A Scientometric Journey Through the FIE Bookshelf: 1982-2020

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***Abstract*—IEEE/ASEE Frontiers in Education turned 50 at the 2020 virtual conference in Uppsala, Sweden. This paper presents an historical retrospective on the first 50 years of the conference from a scientometric perspective. That is to say, we explore the evolution of the conference in terms of prolific authors, communities of co-authorship, clusters of topics, and internationalization, as the conference transcended its largely provincial US roots to become a truly international forum through which to explore the frontiers of educational research and practice. The paper demonstrates the significance of FIE for a core of 30% repeat authors, many of whom have been members of the community and regular contributors for more than 20 years. It also demonstrates that internal citation rates are low, and that the co-authoring networks remain strongly dominated by clusters around highly prolific authors from a few well known US institutions. We conclude that FIE has truly come of age as an international venue for publishing high quality research and practice papers, while at the same time urging members of the community to be aware of prior work published at FIE, and to consider using it more actively as a foundation for future advances in the field.**

I. Introduction

The IEEE/ASEE Frontiers in Education (FIE) conference has been a significant venue for educators, initially primarily in engineering but, increasingly in the last few decades, computing. The conference has expanded from the initial meeting of roughly 100 people to a major peer-reviewed conference with a steady mean annual attendance of close to 600 people. As the conference has expanded and diversified its community, it is relevant to revisit the now 50-year old conference with a view to investigating its scholarly community and the publication and citation practices of that community.

A number of historical stories and overviews of FIE have revealed a vibrant, lively community and gradually changing educational concerns (e.g., [1], [2], [3], [4]). The intention of this paper is to bring those accounts a bibliometric angle in order to explore the conference in terms of collaboration networks, shifts in research focus, and citation rates. Bibliometrics affords researchers a set of tools for transparent and reproducible studies of science and knowledge production. Bibliometric studies have witnessed a remarkable growth as a result of the availability of well-structured scientific research indices and databases, as well as data science and network methods. The possibilities provided by bibliometrics go beyond simple counts to offer a nuanced overview of the temporal evolution of knowledge production. Therefore, the field of bibliometrics has been widely adopted by universities, institutions, and scientists to analyze collaborations, research themes, and researchers' locations in various networks [5], [6]. This paper uses state-of-the-art bibliometric methods to offer an in-depth quantitative perspective of the history and evolution of the FIE conference.

II. A Short History of FIE

In 1963, two engineering institutions —the American Institute for Electrical Engineers (AIEE) and the Institute of Radio Engineers (IRE)— merged into today's Institute of Electrical and Electronics Engineers (IEEE) [7]. In the merger, IRE's Professional Group on Education (IRE-PGE) was transformed into IEEE Education Society, and its journal *IRE Transactions on Education* was renamed in 1963 to *IEEE Transactions on Education*. The journal opened its inaugural issue with dire concerns about a crisis in science and engineering education at multiple levels of education, and announced, as the journal's purpose, to "give teachers an opportunity to exchange ideas and to learn what is going on elsewhere" [8]. The crisis continued and, in 1970, to invigorate the field and to reverse a disastrous economic downturn in their fortunes, the IEEE Education Society started a conference: *Frontiers in Education* [1], [4].

Frontiers in Education was perceived as a success from the start. Over its first few years, the conference grew in size from the initial 100 people, and within the span of three years, the American Society for Engineering Education (ASEE) became a co-sponsor of the conference [3]. With the addition of the ASEE community, the conference doubled in size, and the conference started to publish proceedings the same year [1], [3]. IEEE Education Society decided to organize the conference outside North America in 1974 in order to form an alliance with the Institution of Electrical Engineers (IEE) in London [2], [4]—but spent the next years to recover from the substantial loss of money the European excursion incurred. Starting with 34 papers in 1971 and 30 papers the following year, the number of papers from 1973

