Authorship and Content Analysis of Engineering Education Research: A Case Study

Abstract—In this paper, Engineering Education as a discipline has been analyzed by taking IEEE Transactions on Education (IEEE T Educ) as a case; for examining the various trends that have been emerging over time. Based on various criteria of authorship and citation, an effort is made to highlight the main contributors or top authors of this engineering education community. It was found that authorship trends have been shifting more towards collaboration. It was also found that the authorship community is growing, both in terms of publications and publishing authors. Study of citation patterns during the last decade, reveals a high citation count per article, which indicates a high readership of this journal. Later, the study of authorship and citation patterns shed light on the trend that multi-author articles are cited more often than single-author articles. This study was compared with earlier studies in the field of Engineering Education Research (EER) using keyword analysis and temporal evolution and distribution of keywords. Additionally, key-phrase and topic modeling was performed to identify leading and evolving research areas within the EER. Analysis of word co-occurrence was performed to discover the main context in which the keywords have been used. Lastly, topic modeling techniques were applied for probabilistic distributions of IEEE topics and the results were in line with earlier studies.

Index Terms—bibliometric analysis, citation analysis, collaboration, engineering education research, learning analytics, social network analysis

I. INTRODUCTION AND MOTIVATION

RESEARCH ON EDUCATIONAL ISSUES in engineering, computer science, and other technical areas is growing fast [1] due to the increased interest of funding agencies [2], the fact that facilitation of cross-disciplinary research has attracted substantial attention in recent years [3], also, a growing number of scholars dedicating their career to the intersection of technical fields and education [4], and lastly, higher demands to show the effectiveness of programs for student achievement and retention. At the same time, fields such as engineering education research and computer science education research are solidifying and developing their own identity [5-6], which is strongly indicated by the maturity and growth of field-specific conferences such as FIE (Frontiers in Education) and EDUCON, as well as the new establishment of a special interest group (at the American Educational Research Association), a research interest group (within the National Association for Research in Science Teaching), and research focused on engineering/computer science education within technical and general education communities.

The body of literature in engineering education (EE) is growing substantially and reaching a point where a detailed historical analysis could provide insights and moments for reflection. While such analysis is useful and already conducted for the Journal of Engineering Education (JEE) [7-8], for the International Journal of Electrical Engineering Education (IJEEE) [9] and on a larger scale for the entire field of EE [10]; meaningful analysis of a journal such as IEEE T Educ carries numerous additional benefits: (1) Results might be used to recognize key topics and actors in the community. (2) Recognition of key authors within IEEE can provide a link to those who have expertise in ‘advanced pedagogical methods’ [11] (3) A historical analysis of how certain topics developed and possibly faded could provide insights on how the journal influenced and shaped the field, and could support the development of a shared narrative and memory of the field. (4) Such analysis can further aid in providing a ‘map of the terrain’ for novice researchers in the field [12-13]. (5) An analysis of the content, authorship patterns, and impact of articles could lead to the development of benchmarks and strategic planning. As P. Wankat [11], suggests that the EE journals should devise plans for further enhancement of this field. (6) The journal IEEE T Educ started in its current form in 1963 with aims “both scientific and educational, grounded in the theory and practice of electrical and computer engineering” [14], making it one of the oldest scholarly publications in the intersection of technical fields and education. Thus, analyzing IEEE T Educ provides not only insights into the journal itself, but also a historical window into the history of the emerging discipline of EE and EER.

This paper aims to address the following questions: Who are the main contributors to IEEE? How are the authorship trends changing over time? Can citation be associated with collaboration? What themes have been explored in the past, and what are the emerging themes in this journal? What have been the topics of highly cited publications?

