Tracking Engineering Education Research and Development – Contributions from Bibliometric Analysis

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***Abstract*—In recent years, bibliometric analysis of publications has been receiving growing attention in engineering education research as an approach that can bring a number of benefits. In this paper two such forms, taxonomical analysis and citation analysis, are applied to papers from the first 2011 number of IEEE Transactions on Education (21 papers) and from the two 2011 numbers of the ASEE-published Advances in Engineering Education (22 papers). In the former approach, seven taxonomical dimensions are used to characterize the papers and in the second the references cited in the 43 papers were studied so as to analyze how the researchers were informed by previous studies.The results suggest that the silo effect identified by Wankat for disciplinary engineering education journals in 2009 was still apparent in the IEEE Transactions on Education in 2011. The Advances in Engineering Education papers show a wide range of cited references, including reference disciplines outside of engineering education, and this suggests that research published there is likely to be informed by a broad range of previous studies which may be interpreted as a sign of a growing maturity of engineering education as a research discipline.**

***Index Terms*—Taxonomical classification, bibliometric analysis, citation analysis, engineering education research, silo effect.**

I. INTRODUCTION

Bibliometric analysis of publications is a research approach which has been receiving growing attention in engineering education research (EER) in recent years [1] – [3] and can bring a number of benefits [4], [5]:

1) As EER is gradually gathering recognition as an emergent field [6], [7] this type of analysis can contribute by tracking cross-fertilization between discipline areas and by providing indicators of the maturity of EER as a field of research[8], [9];

2) Itcan help to provide a map of the terrain for new scholars entering the field [10];

3) Showing in numbers how many different research paradigms are applied in the field, what kind of theories are used and how the data is analyzed, can contribute to an awareness of the richness of the field;

4) Furthermore, classification analysis could be used as a measurement tool to reveal differences between various conferences and research journals as well as hidden trends or emerging research paradigms in the field;

5) Bibliometric analysis could also be used as a reference when such publication forums are defining review criteria for different types of papers. One notes that the review criteria in many conferences do not give clear enough guidelines for authors or reviewers on what is expected for the papers (and even in cases where they are clearly set out a recent study has shown these are not always applied [11]).

B. Approaches to Bibliometric Analysis

A wide-ranging study by Jesiek et al. [1] that compared papers presenting empirical data in a large number of US, European and Australasian EER publications between 2005 and 2008identified 38 categories of research, based on analysis of over 800 articles. A contrasting approach was taken by De Graaff and Kolmos [2] who set out with 8 categories of research and used these to classify the papers in two volumes of the European Journal of Engineering Education. A similar but more detailed approach has been applied to publications in computing education whereby a multi-dimensional taxonomy is used to classify research papers. Malmi et al. [4] used 7 dimensions whereas Simon et al. [12] in an earlier paper used 4.

Whereas all three approaches mentioned above imply a degree of subjective categorization and hence involve a process of cross-checking or inter-rater standardization, citation analysis has the advantage of being more objective. Phillip Wankat has used this method to analyze the citations in all of the 2009 papers in 9 US engineering education journals and proceedings (1,721 papers in all) and noted in subsequent guest editorials [13] – [16] that the narrow range of sources cited in papers published in the disciplinary engineering journals suggested a silo effect in operation that could limit cross-fertilization within engineering education research and he warns that this “clearly limits dissemination of results” and could explain the reported slow rate of diffusion of proven engineering education innovations [17].

C. Methodology

This paper is an extended version of earlier work presented in a special track on IT and Engineering Pedagogy at the IEEE EDUCON 2012 conference in Marrakesh [18]. The conference paper used taxonomical analysis in an exploratory study from an IT research perspective of 43 papers published in 2011 in two journals, one with a disciplinary engineering education focus and the other with a broader engineering education remit. We opted to use Malmi et al.’s 7-dimensional taxonomy framework [4] because we believe the dimensions proposed can be readily applied to the EER field, despite having been originally designed to classify computing education publications.