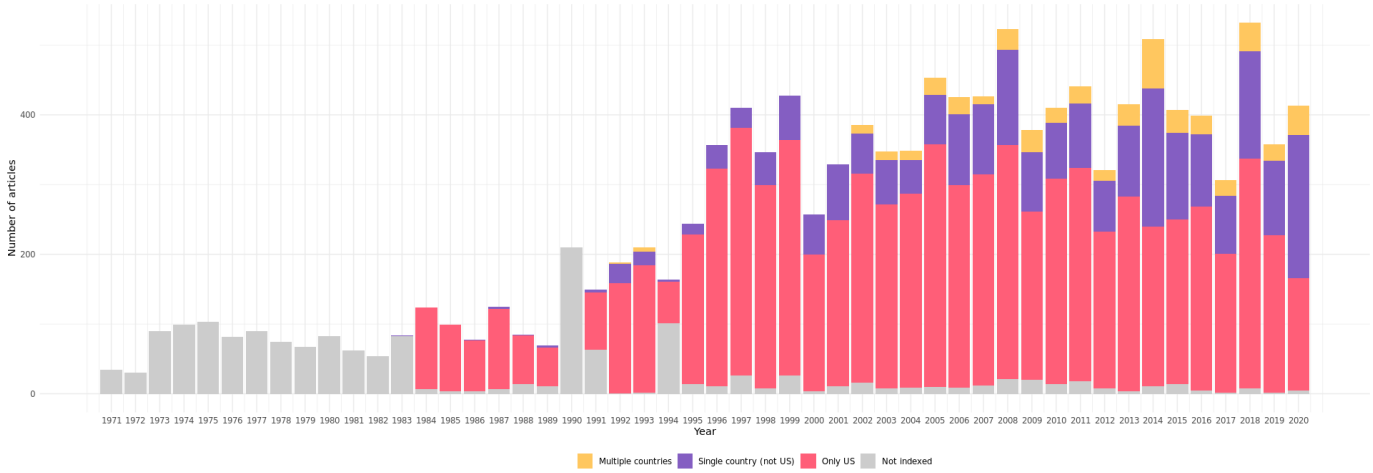

Fig. 1. Number of papers presented and published in FIE conferences, divided to single-country papers (US/other) and multi-country papers (authors affiliated with institutions from different countries). Gray color indicates unavailability of country metadata.

on, though fluctuating slightly from year to year, remained in the vicinity of 100 papers a year up until 1990, when the conference was organized outside North America again (Fig. 1). The 1990 FIE in Vienna and Budapest doubled the numbers of papers in proceedings to 210, and the trend continued upward throughout the 1990s. In 1995, the conference added another important co-sponsor: the IEEE Computer Society, the roots of which can be traced back to 1946 to the time of AIEE and IRE. Since the 2000s, the average attendance has been 576 people, and since 2007 an average number of published papers has been just over 400 per year, at a 53% mean accept rate[1].

The conference has consciously kept the "frontiers" theme alive, to avoid becoming solely a venue for publishing empirical research reports [9], [3]. Innovative practice paper category, non-traditional sessions and work-in-progress, and encouragement of "far-out ideas" have allowed presentation of fresh ideas [3]. Increased transparency and broadening and diversifying the FIE community, increasing participation from outside North America, and clear articulation of vision were prioritized in the period 2016-18 when one of the authors of this paper assumed the role of Chair of the FIE Steering committee. This work continued through the leadership of subsequent Chairs Russ Meier and Stephen Frezza, taking the FIE conference internationally one year in every five, with very successful conferences held in Madrid (2014) and Uppsala (2020).

The conference theme, values and community statement were the result of a program of activities led by FIE Steering Committee Chair Frezza, between 2018 and 2020, resulting in reformulations of the conference mission, values, and committment to an international and diverse community. Since 2010 the Steering Committee of FIE has been very international with representatives from Sweden, Portugal, Spain, and Brazil over the past decade.

[1]Statistics from http://fie-conference.org/conferences

III. Methodology

For the purpose of bibliometric analysis, the metadata of 11,597 publications were retrieved from the Scopus database, as it contains the largest collection of FIE metadata covering FIE conference proceedings from 1982 to 2020 (except for 1990, which were unavailable on all databases and the conference website). Statistics on proceedings prior to 1982 and in 1990 were obtained from [1].

The data downloaded from Scopus were cleaned, and author names with different spellings were checked and fixed. Only original papers were included, resulting in 11,507 records (53 conference reviews and 37 editorials were excluded).

TABLE I
Twenty Most Productive Authors in FIE Proceedings 1982–2020

Author	First	Cites	N	Yrs
CASTRO M	1999	214	67	22
LORD SM	1994	315	64	26
OHLAND M	1995	283	59	21
SMITH K	1982	230	55	28
DANIELS M	1997	217	53	21
FROYD J	1985	255	50	25
ANDERSON-ROWLAND MR	1995	344	47	21
BARBOSA EF	2006	107	39	11
MILLER R	1987	197	39	24
RICHARDS LG	1995	178	38	23
SPANIAS A	1996	121	38	19
CIAMPI MM	2000	50	34	18
MINA M	2005	111	34	15
SHEPPARD S	1992	218	33	19
HEYWOOD J	1989	107	32	19
OAKES WC	2000	124	32	11
FELDGEN M	1998	57	30	17
IMBRIE PK	1995	253	30	15
IMPAGLIAZZO J	1997	55	30	21
LOUI MC	2003	107	30	13

First = First year of appearance, Cites = Cites in Scopus, N = Number of papers, Yrs = Active years