II. DATA COLLECTION AND PROCESSING

In recent years bibliometric analysis of publications has been gaining boom in various disciplines including EER [7, 9, 15-16]. Currently, citation data is available from various sources such as: Institute for Scientific Information’s (ISI) citation databases, Scopus and Google Scholar. Some studies suggest the usage of multiple databases for research assessment [17-18]. However, others suggest that the accuracy of Google Scholar still needs to be tested [19-20] and that the results of ISI and Scopus are comparable [21-22]. Some studies further highlight the
advantages associated with ISI’s Web of Science® (WoS) in terms of processing times[17] and in terms of the available information [23-25]. Also, WoS provides access to the world’s leading citation databases, over 12,000 of the highest impact journals and over 150,000 conference proceedings; it is widely used by researchers, scholars, administrators, faculty and students. The coverage in WoS dates back to 1900 and the information spans over 250 disciplines. Therefore, the data for this analysis has been taken from the ISI’s WoS. WoS as selected database for the current study makes it possible to explore scientific collaboration of interdisciplinary research as well as to define a field of inquiry by identifying citation patterns and core publications [26]. The data for current study1 includes all the *IEEE T Educ* articles and proceedings from 1963 to 2011. The authors manually verified the data to incorporate name variants and missing keyword fields (the bibliographic entry for some of the articles in WoS showed empty keyword field, where as it was present in the article itself). Descriptive statistics for this data are provided next: a) in total there are 2250 articles out of which only twelve (12) are proceedings papers. b) There have been contributions to this journal from 69 different countries. The countries with highest publication counts in *IEEE T Educ* include USA (54.58%), Spain (5.87%), UK (4.44%), Canada (4.27%) and Australia (2.18%). c) The institutes with most number of articles in this journal are: Georgia Institute of Technology (49), US Department of Defense (49), California State University System (45), University of California System (45) and Florida State University System (37). Since the *IEEE T Educ* dataset spans 49 years so it has been divided into decades; except for the last time span which is only 9 years, i.e. 2003-2011 (for the sake of convenience, this time frame will also be called a decade). Before the *IEEE T Educ* was formed from the merger of two professional societies, the predecessor to the *IEEE T Educ* was the Institute of Radio Engineers (IRE) Transactions on Education [27]. However, it was decided to study the journal in its current format and therefore only the issues from 1963 onwards were considered. Due to space limitations, the analysis of the journal will be done comprehensively for the last time frame (2003-2011) along with a thorough explanation of the adopted methodology. However, for earlier decades, a combined analysis will be presented for comparison and investigation.

### III. Authorship Analysis

In this section, the main contributors during the last decade of this journal are analyzed. Contributors within this community are regarded as leading authors. Studies on leading authors and their collaboration date back to Derek Price and other early biblio-metricians [28]. In this paper, contributors are defined by many standards: (1) First classification is based on whether the article is single-authored or multi-authored. (2a) Further classification is then based on each type e.g., in the case of multi-authored articles, an author pair is brought out as a ‘main contributor’ based on the number of joint articles written by the two authors. Similarly, for a given author of a multi-authored article, ‘diversity’ is defined as the number of other authors he or she might have worked with. (2b) For single authors, this level of classification brings out only those authors who have the highest publication counts. (3) Later, the authors of single- and multi-authored articles are classified together, based on the ‘citation counts’ of the articles. Regarding such classification, Klavans and Boyack [29] have suggested that individual publication and citation counts can be taken as an indicator for identifying the leading researchers within a field. Similarly, other researchers suggest that citation and publication counts are obvious indicators of productive and creative scientists within a field [30-32]. These prolific researchers have more impact on the field, and the likelihood that these papers are selected as “creative work” is higher [33]. Another method for identifying the main researchers within a field is through peer evaluation [34]. However, bibliometrics-based methods are easier and more efficient, especially due to the availability of research databases such as Web of Science and Scopus. [33].

Since *IEEE T Educ* is an interdisciplinary journal and its scope covers “education research, methods, materials, programs, and technology in electrical engineering, computer engineering, and fields within the scope of interest of IEEE” [14], it can thus be suggested that the main contributors are authors “who exert influence in both their own discipline and other disciplines”. These researchers can quickly adapt to new knowledge and ideas from related disciplines and for these authors such inter-disciplinarity results in creative problem solving [34].

### 4. Who are the main contributors to this journal?

Before answering this question, it is necessary to define the following terms as used in this paper: *Node or vertex* in this study represents an author; *edge* exists between two authors if they are co-authors of an article; *unique edge count* will represent the overall count of co-authors (irrespective of their mutual article or publication count). Thus, the co-authorship is represented by a line between two different authors or by a loop on a node (as shown in figure 4). Detailed definition of these and various other graph theory related terms, is available at [35-38] The following analysis has been performed with NodeXL tool – an open source template for Microsoft® Excel® [39] which allows users to work on different worksheets such as: ‘Edges’ worksheet can be used to compute the inter/intra collaboration; ‘Vertices’ worksheet allows the display and computation of individual node properties such as degree, betweenness and centrality etc. Table I provides a summary of various statistics, for articles published in the last decade. This table shows that out of the 609 published articles: 129 are single- and the remaining 480 are multi-authored articles. In total, there have been contributions from 1636 different researchers. The table entry for “single-vertex connected component” tell that out of the 129 single-authored publications, 109 are by those authors who do not have any collaborative work within this journal (during the mentioned time-frame).

