (e.g. physics, civil engineering) Population (e.g. undergraduate students, faculty, women) Scale of the study (e.g. individual students, small groups, department, multi- or single-institution)	1. Assessment 2. Design 3. Diversity 4. Educational level 5. Educational settings 6. Educational technology 7. Instruction ^a 9. Professional practice ^a 10. Recruitment and retention ^a 11. Related fields 13. Theoretical frameworks ^a 14. Teams
Purpose/target/motivation Outcome under study (e.g. communication skills, critical, thinking, scientific literacy) Purpose (e.g. diffusion, adoption)	7. Instruction ^a 8. Outcomes 9. Professional practice ^a 10. Recruitment and retention ^a 13. Theoretical frameworks ^a
Research approach Underlying theory Research methods (e.g. qualitative analysis, quantitative analysis) Research tools (e.g. interview, survey, focus group)	12. Research approaches 13. Theoretical frameworks ^a

^aWords appearing in these taxonomy branches are relevant for multiple keyword categories.

Table 8. Example application of keyword guidelines.

<p>Sample abstract (Finelli et al. 2014)</p> <p>Student resistance is often cited as a major barrier to faculty's use of active learning, but there are few research-based strategies for reducing this barrier. To address the need for such strategies, we have initiated a project to identify specific, research-based strategies to significantly reduce student resistance to faculty's use of active learning practices. In this work-in-progress paper, we describe the first phase of our research – the development and pilot testing of a classroom observation instrument to assess student responses to faculty's use of active learning. This instrument, which draws upon other published observation protocols, will allow us to capture data about faculty's use of and students' response to active learning as we undertake our larger research project</p> <p>Selected keywords</p> <p>From context/focus/topic category: active learning, student perception</p> <p>From purpose/target/motivation category: instructional change</p> <p>From research approach category: classroom, observations</p>
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downloaded for free from the Apple app store. Users will also be able to access updates of the taxonomy from the website (<http://taxonomy.engin.umich.edu>).

A password-protected Internet application provides administrator access for the taxonomy. It offers an automated way to update the taxonomy by importing a spreadsheet of taxonomy terms or by adding or removing words directly. The administrator app incorporates web security best practices, allows for user-management, includes password protection and recovery, and allows the administrator to generate a printable version (from a PDF) of the taxonomy for distribution.

4. Discussion

This project had two major goals: create a useful taxonomy and establish an inclusive process. We succeeded in achieving both.

The inclusive approach we used in developing the taxonomy helped produce a useful product. We purposefully engaged the community at multiple, iterative stages of development; this process produced a taxonomy that will be broadly accessible by members of the community and that will allow researchers to see how their work can be represented using its terms. We developed a series of activities for individuals to interact with and navigate the taxonomy, and we focused the

activities on abstracts of recently published papers that were representative of the conference that participants were attending. Because participants reviewed abstracts (rather than full papers), these activities highlighted characteristics of well-written abstracts and, by doing so, had a secondary benefit of educating individuals about how to write better abstracts.

Because users of a taxonomy should share a common understanding of how to apply it, we developed and provided guidelines for assigning keywords. The guidelines help overcome the common mistakes of assigning keywords that are overly specific, that are unlikely to be used by others, or that are too general to sufficiently communicate the unique characteristics of the work. Selecting keywords in a consistent way can increase the number of readers who locate a scholarly work and can facilitate better connections between related activities. Other aspects of a useful taxonomy include uniform depth and specificity (Pack 2002), and we ensured that ours did through our careful revisions that incorporated community feedback, advice from an advisory board, and insights from a professional taxonomist.