The results for the research discipline taxonomical dimension were noticeably different for the two journals studied and given that this dimension has been proposed as a possible indicator of interdisciplinarity and developing maturity of a field of research [19], [20] we therefore decided to apply citation analysis to the same 43 papers to get a more precise picture of what prior research informed the papers in the two journals. For comparison with earlier work, we began by using the same approach employed by Wankat in his 2009 studies [14] but then extended this to analyze the citations in detail to allow a more precise depiction of the previous studies upon which the authors were building.

II. METHOD

Papers were analyzed from the first 2011 number of IEEE Transactions on Education, Vol 54 nº 1 (21 papers) and from the two 2011 numbers of the ASEE-published Advances in Engineering Education (AEE), Vol 2 nº 3, 4 (22 papers). As the original aim was to carry out exploratory research from an IT perspective, the former publication was chosen because its disciplinary IEEE connection. The latter, although non-disciplinary specific, states on its website that its mission "is to disseminate significant, proven innovations in engineering education practice, especially those that are best presented through the creative use of multimedia" and hence this online journal, although relatively new, could represent an interesting channel for EER with an IT perspective.

Each of the journal articles was classified by one of the authors using the Malmi et al. framework [4] and the results were then crosschecked by the other author.

We will now set out how the seven dimensions were employed to classify the articles in the study.

The seven taxonomical dimensions used are:

1) Theory/Model/Framework/Instrument (TMFI)
2) Technology/Tool
3) Reference Discipline
4) Research Purpose
5) Research Framework
6) Data source
7) Analysis Method

1) *Theory / Model / Framework / Instrument*

This dimension is used to show linkages to prior work. Here we list the TMFI – theories, models, frameworks and instruments (established questionnaires) – used in the research reported in the paper. Note that we include only those TMFI that are used explicitly rather than just referred to in motivating or positioning the work. For example, we include TMFI that are applied to a research design or used in an analysis, and we include TMFI that are modified or extended by the reported work. We do not include TMFI that are developed in the paper itself TMFI may range from those that are well known and identifiable by name to those that are unnamed and the result of a single study, such as a theory generated from a phenomenographical study. Note that we do not include technical frameworks (e.g. a Model-View-Controller GUI framework) or research frameworks (e.g. phenomenography) in this dimension. The former will often be represented in the Technology/Tool dimension (section 2) and the latter in the Research Framework dimension (section 5).

2) *Technology / Tool*

Here we list any technologies or tools (TT) used in the work reported in the paper; for example, a visualization tool, a class library, software or hardware. As with the TMFI dimension, we are looking for an explicit level of use which is more than just a reference to the technology or tool, and we do not include original TT that areproposed in the paper itself. We only include technologies whose use is significant for the purpose of the paper.

3) *Reference Discipline*

In this dimension we list the disciplines that the reported work is linked to through use of theories, models, frameworks, instruments, technologies or tools. These are commonly termed reference disciplines [19], [20]. As the papers we analyze are positioned in engineering education research, we only note reference disciplines outside of engineering education.

4) *Research Purpose*

The research purpose is concerned with the goals of the research. This dimension is based on the "research approach" dimension of Vessey et al. [21], [22], which was developed from the work of Morrison and George [23]. The three categories are:

Descriptive – description of a tool, technology or system. This may involve detailed explanation of features, functionality and rationale for development.

Evaluative – assessment of a tool, method or situation, typically through a systematic process involving data gathering, analysis and reporting. This may involve hypothesis testing and may be exploratory or investigative in nature.

Formulative – development and/or refinement of a theory, model, standard, or process, or proposition of a new concept. Typically this will involve synthesis and integration of information and argumentation. The use of these terms depends on the perspective of the researcher: a taxonomy may be considered a model and may also be used as a framework for further research. For every paper we identify at least one research purpose. As many papers report studies with several parts, we also list further research purposes where appropriate.