#### 1) Multi-author trends:

The authorship trends during the last decade have been presented in Figure 1. Here the authors have been grouped and colored (group G1 – G13) based on the count of distinct researchers they have worked with.1 The dots repre-

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1 Most data was downloaded in early 2012, unless specified otherwise.
sent the authors and the collaboration between authors is represented by lines or edges. The darker this line gets, the greater the number of articles between those two authors. From this figure it can be seen that the degree of authors ranges from 1 – 23; showing that some authors have worked with just one other author while some have worked with 23 other authors.

From Figure 1 some of the outliers are apparent such as in G10 there are 24 authors each with degree 23; it was found that they all co-authored in one article “The Olin curriculum: Thinking toward the future”. Similarly, it was found that there are 35 authors each with degree 10. Since degree in this context is a measure of collaboration with distinct other researchers; so based on this information it was decided to bring out the most prominent authors of multi-authored articles. However, before processing any further, it was necessary to eliminate the outliers (such as, the one with a very high count of co-authors - 24; since they could skew the results of the analysis and may bring the authors of such articles on top (where as the aim is to study the general authorship trends and not just one article where a larger number of co-authors appeared). For this purpose the article–author distribution was extracted as shown in Figure 2. It was found that 21% of articles are single-authored and that the remaining 79% - the co-authored articles, are distributed as follows: 22.7% are a result of collaboration between two authors, 25.3% are a result of collaboration between three authors, and the remaining 31% are the collaborative work of four or more co-authors. It was found that only 18 articles (nearly 3% of all articles) were a result of collaboration between seven (7) or more authors. Therefore, these articles were considered outliers and were excluded from the analysis.

Thus, the main contributors based on degrees of diversity are presented in Table II, which lists the top ten authors with highest degree counts and their associated publication and citation counts.

The above data was retrieved manually from WoS to include author name variants etc. These top authors were further investigated to study their authorship patterns in terms of collaboration. Collaboration as defined in Oxford dictionary [40] is the ‘action of working with someone to produce something’ and in current context it represents co-authorship of an article by two or more researchers. (This term can be extended to institutes and even to countries and hence extended collaboration patterns can be extracted - but due to space limitation, this study cannot be presented here). Smith [41] was one of the early researchers who suggested that multi-author papers can be used ‘as a proxy measure for collaboration among groups of researchers’. However, he reported that such studies only provide an ‘approximate measure of group efforts’ [42-43]. Despite this limitation, many studies have utilized co-authorship as a measure of collaboration [44-47] and the general consensus is that the growth in multiple-authorship is a proof of increase in collaboration [45-49]. Therefore, the collaboration patterns of top authors of Table II were further examined and it was found that the total number of authors brought out by these top ten researchers is 54 and none of these top authors had any single-author publication (during 2003-2011 in this journal). Moreover, all of these authors are from Spain except Ramachandran, RP and Garcia, A and they both are affiliated with the ECE departments in

<table>
<thead>
<tr>
<th>Authors</th>
<th>Degree</th>
<th>Publications</th>
<th>Citations</th>
</tr>
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<tr>
<td>Martinez, M</td>
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<td>15</td>
</tr>
<tr>
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<td>3</td>
<td>5</td>
</tr>
<tr>
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<td>3</td>
<td>28</td>
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<tr>
<td>Soria, E</td>
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<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Magdalena, R</td>
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<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Rodriguez, S</td>
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<td>Kloos, CD</td>
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<tr>
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<td>7</td>
<td>3</td>
<td>28</td>
</tr>
</tbody>
</table>

* Citation data was downloaded from WoS in October, 2013
USA. Sanchez, FM and Rodriguez, S. belong to the faculty of CS; Kloos, CD is affiliated with Telematic Engineering and Martinez-Torres, MR is affiliated with Business and Management School and all the others belong to EE departments with research focus in communication systems and digital signal processing etc.