TABLE II
TWENTY FIE PAPERS WITH MOST CITATIONS IN SCOPUS

Title	Year	C/A	Cit.
Remote Laboratories Versus Virtual And Real Laboratories [10]	2003	AU	147
Enhancing The Engineering Curriculum Through Project-Based Learning [11]	2002	US	132
Flipping The Work Design In An Industrial Engineering Course [12]	2009	US	130
On The Development Of Professional Identity: Engineering Persisters vs Engineering Switchers [13]	2009	US	126
A Comparative Analysis Of Techniques For Predicting Academic Performance [14]	2007	TH	108
Evaluating The Effectiveness Of Flipped Classrooms For Teaching CS1 [15]	2013	US	82
Lab Kits Using The Arduino Prototyping Platform [16]	2010	US	81
A Framework For Posing Open-Ended Engineering Problems: Model-Eliciting Activities [17]	2004	US	80
Predicting Student Performance: An Application Of Data Mining Methods [18]	2003	US	78
Blackboard Vs. Moodle: Comparing User Experience Of Learning Management Systems [19]	2007	US	76
Remote Versus Hands-On Labs: A Comparative Study [20]	2004	US	75
Adoption Of Active Learning In A Lecture-Based Engineering Class [21]	2002	US	72
Progress On Concept Inventory Assessment Tools [22]	2003	US	69
An Articulation Of The Concepts And Skills Which Underlie Engineering Statics [23]	2004	US	67
Deploying Interactive Remote Labs Using The Ilab Shared Architecture [24]	2008	US	66
Enhancing Software Engineering Education Using Teaching Aids In 3-D Online Virtual Worlds [25]	2007	US	63
Work In Progress - An Innovation Merging "Classroom Flip" And Team-Based Learning [26]	2010	CA	62
Teaching Teamwork In Engineering And Computer Science [27]	2011	US	61
Creating The CDIO Syllabus, A Universal Template For Engineering Education [28]	2002	US	59
Effect Of A Freshman Engineering Program On Retention And Academic Performance [29]	2002	US	51

C/A = Country of the first author's affiliation, Cit. = Cites in Scopus

Data from proceedings that were published the year after the conference took place were aligned with the actual conference dates. As country and state are not standard fields in Scopus metadata, they were extracted from the affiliations of the authors.

The data were analyzed using the Bibliometrix R! package [6]. The analysis included descriptive statistics in which the count of documents, authors, article types, keywords, locations, citations (according to Scopus) and other statistics were calculated. The productivity of authors was analyzed by each author's number of published articles as well as their most cited ones. The analysis also included the top cited articles, the top countries, the top US states, and the top keywords. As author keywords are restricted by count and number of characters, and as they are not well standardized, similar keywords were grouped together. For instance, keywords such as (computer, computers); (collaboration, collaborative); (students, learners) were combined. Analysis of the evolution of author-defined keywords was performed using all the keywords that appeared in the top five keywords in any year of FIE.

Network analysis was used to examine the relational and thematic structure of the publications in terms of keywords, as well as collaboration between authors and countries [30]. A network of keyword co-occurrences (keywords that appear together in the same document) was constructed to map the relationships between different concepts and research themes. For the readability of relationships and labels, the network size was limited to the top 40 keywords. A country collaboration network was created for documents with two or more authors affiliated with institutions in different countries. For clarity, the network was limited to the 40 most productive countries. To visualize the most active collaborations and active groups of authors, co-authorship data were used to construct an author collaboration network. All authors with more than 30 unique collaborators were included in the network. To visualize the structure of the networks, those nodes (keywords, countries or authors) that were closely related were clustered using Louvain modularity method for community detection [31]. Communities were colored differently in the network plots. Community detection was applied to the keywords network as well in order to cluster the words that were mentioned together in the same articles. Keywords that belong to the same community reflect common research themes. In the country and author networks, communities reflect common and frequent collaborations.

IV. AUTHORS

FIE has been a very popular venue for engineering and computing educators. Since 1982, 17410 different people have authored or co-authored papers in the proceedings. Among the authors of FIE papers, 12206 people (70%) appeared in FIE proceedings just once, and 2588 people (15%) twice, with 1.85 mean papers per author. For those FIE attendees who appeared twice or more (29.9%) the mean number of publications is 3.85. Some 29.6% out of all FIE attendees have appeared more than once in the last decade (after 2010), and some 26.8% have appeared more than once in the last five years (after 2015).

A large number of people stand out for massive, enduring contributions to the conference: 53 people have appeared in twenty papers or more. On the list of twenty most productive authors in FIE proceedings (Table I), all have published thirty or more contributions to the conference. Several people made it to Table I with more than 30 contributions in just 11 proceedings. The largest number of paper authorships in one year was 11 by Matthew Ohland in 2014.