The categories considered are the following:

Descriptive-information/human system (DI), Descriptive-technical system (DT), Descriptive-other (DO), Evaluative-positivist (EP), Evaluative-interpretive (EI), Evaluative-critical (EC), Evaluative-other (EO), Formulative-concept (FC), Formulative-model (FM), Formulative-process, method, algorithm (FP), Formulative-standards (FS).

5) *Research Framework*

A research framework is an overall orientation or approach that guides or describes the research, as opposed to a specific method or technique. A research framework may have associated theoretical, epistemological, and/or ontological assumptions (e.g. phenomenography), may prescribe or suggest the use of particular methods (e.g.

grounded theory), or may simply be a descriptive term for a kind of research activity that has certain characteristics (e.g. action research, case study). Not all papers will have a research framework.

In this case the categories considered are:

Action Research (AR), Case Study (CS), Constructive Research (CR), Delphi, Ethnography (Eth), Experimental Research (Exp), Grounded Theory (GT), Phenomenography (PhG), Phenomenology (PhL), Survey Research (Survey).

6) *Data Source*

The data source dimension describes the nature of the data and how it was gathered in the reported research. Most research papers will have at least one data source.

The categories considered are:

Naturally occurring data (Nat), Research specific data (Res), Research specific data (Res), Reflection(Ref), Software (Sw).

7) *Analysis Method*

An analysis method describes how empirical data was analyzed or what other means were used to draw conclusions. Practically all papers will have at least one kind of analysis method. If a paper has a research framework, that framework might well direct the analysis method that is used; but the same analysis method can of course be found in a paper that is not applying a specified research framework.

The categories considered are:

Argumentation (Arg), Conceptual Analysis (CA), Descriptive Statistics (DS), Exploratory Statistical Analysis (ESA), Interpretive Classification (IC), Interpretive Qualitative Analysis (IQA), Mathematical Proof (MP), Statistical Analysis (SA).

III. RESULTS

A. *Taxonomical Classification*

The taxonomical classification of the two publications is shown in Tables I, II, III and IV, for the TMFI and Technology / Tool dimensions.

In the charts presented in Figures 1 to 4, it is possible to observe the relative importance of research paradigms, kind of theories used and way data is analyzed, within the TMFI and Technology / Tool dimensions.

In Table V we can see an overall comparison of the papers in the two journals studied with respect to all seven dimensions described above.

In the AEE papers we see that 73% stated the previous research on which the presented work was based and aimed to extend (which is generally seen as a positive attribute in reporting research [4]) while in the case of the IEEE journal this stood at 62% (see Figures 1 and 2). This is somewhat higher than the value of 60% found for the 72 computing education papers analyzed by Malmi et al. [4] although the fact that the latter study classified conference papers rather than journal articles may account for the difference.

Both journals analyzed featured 50% or more articles involving the use of technology tools (see Figures 3 and 4) and there was quite a range of different tools involved (Tables III and IV) which would indicate that for researchers with an IT-based approach, either of these journals could provide an appropriate outlet and readership base. The difference in the reference discipline dimension is notable: whereas no Transactions on Education papers included an outside reference discipline, a significant number of AEE articles did include broader frames of reference (examples include Psychology, Organizational Change Theory; Sustainability, Teacher Training, Community Studies and Medicine) which may be indicative of a developing maturity of EER as a field of scholarship [8] which is being captured in this recently-launched journal.

The Research Purpose dimension tended towards the descriptive in both journals with a smaller number of papers being formulative.

The majority of the papers did present a research framework of some kind with a case study framework being the most cited in both cases: 95% and 55%, for the IEEE and the AEE, respectively, whereas in the case of the CER study the value was 79% [4]. The relatively high number (45%) of papers without such a framework for the AEE may arise from the fact that one of the volumes studied was a special issue devoted to curriculum initiatives and such papers tended to have a more descriptive structure.