As mentioned earlier, the main contributors of multi-authored articles can also be defined by joint publications between two authors. Therefore, the analysis of such articles is presented in Table III. Here, the presence of same co-author(s) in more (than one) papers indicates (strong) collaboration and hence suggests that these authors share the same interests. Interestingly, all of the top author-pairs for this journal during 2003-2011 have jointly worked in three (3) articles. Moreover, Chang, GW; Chang, HM and Yeh, ZM worked together in three articles. These main contributors belong to USA, Taiwan and Spain and disciplinary affiliations include not only EE, CS, Telematic Engineering but also Mechatronics.

Lastly, the multi-author article trend was studied based on the counts of unique authorship pairs. Therefore, during the last decade only six author pairs have co-authored three (3) articles, eighty five (85) author pairs co-authored two (2) articles and 2,638 author pairs have worked on just one article together7. Thus it can be concluded that co-authorship between same author pairs is not very common in this community. Therefore, the total count of unique author-pairs is high:

\[ 3(6) + 2(85) + 1(2638) = 2826. \]

2) Single-author trends:

Next, the single-authorship patterns were studied using NodeXL in which ‘self-loop count’ with value zero (0) shows multi-authored patterns and positive value (greater than or equal to one) indicates single-authored articles. It was found that out of 119 single authored articles, 109 are by the authors with no collaboration within IEEE T Educ. And only 10 of the single authored articles are by the authors who have some collaborative work in IEEE T Educ during the last decade8. The summary is: Hwang, GJ; Chen, WF; Shirsavar, SA and Aleman, JLF have worked with 2 other persons (in addition to having single authored articles) and Ruiz-del-Solar, J; Frolik, J; Parent, DW; Sarkar, NI; Hamblen, JO and Mazhari, B have worked with one other person in addition to their single authored work. Lastly, none of the remaining 109 authors have worked with any other researcher in IEEE T Educ from 2003-2011. Thus, the patterns of single-authored articles can be summed up as: out of the 129 single-authored articles, 85.3% were written by authors who have only one single-authored publication; the remaining 14.73% were written by authors who have two or three single-authored publications. Based on these publication counts, the top authors of single authored articles were extracted as listed in Table IV.

This table presents relatively diverse authorship community in that the authors belong to countries such as New Zealand, India, Korea, Romania, Israel, USA and Spain. Interestingly Buïu, C belongs to Department of Automatic

7 This information is based on the data preparation for input into NodeXL, and its complete explanation is provided in Supplementary Material.
8 NodeXL counts the single authored publications as a work with distinct researcher. For further details please see “NodeXL degree calculation for self– loops” as provided in the Supplementary Material.
The authorship graphs have been split into single- and multi-authorship (separated by arrows). Here authors have been placed in a circular layout (rather than the Harel-Koren Fast Multiscale layout which was used in Figure 1) to better display the changes in authorship patterns within the community of IEEE. Left side of each figure shows multi-authorship trends for the mentioned time span, and the right side is for single-authorship trends. As mentioned previously, the lines show collaboration, and an increase in intensity of these lines indicates increase in collaboration. *Thin circles* are representatives of the authors; with varying diameter as an indicator of diversity (or degree). *Thicker circles* are self-loops for single-authorship trends and are self-loops for single-authorship. 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normalized values it is found that the paper by A.C. Graesser et al. was cited most frequently and received 7.14 citations per year. Clearly, the articles published in earlier years 2003-2006 have made it to the top list due to the fact that they have been available to readers for a longer time. Additionally, key-phrase analysis of the most cited articles was performed to study their research area. It was found that all the articles covered one or more of the following topics: intelligent tutoring system, distance learning, remote laboratory, remote education, web-based education and automatic control etc. Based on this analysis, it can be asserted that these research areas represent the recent trends in EER and online learning can be regarded as one of the primary focus areas. Lastly, these top authors represent a culturally diverse community, their nationalities include: USA, UK, Greece, Italy, Spain, Australia, Ireland, Switzerland etc.7

Next, the citation patterns during the last decade of this journal were studied. A count of TC (times cited) is summed up in Table VII. From this table, 68.14% of all the articles (415 out of 609) published during 2003–2011 were cited8.

This high percentage is an indicator of the high readership of the journal. Some of the articles from 2011, however, might not be available to the researchers; hence, the citation count for 2011 is expected to rise in the coming years. It is also interesting to see that some articles have been cited more than 50 times while others have been cited only once. Therefore, it was necessary to normalize the citation count by finding its weighted average, which turns out to be 4.09 citations per article (which is again fairly high).