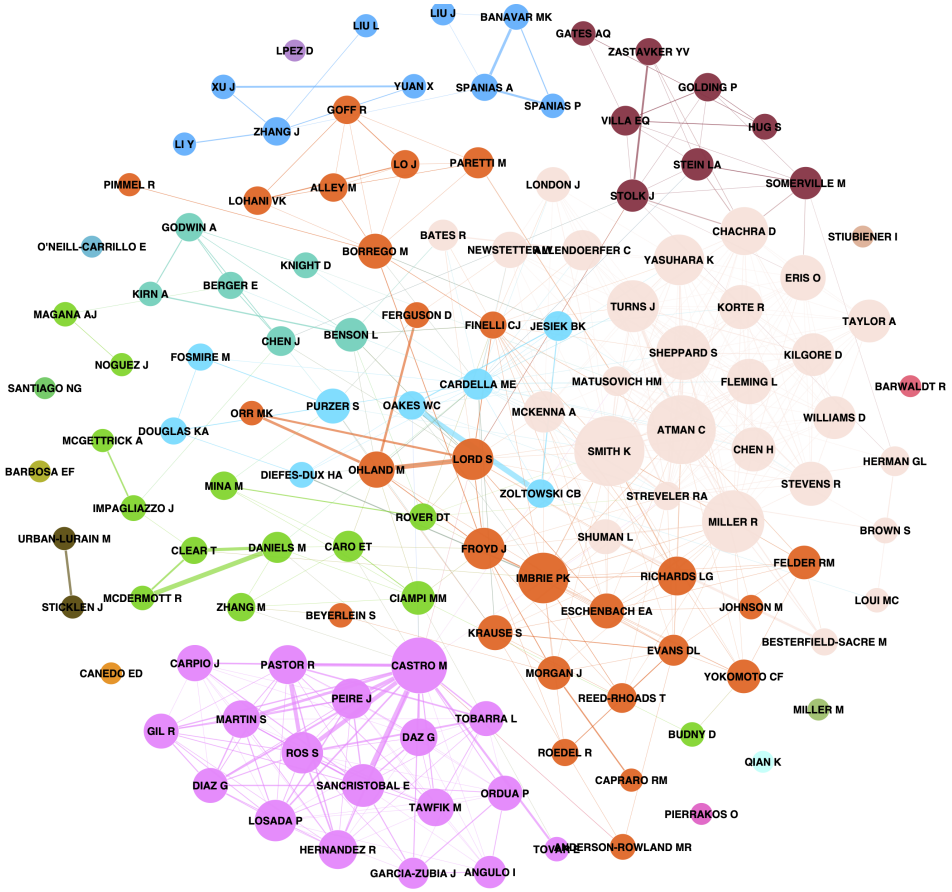

Fig. 2. Co-author network of FIE authors with most collaborators. Node size indicates the number of unique co-authors, edge thickness indicates number of co-authorships, and colors indicate communities of researchers who frequently collaborate together (using Louvain modularity algorithm). Unconnected authors have at least 30 co-authors all of whom are less connected.

The top positions on the list of most productive authors featured a number of ASEE/IEEE Fellows. Manuel Castro was involved in 67 FIE papers over 22 separate years, which earned him the top position on the list of most productive authors in FIE. Just a few papers short were Susan M. Lord, a familiar face from FIE special sessions (64 FIE papers over 26 years of activity), and Matthew Ohland of ASEE fame (59 FIE papers and 21 years of activity). Karl A. Smith had the longest engagement with the conference: his name appears on 55 papers in 28 FIE proceedings from 1982 to 2020—and possibly earlier, as Scopus data starts from 1982. Mats Daniels held the fifth position with 53 papers in 21 separate issues of FIE proceedings.

Above all, FIE has been a forum that brings people together—and not just to convene but to co-author. The mean number of authors per paper is 2.79, and the most common number of authors in papers is 2. Co-authorships in FIE papers form a network, with a number of stronger connected clusters—and especially the network of most active collaborators is surprisingly dense. Figure 2 presents the authors with most co-authors (at least 30 unique collaborators), and co-authorships between them. Unconnected nodes in Fig. 2 are active collaborators whose co-authors are not among the most active collaborators in Fig. 2. Some clear clusters have formed on different grounds, such as one around Olin College (burgundy red cluster at one o'clock), and a strong, but somewhat independent Spanish cluster centered around Manuel Castro (pink cluster at seven o'clock). Other non-US based clusters are not apparent due to low co-authoring frequencies, with the exception of a small cluster centered on the productive author Mats Daniels from Sweden.

The person with most collaborators over the years was by far Manuel Castro, with an impressive set of 176 unique collaborators involved in his 67 papers. Several other well known members of the FIE community have also involved impressive numbers of collaborators, e.g., Karl Smith (108), Jeffrey Froyd (104), Sheri Sheppard (97), Elio Sancristobal (93), and Matthew Ohland (93). Closer investigation reveals that special sessions, panels, and round-tables have played an important part in bringing people together, and they often include large numbers of authors. For example, one FIE'07 special session paper [32] listed 29 authors.