The use of natural data in more than 50% of both sets of papers is interesting in that it may denote a maturing field of research in that there are significant efforts to correlate research-generated data with that which is naturally generated such as student success, attrition and choice of course. Indeed in the case of the CER study cited above the breakdown was Natural 16% and Research 79%. More than 50% of papers in both journals used some sort of statistical treatment of data (52 and 73% for the IEEE and the AEE respectively compared with 70% in the CER study) although it is noticeable that 43% of those in the IEEE Transactions were basing their conclusions primarily on a form of argumentation.

TABLE I.
TMFI DIMENSION, IEEE TRANSACTIONS VOL. 54, N. 1

Paper	Theory	Model	Framework	Instrument	Other	None
1						×
2		Project-based learning				
3				Wireless sensor networks (WSNs)		
4				SPICE		
5		Project-based learning				
6		Combined Strategies: DL, PBL and RBL				
7						×
8		Problem-solving		Conceptual Survey of Electricity and Magnetism (CSEM)		
9		Problem-based learning				
10				Universal Student Ratings of Instruction		
11	Collaborative Learning	Project-based learning	Blooms Taxonomy			
12						×
13						×
14	Collaborative Learning		Wiki Assignment 10 step framework			
15						×
16						×
17						×
18						×
19	Residue Number System (RNS)					
20	Collaborative Learning					
21	Collaborative Learning				Virtual pair programming	

TABLE II.
TMFI DIMENSION, AEE VOL.2, N. 3 AND 4

Paper	Theory	Model	Framework	Instrument	Other	None
1						×
2			Interdisciplinary collaboration			
3			How people learn			
4						×
5			Reflective practice			
6						×
7	Social network Theory	Adaptation Innovation		KAI - social network analysis	Learning Styles	
8						×
9				Experience Sampling Method	Learning Styles	
10						×
11					DLR Program	
12			Bloom's Taxonomy		Systems Theory	
13						×
14	Cognitive Theory		Bloom's Taxonomy		Learning Styles	
15					Learning Styles	
16	Organizational change theory		Sustainable Development			
17			Service Learning			
18	Learning Theory	PBL	Bloom's Taxonomy		Refers to Learning Styles	
19		Spiral Curriculum Development			Learning Styles	
20				Concept inventory and maps		
21	Experiential learning		Interdisciplinary collaboration			
22			How people learn			

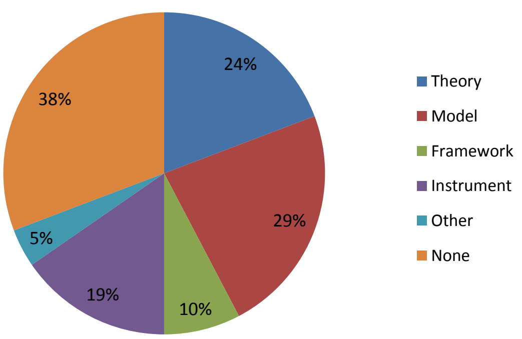

Figure 1. TMFI, IEEE Transactions Vol. 54, N. 1

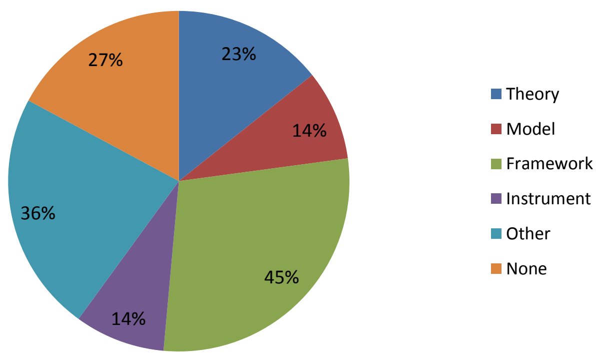

Figure 2. TMFI, AEE Vol.2, N. 3 and 4

TABLE III.
TECHNOLOGY TOOL DIMENSION, IEEE TRANSACTIONS VOL. 54, N1

Paper	LMS	Evaluation tool	Robot	Game	Virtual/ Remote Lab	Other	None
1	SCALE						
2							×
3						WSNs	
4						SPICE	
5			LEGO NXT Mobile Robots		LabVIEW		
6					×		
7						MATLAB / Simulink	
8							×
9							×
10						MATLAB	
11	Moodle	Rubrics				MATLAB / Simulink	
12	E-CHO			×		MATLAB	
13						MATLAB	
14						Wiki Web Sites	
15							×
16							×
17							×
18				×			
19							×
20	XTutor						
21						Group-ware technol-ogy	