This completes the citation analysis for the period 2003–2011. The aim of the next section is to relate the already analyzed fields of citation and authorship patterns (collaboration).

<table>
<thead>
<tr>
<th>TABLE VII</th>
<th>CITATION TRENDS FOR IEEE T EDUC, 2003-2011</th>
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<td>Times Cited</td>
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</tr>
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<td>6</td>
<td>26</td>
</tr>
</tbody>
</table>

7 Complete author affiliations are provided in supplementary material.
8 The data was downloaded in early 2012.
C. Can citation be associated with collaboration?

Table VIII is aimed at seeing if there exist any relationship between citations and collaboration? Since some of the articles were getting cited more than 100 times and some were not getting cited at all, it was necessary to normalize the citation weights in order to compare the two trends. From cited weighted average the overall trend is that: the multi-authored articles get cited more frequently than their single-authored counterparts (even when the total number of single-authored articles is higher, e.g. during 1963–1972, 1973–1982, and 1983–1992).

This phenomenon has also been studied by other researchers [53-54]. Sooryamoorthy in fact states that it is now commonly accepted that co-authorship leads to higher citation rates [55]. One reason for the high citation count could be collaboration and inter-disciplinarity, which means that a multi-authored paper could be the result of collaboration between authors from different disciplines, and hence the article tends to cover a broader scope. Such an article, thus, draws a larger audience and gets cited more often. As T. Bart [56] suggests ‘multi-authorship increases above all the probability to be cited by others’.

Furthermore, some of the earlier studies have suggested that research by larger groups tends to be more influential [57-58]. The second reason for high citation counts could be self-citation. In multi-authored articles, self-citation occurs when at least one author is common between the citing and the cited articles [59]. Thus, the more the number of authors per article, the higher is the probability of getting self-citations [56]. This completes the analysis regarding main contributors, authorship trends, collaboration, and citation. The next section covers questions regarding the themes within IEEE T EDUC.

IV. CONTENT ANALYSIS

A. What are the past themes that have been explored in this journal, and what are the new emerging themes?

This question will be answered by studying the trends that have been taking place in this journal since its inception in 1963. For this purpose the keyword (DE and ID) field [and abstracts (AB) for key-phrase and topic modeling], which indicates ‘core concepts and central fields of concern’ [60] will be used. In the absence of the keyword field, it was decided to use the titles (TI field) for keyword extraction due to correlation values calculated6. The relevance of titles as a source of keywords has been discussed in [61-67]. Like the authorship analysis, a more comprehensive study is presented for the last time span i.e., in addition to the keyword and key-phrase analysis, word co-occurrence and topic modeling techniques will be applied to get better context of research topics.

1) Content Analysis:

Content analysis is a systematic and replicable approach for reducing many pieces of data into more relevant and manageable contents based on explicit rules of coding [68-72]. Holsti [73] defines content analysis in a broader way as “any technique for making inferences by objectively and systematically identifying specified characteristics of messages.” According to Palmquist [74] “it is used to determine the presence of certain words, concepts, themes, phrases, characters, or sentences within texts or sets of texts and to quantify this presence in an objective manner”. The aim of content analysis in this article is to identify the latest research trends therefore, word co-occurrence analysis and topic modeling is performed on the abstracts of the articles during the last decade of the journal.

2) Frequency Analysis:

Frequency analysis – the concept of using keyword counts, has been used for similar studies by many researchers. The question is: How well can this method predict the research trends? As Summers [75] suggests, “all aspects of lexicography are influenced by frequency.” Similarly, Kilgarriff [76] is of the opinion that the significance of a word is known by its usage. The more common it is, the more important it is to know. R.A. Bentley [77] suggests: “The evolution of vocabulary in academic publishing is characterized via keyword frequencies recorded in the ISI Web of Science citations database.” Other authors have also suggested the importance of frequency-based analysis for the more frequently occurring words [79-80], so usage of frequency-based analysis is justified. In this paper the usage of frequency based analysis is for studying the evolution of EER as a field and for this purpose keyword and key-phrase analysis is performed. A similar study for the field of Marketing Science which relies on the usage of keyword counts can be found at [81], A. Duvvuru et al. [82] conducted a keyword based study for the European Journal of Operational Research. They suggested a network analysis technique for the keywords in scholarly articles. X. Wang et al. [83] conducted a study for the Journal of Scientometrics where they proposed a real time method for detecting the emerging research trends by monitoring the downloads of research articles of this journal and aggregating it with the article keywords.