The sense of FIE community is very strong at the conferences, where traditions of speaker breakfast buffets in the conference venue, and plated lunches in large conference ballrooms are features that help connect delegates and establish

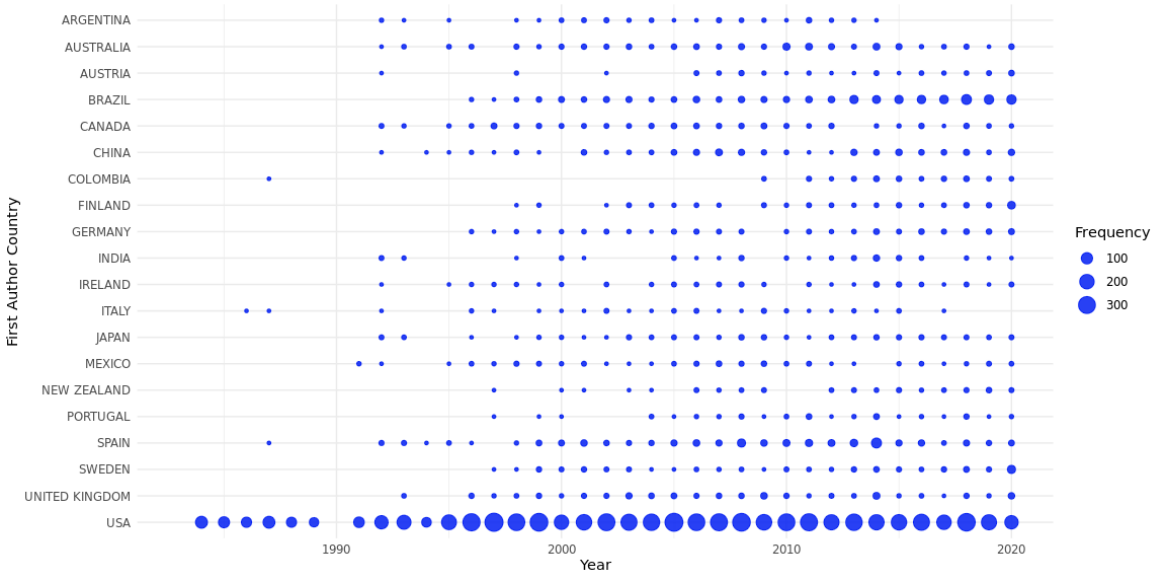

Fig. 3. The 20 most active countries in FIE proceedings by the number of articles published as determined by the affiliation of the first authors. The size of the circle indicates the number of first authors from a given country each year. In most early years, only the US exceeds the threshold for visualization.

a sense of belonging. This sense of community is, however, less evident in the citation practices of FIE authors. While there is a strong core of FIE attendees, in the past decade approximately 30 percent of authors are repeat publishers at the conferences, a figure that also holds true for the entire lifetime of the conference. Of those who published more than once, the average number of contributions is around 4, meaning that they published a paper approximately every other year. Interestingly FIE papers cite other FIE papers rather seldom, the average citation rates for the period 1999 to 2019 are under 0.5, except for the years 2018 and 2019, which means that less than half of the papers published at FIE refer to one other paper previously published at FIE in the preceding 3 years during that time period.

V. Articles

The diversity of FIE is clearly demonstrated by the conference's most cited papers: There is no single recipe for engaging the interest of the community. The most cited FIE paper from 2003 [10] is a technology paper that presented a remote lab and weighed its pros and cons: With 147 citations in Scopus, the paper has become a popular reference in STEM education. The second most cited FIE paper from 2002 [11], is a pedagogical paper that reported the adoption of and experiences from project-based learning (PBL) in engineering education. The third most cited paper, cited 130 times, reported results from a flipped classroom experiment [12]. Interestingly these authors seem not to be closely connected to the central members of the community identified in Figure 2, implying that you do not need to be well known in order to gain traction in terms of citations (and the same applies to many other top-cited papers, too). Their citations also come primarily from outside the FIE sphere: For instance, of the 147 documents that cite [10] only seven are FIE papers.

Table II shows a list of 20 most cited FIE papers. Many topics in Table II are about pedagogy, including flipped classroom ([12], [15], [26]), PBL ([11]), model eliciting ([17]), active learning ([21]), and concept inventories ([22], [23]). Reports on interventions and innovations in educational technology were many, from remote labs ([10], [20], [24]) to lab kit hardware ([16]), online learning environments ([19]), and virtual reality (using the once fashionable Second Life) ([25]). Other oft-cited papers include reports on teamwork in education ([27], [26]), curriculum design (CDIO syllabus) ([28]), development of professional identity ([13]), and educational data mining ([14], [18], [29]). Even after IEEE Computer Society became a co-sponsor of the conference in 1995, there were few computing education papers among the most-cited ones ([15], [25], [27]).

Despite the 50 year old history of FIE, all the twenty most cited papers were published in the 2000s, primarily in the early 2000s. Many factors may contribute to this: Most importantly, as the field of engineering education has matured, it has become more strongly intertwined with education research in other disciplines. For example, many citations of the oft-cited FIE papers on flipped classroom [12], [15], [26] and virtual labs [10], [20], [24] come from outside of engineering education, such as STEM education research. The fewer "Marco Polo" articles (experience reports) are published ([33], [34], [35]), and the more papers are linked with pedagogical theory, models, innovations, and frameworks in educational sciences [36], the more relevant they become to other discipline-based education research.