TABLE IV.
TECHNOLOGY TOOL DIMENSION, AEE VOL. 2, N. 3 AND 4

Pa-per	LMS	Evalua-tion tool	Ro-bot	Game	Virtual/ Remote Lab	Other	None
1						Video	
2						Webpage creation tools	
3						Global Real-time Assessment Teaching Tool for Teaching Enhancement	
4							
5							×
6	VIEW				×		
7		UCINET				Online forums	
8						Screencasts	
9				EduTorcs			
10	Moodle						
11							×
12							×
13							×
14							×
15					eLive		
16							×
17							×
18					Lab-view		
19							×
20							×
21							×
22					Lab-view	Matlab	

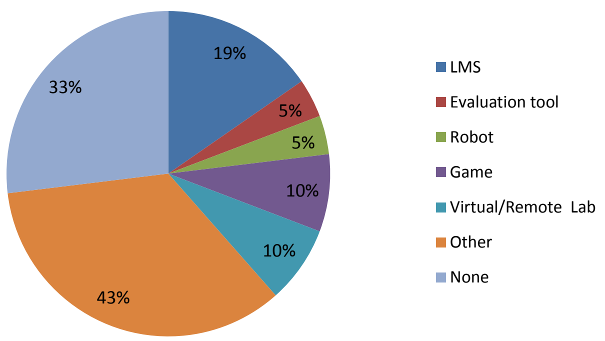

Figure 3. Technology Tool Dimensions, IEEE Transactions Vol. 54, N. 1

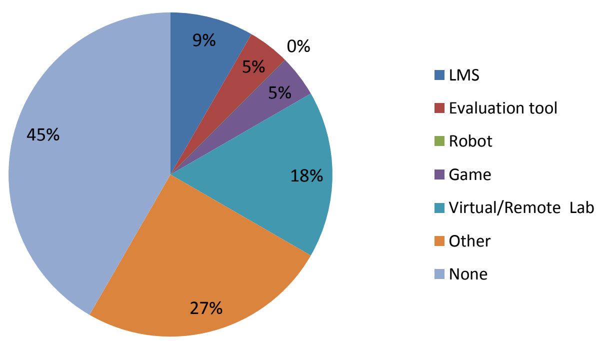

Figure 4. Technology Tool Dimensions, AEE Vol.2, N: 3 and 4

TABLE V.
SUMMARY OF THE SEVEN TAXONOMICAL DIMENSIONS FOR THE 2 JOURNALS

Dimension	Trans Educ. (21 papers)	AEE (22 papers)
1 TMFI	62%	73%
2 Technology Tool	14 tools; 67%	12 tools; 55%
3 Reference Discipline*	0%	27%
4 Research Purpose **	D 86%; E 0%; F 14%	D 82%; E 14%; F 32%
5 Research Framework	CS 76%; none 5%	CS 27%; none 45%
6 Data source **	Nat 52%; Res 81%	Nat 55%; Res 64%
7 Analysis Method **	Arg 43%; DS 19%; ESA 33%	Arg 18%; DS 50%; SA 23%; ESA 0%

* Excluding Engineering and Education

** Each paper may have more than one value and hence the total may exceed 100%

B. *Citation Analysis*

The 43 papers studied contained a total of 1,261 citations with the AEE papers having an average of 36 references per paper while the Transactions on Education had a somewhat lower average of 22.

We first looked to see the number of times the 9 sources listed in Wankat's study were cited. These were the Journal of STEM Education, Proceedings of the ASEE Annual Meeting, Proceedings of the Frontiers in Education (FIE) Conference, Chemical Engineering Education, IEEE Transactions on Education, Journal of Engineering Education, Journal of Professional Issues in Engineering Education and Practice, ASEE Advances in Engineering Education and Prism.