3) Methodology:

This methodology relies on the usage of keywords and key-phrases and attempts to see their spread in the five decades. Regarding, the keyword rank and classification as presented in this study, it is suggested that: “academic keywords should be ranked in order of popularity from year to years...to see what’s hot and what’s not [77]” To generalize the results of this study across the EER field, comparisons are made to earlier studies [7-9, 78] in engineering education that utilized keywords for predicting the trends of this community. As mentioned earlier, all the analysis is done only on the keywords field (DE, ID fields from ISI WoS) and when this field is absent the keywords

<table>
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<th>Cited Average</th>
<th>Cited Weighted Average</th>
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<td></td>
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<td>139</td>
<td>43.88</td>
<td>56.12</td>
<td>1.719</td>
</tr>
<tr>
<td>1983–1992</td>
<td>single-author</td>
<td>203</td>
<td>26.6</td>
<td>73.4</td>
<td>3.31</td>
</tr>
<tr>
<td></td>
<td>multi-author</td>
<td>182</td>
<td>25.82</td>
<td>74.18</td>
<td>3.7</td>
</tr>
<tr>
<td>1993–2002</td>
<td>single-author</td>
<td>217</td>
<td>28.11</td>
<td>71.89</td>
<td>3.456</td>
</tr>
<tr>
<td></td>
<td>multi-author</td>
<td>378</td>
<td>15.34</td>
<td>84.66</td>
<td>6.272</td>
</tr>
<tr>
<td></td>
<td>multi-author</td>
<td>480</td>
<td>31.46</td>
<td>68.54</td>
<td>4.34</td>
</tr>
</tbody>
</table>

6 The methodology for finding the correlation values is presented in the supplementary material of this paper.
are extracted from the titles (TI field of ISI WoS). Once the titles and keywords have been parsed out of the articles, frequency analysis is then used for the purpose of extracting top keyword during each decade by using the Hermetic Word Frequency Counter (HWFC) software. HWFC first processes the data to eliminate some 353 common English words and then generates the top keywords. After this, following refinements were made in the top keywords list: elimination of obvious keywords with reference to the scope of the journal (like engineer, education, students, etc.), elimination of too broad or general terms (such as new, paper, presents, etc.), and merging of word variants (learn[ing], lab[s], laboratory, design[s], designed, etc.). Once the top 20 keywords during each decade were obtained, they were plotted using the IBM software tool Many Eyes, as shown in Figure 5. The size of each keyword is based on the number of times it occurred. This number is also written inside each circle – however, rather than absolute counts, the relative rank or position of the keywords in the given time span will be used to answer questions related to trends. Some of the keywords maintain their overall rank during each decade, such as curriculum (as shown by dashed blue squares). During the third decade, it appears that the usage of curriculum might have decreased since it did not make it to the top keyword list. But it was found that this word was still used as many times as eight (8). So it can be said that the topics pertaining to curriculum development have consistently retained their rank within this journal. The keyword curriculum also made to the top list for the JEE in [7-8] between the years 1993-2002 (in these studies the articles of the JEE were manually coded for classification). Using the key-phrase analysis, it was found that curriculum has been used in the context of engineering curriculum, undergraduate curriculum, curriculum planning, design and development, Elect. Engg and ECE curriculum etc.

Similarly, it can also be concluded that topics pertaining to diversity, such as women and minority education, as well as continuing education, gained more interest during the second decade of this journal, as evident from the keywords (shown by grey triangles). Interestingly, these topics did not make to the top list of IEEE [9], however, for JEE these topics made to the top list [7-8]. Key-phrase analysis of IEEE revealed that these keywords have been used for gender differences, gender race retention and women in engineering etc.

Keywords highlighted by red circles show the emergence of new themes, such as when optics appeared in the top 20 list during the second decade and when, in the third decade, some related keywords such as VLSI, microwave, electromagnetics, etc., appeared in the top list. Key-phrase analysis revealed that optics has been used in the context of fiber optics, photonics and lasers etc. Interestingly
learning made to the top list only during the fourth decade of IEEE during which its usage (based on the first three decades) went beyond learning styles and encompassed newer terms such as: distance learning, computer aided learning, problem and project based learning, active learning, cooperative and collaborative learning etc.