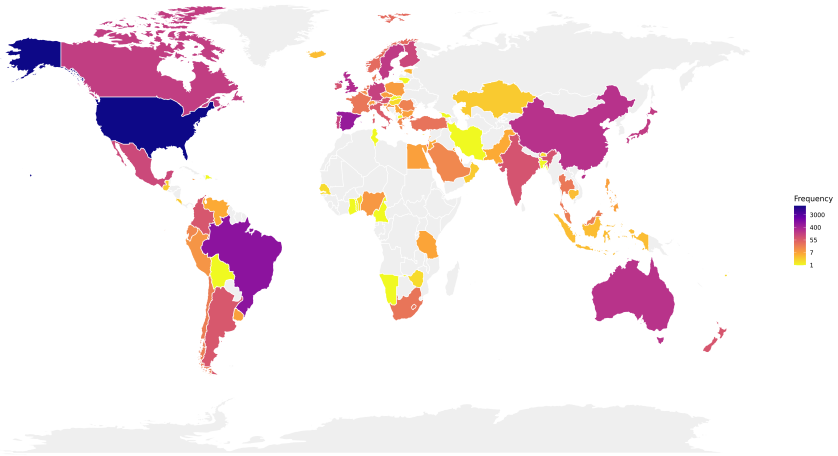

Fig. 4. Articles published in FIE proceedings around the world.

VI. International collaboration

FIE has always been a US-oriented but increasingly international conference (see Section II). Figure 3 shows the frequency of contributions per country each year, as determined by the affiliations of the first authors. Prior to 1990, only a small number of papers originated from outside of the US. The US is by far the single largest contributing country in FIE in terms of number of published articles (see Figure 3). The number of articles from other countries has increased over the years, and nowadays a significant portion of FIE papers originate from South American, European, African, Oceanian, and Asian countries, showing that FIE is turning into an international and intercontinental event and publication venue. Figure 4 shows the division of all FIE articles to different countries around the world.

Figure 1 shows that while an increasing portion of papers originate outside the US, most papers are still single-country publications (all authors from the same country). The share of multi-country papers (with authors from multiple countries) is steadily growing. Over the years, some 4.5% of papers have had authors from more than one country, some 70% of papers were written by a US-only author team, and some 21% of papers were written by authors from a single country, which is not US. Roughly 5% of papers could not be indexed with regard to author country. The situation is changing, and in 2020, some 10% of papers were written by authors from multiple countries.

A closer look at the 8,337 papers that had at least one US-based author (Fig. 6) shows that while papers have originated from all around of the US, the top seven contributing states are Indiana (1346 papers), Pennsylvania (827 papers), California (796 papers), Texas (711 papers), Virginia (633 papers), New York (561 papers), and Massachusetts (536 papers)[2]. Most US-based papers (78.2%) included authors from a single state, and 10.6% of papers included authors from two or more US-states.

During its operation from 1971 to 2020, FIE has been arranged outside the US a total of five times (one of which was compelled to be conducted in a virtual form due to the COVID-19 pandemic): in 1974 (London, UK), 1979 (Niagara Falls, Canada), 1990 (Vienna, Austria and Budapest, Hungary), 2014 (Madrid, Spain), and 2020 (Uppsala, Sweden, turned virtual)[3].

VII. Keywords and themes

The analysis of keywords reveals the emergence, popularity, rise and fall of topics and trends in varying times of the FIE conference. Analysis of keywords is possible only post 2001, as keywords did not exist prior to that. Prior to 2001 the conference listed conference "themes", but those themes are not suitable for analysis and comparison to actual keywords.

Figure 5 shows yearly occurrences for all 21 keywords that have appeared in the top five keywords during one or more years of FIE'01–FIE'20. The figure shows the emergence of keywords. For example, the keywords *STEM* and *sustainability* were rare in the early 2000s, but have become increasingly popular since. Declining keywords include *distance learning*, *software engineering education*, and *assessment*. Some, like *engineering education* and *active learning*, have kept their popularity throughout the years.

The network in Figure 7 visualizes the keywords most commonly found together, and identifies clusters of keywords. The *orange cluster* contains engineering education and aspects typically associated with the professional practice of engineering, such as design, innovation, ethics, professional development, and sustainability. The *purple cluster* contains topics typical of computing education research, including programming, software engineering, computational thinking, and computer science. The orange and purple clusters represent the two major domains of FIE: engineering education research, and computing education research.

[2]The state information could not be retrieved for 11.2% of papers, and those papers were excluded from Fig. 6.