In addition, we also include a number of additional indicators which help to capture more details of the prior studies used by authors in the two journals. For this we created additional categories to include cited references which in their title had some form of each of the following terms:

- Chemical Education;
- Physics & Computing Education;
- Maths Education;
- Psychology.

For example, in the first category we include books or papers with chemistry or chemical in their title.

Finally, to get information on global dissemination of research, as both journals are US-based we include the category International Engineering Education where we aggregate citations of some non-US engineering education journals (International Journal of Engineering Education, European Journal of Engineering Educationand Australasian Journal of Engineering Education). The results can be seen in table VI.

The chart in Figure 5 shows a comparison betweenthe data for the two journals in our study and the results published for the IEEE Transactions on Education in 2009 where we use the same indicators as Wankat [14]. We see that the citation pattern for Transactions on Education is similar in both studies and indicates a noticeably high degree of citation from the journal itself and that in 2011 as in the previous study, there was relatively little citation of other sources. The AEE papers, however, do show a more catholic list of prior work.

TABLE VI.
SOURCES CITED IN THE TWO JOURNALS IN 2011 AND COMPARISON WITH PREVIOUS DATA FOR THE IEEE TRANSACTIONS IN 2009

Citations	Advances in Engineering Education				IEEE Transactions on Education		
	Vol. 2 N. 3	Vol. 2 N. 4	Total	% in 2011	% in 2009 [14]	Vol. 54 N.1	% in 2011
ASEE Proceedings	12	12	24	3.0	1.9	4	0.8
J. Eng. Education	13	21	34	4.3	1.7	1	0.2
ASEE/IEEE Frontiers in Education Proceedings	4	21	25	3.2	3.6	1	0.2
IEEE Trans. Education	1	3	4	0.5	9.6	54	11.5
Chem. Eng. Education	3	2	5	0.6	0.5	0	0.0
PRISM	1	0	1	0.1	0	0	0.0
J. Prof. Issues	0	3	3	0.4	0.1	0	0.0
J. STEM Issues	0	0	0	0.0	0	0	0.0
Advances Eng. Education	1	2	3	0.4	0	1	0.2
Psychology references	21	14	35	4.4	n.a.	1	0.2
International. Eng. Education references	5	6	17	2.2	n.a.	6	1.3
Chemical Education references	4	10	14	1.8	n.a.	3	0.6
Physics & Comp. Education references	4	0	13	1.6	n.a.	59	12.5
Maths Education references	0	1	1	0.2	n.a.	3	0.6

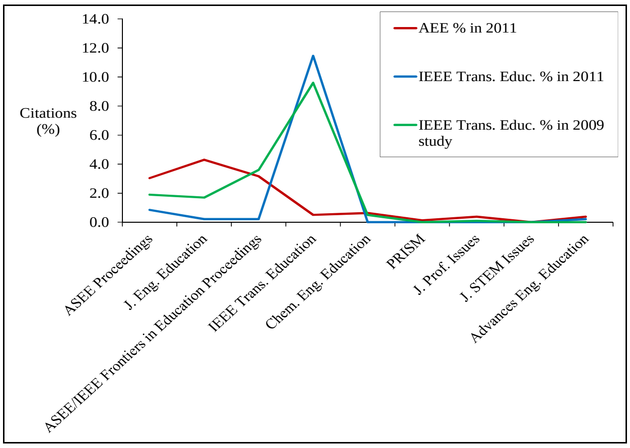

Figure 5. Comparative citation analysis of the journals in 2011 and 2009 using Wankat's indicators

The chart in Figure 6 shows an extended analysis of the citations in the two journals for 2011 using our additional indicators. This shows that in the case of Transactions on Education, apart from the journal itself, the other major sources were in the disciplinary areas of physics and computing education.

AEE papers can be seen to include more psychology citations and to provide a broad overall range of disciplinary references.