Wankat [7-8] highlighted the top three keywords of JEE as teaching, design and computer and these three keywords also appear in the top list of IEEE; however, this study additionally reveals that the usage of keyword teaching is decreasing over time. The keywords computer and design show varying trends; however, during the last decade they are the top keywords — showing a possible surge in computer programming and design technology etc. This completes the keyword and key-phrase analysis for the entire duration of the journal, and next the word co-occurrence analysis is performed for the last decade (2003-2011) to see the upcoming trends in the field of EER. For this Sci2 tool [84] has been used which works on the abstracts of the articles to find co-occurring words. The complete methodology for using Sci2 has been provided in the supplementary material. Here only the results are presented. Figure 6 shows that student*, experiment*, design*, learn*, course*, develop*, engineer*, education* etc. are among the top nodes. Whereas, graduate*, module*, teach*, pedagog*, virtual* etc. are some the peripheral nodes. Next, the top five keywords of Figure 5 (for the last decade) are taken: design, computer, control, circuit, and laboratory. Using IBM’s tool Many Eyes, the network diagram of each of these keywords is plotted in Figure 7. This diagram represents the top 15 co-occurring words for each of these top keywords (and relies on the word co-occurrence analysis of Figure 6, done by the Sci2 tool). It is interesting to observe that none of the network diagrams have the word theory in them. Also, they all have the words design* and develop* in them, which shows that research trends in this journal during the last decade are more about developing hands-on expertise in the students. Words like teach* and learn* are also present in all of

network diagrams, since they are the main scope of this journal.

Lastly, the authors applied topic modeling [98] techniques to identify the emerging research topics within the community. The results of Table IX are compared with the prior study conducted by Madhavan et al. [78]. It was found that Matlab—a software tool for design and analysis made to the top list of topics just like in [78]. Areas within EE/ECE most commonly addressed in IEEE include: control systems, power electronics and signal processing etc. It was also found that design and modeling etc. are among the major topics found in IEEE just like in [78], it highlights the significant role of these topics in engineering learning and practice. Moreover, the topics: distance/online learning, remote laboratories, interactive web based applications are among the dominant topics within IEEE. Also, curriculum, PBL, evaluation and assessment are part of the topics highlighted by topic modeling tool.
V. CONCLUSIONS AND DISCUSSION:

The authors would like to start this section with a comment that this study is data-driven (scientometric study). Here the structure and content of the publications of IEEE T Educ served as a guideline for the analysis. Such data-driven methods have been used in other disciplines too such as in Human-Computer Interaction (HCI) by N. Henry [85]. He suggests that peer reviewed publications are one of the most fundamental tools for communicating and accessing results in any learning and scientific society. Therefore, this study has utilized the publications (and associated citation data) of IEEE to make known the evolution and patterns of this journal and the field of EER. As S. Redner [86] suggests, citation data can be used to identify influential research and researchers, new potential in research, unforeseen connections across fields, and downturns of the subfields that are exhausted.

In this study only citation counts were considered and the citing or cited sources were not studied. For IEEE these sources are already studied by Wankat [11] and Williams [12] These, and other such studies [87-89] revealed that there is limited cross fertilization of engineering education research and development (R&D). There have also been some other studies that highlighted the slow rate of dissemination of EER [89-90]. Therefore, the content analysis as presented in this paper may help dissemination of EER by highlighting the emerging trends in this area for interested engineering faculty to follow. Furthermore, due to the interdisciplinary nature of the field of EER the authors believe that this study can benefit not only the members of this field but also those who interact with them. Rookies in EER may find a road map to its emerging education research and development (R&D). Like other studies, this study has some caveats. Firstly, the current trends in the field of citation analysis are due to the data availability from Science Citation Index (SCI) by the ISI [92]. One limitation of SCI is although it is the biggest database but it does not cover all the scientific and technical venues; nor it intends to do so [93]. Secondly, 5-10% of citations can be flawed (due to spelling errors etc.) [94-95]. Third, high citation of an article could be due to various reasons while some are practical (such as: to introduce a study that builds on previous knowledge, to refer to methodologies already developed or utilized in previous articles [96]) but others are doubtful (such as excessive self-citation and ‘citation of poor work’ [97] etc.).