[3]source: http://fie-conference.org/conferences/listing/past

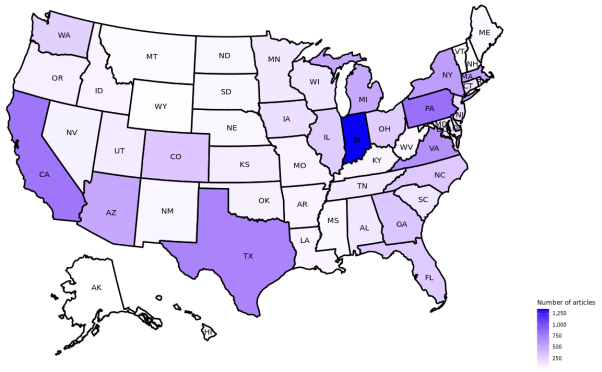

Fig. 6. Distribution of FIE articles across the US.

The small *light green cluster* contains papers related to computer-supported collaborative learning (CSCL) and related educational technology research. The *dark green cluster* represents research that applies concepts and theories from educational psychology in order to better understand students' learning; those concepts include motivation, self-efficacy, persistence. The educational psychology concepts in the cluster are combined with understanding diverse learner groups, gender, and retention in engineering and STEM education. The *light blue cluster* brings together the major theme "assessment" in the context of constructivist and collaborative pedagogical approaches in software engineering and design: project-based learning, collaborative learning, active learning, service learning, experiential learning, teamwork, and engineering design.

VIII. Discussion

This paper presents an investigation of the publication demographics, key participants, and citation and co-publication constellations of the FIE conference community during the period for which Scopus publication data is available: 1982 to 2020. In the sections above we identify highly prolific authors, periods of focus on research sub-areas, and co-authoring patterns. Our narrative follows the evolution of the field, and the history of publications of some of its "big players" as they can be charted from FIE's inception to the present day.

One area of innovation that has been sustained through the history of the conference is the tradition to open up the frontiers of engineering education by encouraging submissions that traditionally fall outside the definition of a scholarly article. In particular the conference has a continuing focus on categories of submission relevant to practitioners, such as "innovative practice" papers, as well as stimulating the community to think "outside the box" through mechanisms such as "special and interactive sessions", as well as providing a platform for the dissemination of research driven practice through workshops and work-in-progress contributions.

The quantitative analysis reveals the presence of a cohort of highly productive authors, whose contributions in some cases appear to have had high impact, but in other cases less so. It is clear from the geographical author demographics in Figure 1 that FIE became significantly more international from around 2001. If we consider the data from the last decade we can also see the impact of moving the conference abroad, with record proportions of non-US papers clearly apparent in 2014 and 2020. This demonstrates the crucial role that holding the conference outside the US plays in diversifying the FIE community and bringing more authors into the FIE family.

While there is a stable core community of approximately 30% of FIE authors who publish regularly in the conference, approximately 70% of authors attend only once. The tendency to cite other FIE works is also rather limited, with fewer than half of FIE papers citing one or more prior works published

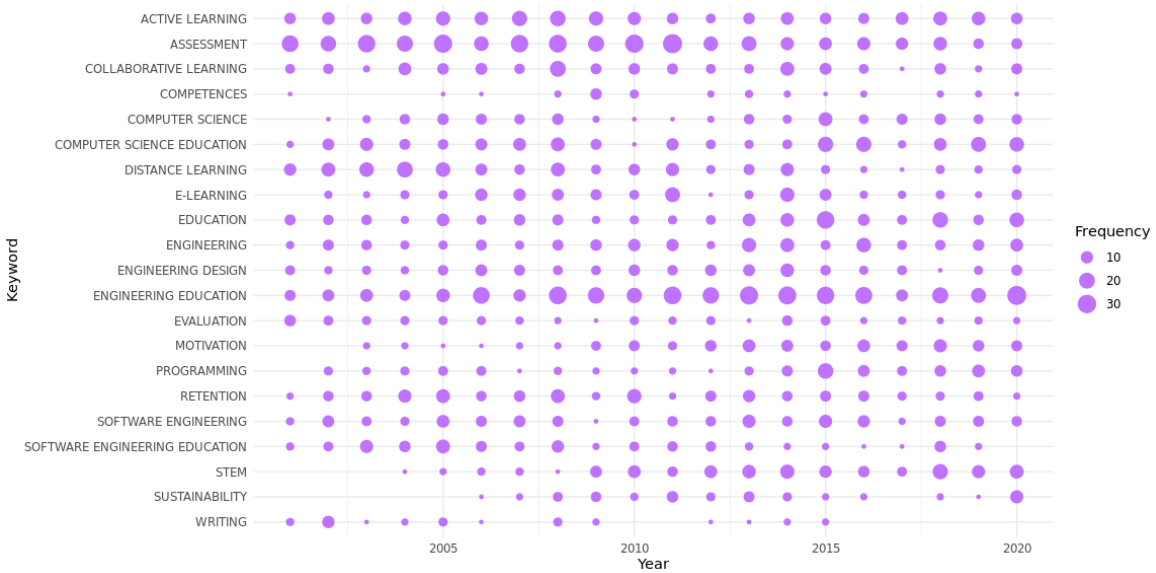

Fig. 5. Yearly counts of all keywords that were among the five most popular keywords in any year between 2001 and 2020.