We established an inclusive process in the development of the taxonomy in several ways. Rather than using invitation-only activities that would exclude some members of the community, we issued open calls

for participation that we distributed widely. We used transparent procedures to select participants when space was limited, and our selection criteria emphasised diversity of perspectives. Through a variety of evolving activities at conferences around the world, we engaged a large number of participants at various career stages. We also learned more inclusive ways to develop the taxonomy. We found from the Mapping the Field Conference that some participants inferred that the outline structure of the taxonomy implied a hierarchical ordering of the terms. Many groups offered suggestions for new branches, and two groups chose to reorganise the entire list of terms. Participants argued that specific topics were foundational and deserved to be main headings in the hierarchy. We reflected on our experiences at that conference; then we altered our subsequent activities to emphasise that the outline was merely intended as an organisational structure to provide context, to further define the terms, and to help authors and indexers find terms. We also systematically arranged taxonomy terms in alphabetical order within the outline to make these points even clearer. Further, we decided early in our work that prioritising important research areas would be detrimental to our goal of creating a comprehensive map for the field, so we purposefully decoupled discussions about a research agenda from development of a complete taxonomy.

5. Summary and recommendations

Although taxonomies are in widespread use, there is little empirically based literature to guide development and validation of new ones. We enlisted expertise from a professional taxonomist and the engineering education research community to adapt known procedures to develop a useful taxonomy through an inclusive process. Once our taxonomy is in place and authors routinely assign keywords to their publications, the field will be in a better position to make evidence-based decisions about gaps and priorities for future research.

We offer advice for others undertaking similar initiatives. Authors know their work best and therefore should assign their own keywords. Linking abstract and paper submission portals to a taxonomy empowers authors to index their own work and helps generate the types of metadata that will be useful for analysing publication trends in the field. Users, though, need guidelines for assigning keywords to help balance specificity with the need to use a common set of terms to connect related work. Throughout this project, we spent significant time developing and testing guidelines with potential users. These guidelines increased reliability, and users indicated satisfaction with them. Since different journals represent different perspectives on the field and different regional foci or interests, it was important to consider

publications from multiple sources in developing, refining, and validating the taxonomy.

6. Future work

One limitation of this project is that, due to time and funding constraints, the taxonomy focuses on engineering education research in the United States. Although our process was inclusive of some members of the international engineering education research community, and we received some feedback about ways to reflect different approaches and terminologies used outside of the United States, we did not aim to develop a truly international taxonomy. Among other things, doing so would involve using a different set of preferred terms, mapping preferred terms for the United States to those preferred in other regions, and introducing different or expanded branches to reflect other research emphases. Expanding our current taxonomy or recreating the process on a more international scale is one potential direction for future work.

Future work also involves making ongoing updates and refinements to the current taxonomy. Although the organisation of the terms within the taxonomy provides contextual cues for the definition of each term, participants frequently requested definitions for all terms. Writing and vetting definitions, providing examples of the keywords in practice, and fully cross-referencing related terms are all future work that would help reduce confusion and ambiguity for users. In addition, for the taxonomy to remain relevant and usable, the list of terms needs to be updated regularly (Levy 2004). In other fields, the approach for regularly maintaining a taxonomy consists of having one or a few taxonomists who accept and evaluate suggestions for new terms, monitor the taxonomy for outdated terms that can be deleted or merged with others, and monitor the use of the terms and provide clarification when needed (Hedden 2010). On a longer but still regular schedule, a broader cross section of the community would be involved in updating the taxonomy, for example every five or ten years.

We propose our field adopt similar mechanisms to allow community members to suggest new terms for addition to the taxonomy by establishing a committee of representatives from the journals jointly publishing this report. The committee could manage the periodic evaluation of community suggestions to ensure that the taxonomy remains relevant and useful to the engineering education research community in the future.

Consistent with our inclusive approach, we synthesised the suggestions of hundreds of community members to produce our final version of the taxonomy. Future work will include procedures for adding new terms as they are needed. The taxonomy itself is copyrighted under a Creative Commons licence, which allows others to adapt and update the work with attribution to the original. We hope the Creative Commons licensing

promotes continued community ownership and updates of the taxonomy so that it remains relevant and useful.

Finally, many of the features of the iPhone app are consistent with expert recommendations for displaying taxonomies (Hedden 2010). We will continue to solicit suggestions for updating the app. Future features of the app will include a way to suggest new terms for the taxonomy and a more seamless interface with manuscript submission sites so authors can use the app to select keywords that are automatically uploaded to the journal's manuscript submission site.

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