Data for both journals indicate that authors consulted some engineering education publications from outside the US.Indeed the 21 papers in Transactions on Education cited noticeably more international engineering education journals (6)than they did the ASEE Journal of EngineeringEducation (1).

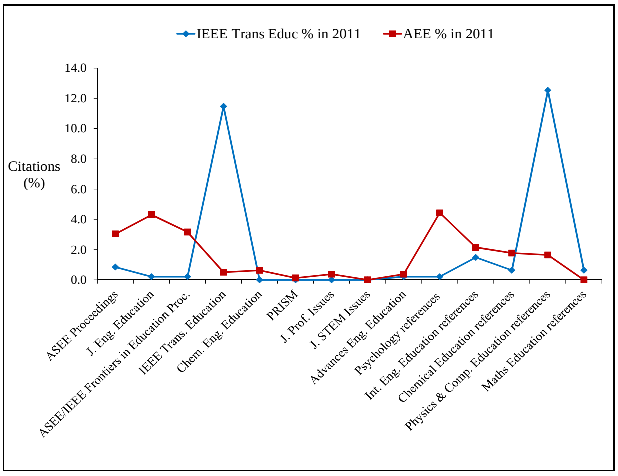

Figure 6. Extended citation analysis of the 2 journals in 2011

In a 2005 guest editorial for a special issue of the Journal of Engineering Education [24] Felder, Sheppard, and Smith argued that in order to go forward, engineering education would require "research guided by theories grounded in cognitive science and educational psychology and subjected to the same rigorous assessment and evaluation that characterize first-rate disciplinary research". The silo effect seen in both studies would appear to represent a clear obstacle to this aspiration as well as reducing the likelihood of cross-fertilization between researchers and practitioners.

C. Possible limitations of citation analysis

In the previous section we have assumed that the references cited in the published papers can serve as a reliable indicator of the prior work on which the research is based. Although there have been reports that "very occasionally, authors of a paper would follow identically the reference list used by another paper" [3], we believe it can be assumed that given reasonably sized data samples this is unlikely to be a major factor and although our sample size is relatively modest (43 papers, 1261 citations) our findings mirror those of earlier larger studies [14].

IV. DISCUSSION

A. From a research field perspective

In the case of IEEE Transactions on Education our results are similar to those reported by Wankat for the journal in 2009 and show that the silo effect that he warned of in his editorial in that journal [14]was still apparent in 2011. The fact that for the 21 papers analyzed,presenting a total of 471 references, the Journal of Engineering Education is only cited once is particularly surprising given that it has the highest impact factor within the field according to the Thomson ISI index and is frequently described as the most rigorous archival journal for engineering education research [8]. Likewise the rather narrow concentration of cited references in the fields of Physics and Computer Science and the virtual absence of Psychology references all go to confirm the presence of a silo effect which is likely to have implications for cross-fertilization and diffusion of proven engineering education innovations.

By contrast, the results for AEE show that in addition to citing more references on average, the authors appear to be reading more broadly and their work is informed by both engineering discipline research and other reference disciplines. This could be interpreted as a sign of developing interdisciplinarity and maturity of EER as a field of research.

B. From an IT education researcher perspective

Both of these journals represent attractive publication channels: the long-standing IEEE Transactions on Education because of its overall technological focus, its links with IEEE and archiving in Xplore, and the newer online AEE because it appears to be developing as a versatile forum for an applied research approach. It has taken a lead among EER publications in augmenting the journal format (based on the traditional printed design), to take advantage of the potential which current IT developments allow by encouraging the use of video, Excel files and other multimedia formats to allow a significantly richer published product.

V. FINAL REMARKS

Although the work presented, 43 articles from two EER journals in the same year, represents a relatively small sample of the overall volume of EER publications in 2011, we believe the study demonstrates the value of a bibliometric analysis approach to EER to study the developing maturity of the field, identify opportunities for cross-fertilization and to help authors choose suitable publication channels.

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