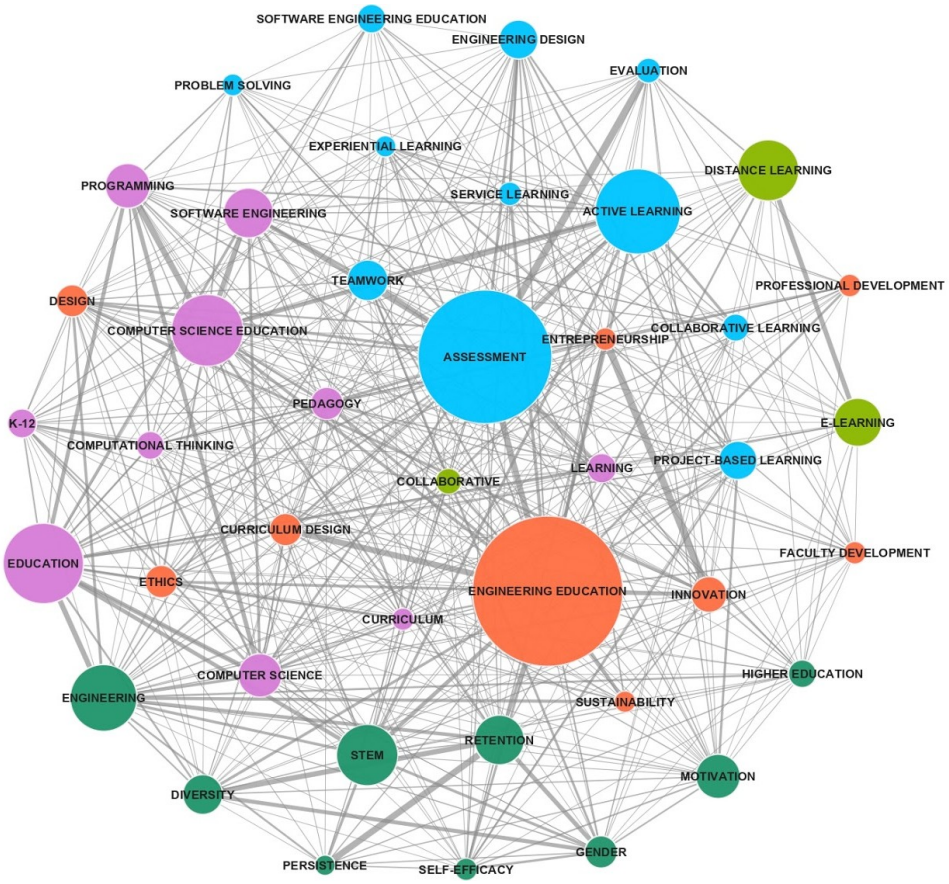

Fig. 7. Associations between keywords in FIE papers and clusters they form. Circle size illustrates the number of keyword appearances in the sample, line thickness illustrates the frequency of co-occurrences, and colors indicate clusters identified by Louvain modularity algorithm.

at an FIE conference in the preceding three years. Why is it that FIE papers seldom refer to other results published at FIE? One answer might be that FIE lives up to its name, and papers exploring the Frontiers in Education are largely groundbreaking in nature, and build on little earlier work in the field. However, analysis of Scopus citation data provided at scimagojr.com indicates that the majority of papers published at FIE are never cited, which is a problematic observation. Of course citations are not the only measure of impact of a publication, since many papers are read and downloaded by interested educational practitioners. However, these metrics warrant some reflection on the part of our community.

IX. Conclusion

FIE has grown from its beginnings as a conference for US based engineering tertiary teaching practitioners into a high profile international practice, innovation and discipline based tertiary education research conference over its 50 year history.

While collaboration networks were initially US based, we see increasing visibility of clusters outside North America, with significant clusters centred on highly productive and collaborative individuals in Spain, Brazil and the Nordic region. The 2020 conference was the first in FIE's 50 year history to publish more contributions from non-US authors than US authors, and thus sets a high tide mark in the internationalisation of the conference.

Overall citations of FIE papers are relatively low, and few FIE contributions refer to other work published at earlier FIE conferences. This is something the community should reflect upon. Is this desirable? Should there be stronger connections to other work in the FIE community in the future? How should the conference evolve to better serve the community, and expand the core community of returning authors above the 30% level, which has historically been the norm?

As we enter the new era of post-covid pandemic academia it will be interesting to follow the evolution of this conference, as hybrid-format conferences are likely to become main-stream, increasing accessibility of the conference to those who cannot travel, or for other reasons prefer to attend a virtual event.

Acknowledgments

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