VI. LIMITATIONS:

Like other studies, this study has some caveats. Firstly, the current trends in the field of citation analysis are due to the data availability from Science Citation Index (SCI) by the ISI [92]. One limitation of SCI is although it is the biggest database but it does not cover all the scientific and technical venues; nor it intends to do so [93]. Secondly, 5-10% of citations can be flawed (due to spelling errors etc.) [94-95]. Third, high citation of an article could be due to various reasons while some are practical (such as: to introduce a study that builds on previous knowledge, to refer to methodologies already developed or utilized in previous articles [96]) but others are doubtful (such as excessive self-citation and ‘citation of poor work’ [97] etc.).

<table>
<thead>
<tr>
<th>Topic</th>
<th>Top ten words in the topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. control power simulation presented implementation matlab modeling</td>
<td>1. control power simulation presented implementation matlab modeling electric designed</td>
</tr>
<tr>
<td>2. study results academic technology effective higher instructional</td>
<td>2. study results academic technology effective higher instructional groups impact strategies</td>
</tr>
<tr>
<td>3. learn teachers active traditional classroom collaborative distance</td>
<td>3. learn teachers active traditional classroom collaborative distance satisfaction online</td>
</tr>
<tr>
<td>4. model proposed data practice signals measured space designing</td>
<td>4. model proposed data practice signals measured space designing characteristics</td>
</tr>
<tr>
<td>5. student assessment test group improve strategy ee online concept</td>
<td>5. student assessment test group improve strategy ee online concept quality</td>
</tr>
<tr>
<td>6. students experience skills information learn communication</td>
<td>6. students experience skills information learn communication technologies application</td>
</tr>
<tr>
<td>7. mobile modern measurement fundamental technique topic understanding</td>
<td>7. mobile modern measurement fundamental technique topic understanding mathematical</td>
</tr>
<tr>
<td>8. web educational software environment tool open interactive principles</td>
<td>8. web educational software environment tool open interactive principles oriented authors</td>
</tr>
<tr>
<td>9. teaching designed knowledge modules language materials learned</td>
<td>9. teaching designed knowledge modules language materials learned game framework</td>
</tr>
<tr>
<td>10. digital hardware field processing signal logic techniques complex</td>
<td>10. digital hardware field processing signal logic techniques complex integrated</td>
</tr>
<tr>
<td>11. engineering curriculum education school technology</td>
<td>11. engineering curriculum education school technology university science faculty ece</td>
</tr>
<tr>
<td>12. computer courses teaching architecture</td>
<td>12. computer courses teaching architecture science years assignments pbl instruction</td>
</tr>
<tr>
<td>13. laboratory experiments virtual internet remote network platform</td>
<td>13. laboratory experiments virtual internet remote network platform access lab wireless</td>
</tr>
<tr>
<td>14. results evaluation methodology education pedagogical introduction</td>
<td>14. results evaluation methodology education pedagogical introduction result goal found</td>
</tr>
<tr>
<td>15. approaches program research undergraduate students computing topics</td>
<td>15. program research undergraduate students computing topics material graduate wide curricula</td>
</tr>
</tbody>
</table>

TABLE IX.
TOP TEN TOPICS FOR IEEE T EDUC, 2003-2011

http://www.i-jep.org
citation count can only provide ‘an approximate measure for scientific quality’ [85]. A visual limitation of this analysis is based on the selected software tool NodeXL, in which the single-author patterns are represented by self-loops. However, this limitation is just visual and has no effect on the data and results. In some of the earlier studies the nature of citing/cited sources for EER venues have been studied. However, due to broad range of topics covered in this paper, this analysis is restricted only to citation counts. Lastly, in this paper the bibliometric data has been taken from a single database (WoS).

**FUTURE WORK AND IMPLICATIONS**

To extend the current work, interested reader may also explore questions like the followings: What are the factors controlling the co-authorship network? Can research be associated with authorship/co-authorship?

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AUTHORS

Sadia Nawaz is PhD student in the school of Computing and Information Systems at the University of Melbourne (UniMelb), Australia. Prior to starting her PhD, she worked as RA in the Learning Environments of UniMelb. She holds Master of Science in Electrical and Computer Engineering from Purdue University, Indiana, USA (email: sadia.nawaz@unimelb.edu.au).

Johannes Strobel is with University of Missouri, Columbia, MO, USA. He is Professor in the School of Information Science & Learning Technologies (iSchool) (email: strobelj@missouri.edu).

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