Investigating co-authorship, research themes, and funding streams for the Frontiers in Education community

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***Abstract*—This full, research paper will inform the Frontiers in Education community about patterns of collaborations between authors, disciplines/research themes, and funding sources for the Frontiers in Education community over the last ten years. The study involves a text-based analysis of all Frontiers in Education (FIE) proceedings papers from 2010-2019. The FIE proceedings was chosen for this analysis because of the central role the FIE conference plays in the Engineering and Computing Education communities. This proceedings represents these communities across a broadly inclusive set of factors such as institution, scope of project, stage of project, and experience of the researchers. The Engineering and Computing Education communities represented at the FIE conference are uniquely placed to capitalize on recent shifts in policies and funding streams toward interdisciplinarity and partnerships/collaborations to achieve complex future-looking goals. Understanding the community's history of collaborations, research disciplines/themes, and funding can enable the community to move forward in new and better directions. For example, this research shows that funding in FIE papers went from 43% in 2010-2011 to 29% in 2018-2019, that on average 72% of work is intra-institutional, and that relatively little work focused on certain engineering disciplines or senior level students. This suggests that there may be untapped research, and funding, opportunities for projects that focus on inter-institutional partnerships to investigate these less studied populations and engineering disciplines.**

***Index Terms*—Interdisciplinary Collaboration, Science Funding Policy, Text Analysis.**

I. Introduction

One goal of the Frontiers in Education (FIE) 2021 conference is to create a convergence between engineering education and workforce development. This is a timely goal since recent shifts in policies and funding streams toward interdisciplinarity have also included a focus on the workforce of the future [1]. In addition, there is increased recognition by government and funding agencies of the need to invest in partnerships and collaborations to achieve future-looking goals such as this convergence, which requires integrating knowledge and techniques from multiple disciplines [2]–[4]. The Engineering and Computing Education communities represented at the FIE conference are uniquely placed to capitalize on these funding shifts as they sit in the overlaps of engineering, computing, education, and other disciplines. However, there is complex and important feedback that occurs between policies set through funding streams or established by industry and the research completed by research communities such as FIE [4], [5]. Indeed, understanding the history of research collaborations/partnerships, research themes and disciplinary areas, and funding in the FIE community will be useful in determining how, where, and which policies might provide the most benefit to the community and help the community achieve its future-looking goals.

This study investigates the status of co-authorship, research themes and disciplinary areas, and funding streams for research projects published in the FIE proceedings between 2010-2019. The study involves a text-based analysis of all FIE proceedings articles in this time window, and follows a rich history of meta-analysis in Education Research [6]–[12]. The FIE proceedings was chosen for this analysis because of the central role the FIE conference plays in the Engineering and Computing Education communities. This proceedings represents these communities across a broadly inclusive set of factors such as institution type and size, scope of project from small to large, stage of project from beginning to finished projects, and experience of researchers from new to established in the field. These results are also contrasted with findings from the Physics Education Research (PERC) proceedings, the Computer-Supported Collaborative Learning (CSCL) proceedings, and the International Conference on Learning Science (ICLS) proceedings to provide context for these findings.

Informing the community on the past history of co-author collaboration, research areas/disciplines, and funding streams will allow the community to observe the scope of publication and collaboration in the FIE community, leverage points for using existing partnerships to innovate FIE research, identify grant streams important to the community, and identify gaps in research areas or partnerships. The overarching, motivating goal of this work is to provide insight into the community's history and ten-year trajectory so that the community can consider how to best move the field forward in new directions. Finally, this research is even more significant given the recent upheaval due to the Covid-19 pandemic as it can provide a benchmark for future efforts to investigate how the community's collaborations, research, and funding have been affected.

The guiding research questions are: What is the history of co-authorship and disciplinary/institutional collaboration as represented by co-authorship in the FIE proceedings? What are the major trends seen in research themes and disciplinary areas in the last ten years? What is the landscape of funding among those who are published in the FIE proceedings and how has this landscape changed in the last 10 years? In addition, the following questions about funding were identified: What are the agencies that support this research? Within these agencies, what funding streams or disciplines are represented? Data based on institution collaborations and partnerships between authors seeks to answer the questions: Which institutions publish in FIE? Do authors mostly collaborate with authors at their institution or with other institutions? Has the pattern of collaboration shown in FIE changed with time?

II. Methodology

To answer these research questions, a series of text-based analyses were conducted. First, proceedings papers were located and downloaded from archived conference proceedings pages. These documents were all publicly available and free to download. FIE papers were downloaded from http://fie2014.fie-conference.org/ which actually had proceedings from 1995-2019 available via dropbox. PERC proceedings were pulled from https://www.per-central.org/perc/Proceedings.cfm and ICLS/CSCL proceedings from https://www.isls.org/. Second, all information about the authors, institutions, titles, and grant/grants that supported each paper's work were scraped using an advanced lexicon search within MAXQDA and pulled as text information into Excel. Once the data was in Excel further analysis, via open coding, and extensive data cleaning and data reorganizing was completed. Each of the three different analysis (coauthor/institutional collaborations, research themes/areas, and grants funding) all required slightly different kinds of analysis that are detailed below. In addition, FIE proceedings for 2010, 2011, 2016-2019 and all PERC proceedings were available as each paper in an individual pdf. FIE proceedings for 2012-2015 could only be found bundled together into one large pdf for each year. This required two slightly different strategies for extracting the information with MAXQDA.

For completing coauthor analysis, the search term "abstract" was used. A file for each year was created in MAXQDA and all text information from the papers that occurred prior to the word "abstract" was pulled into Excel. MAXQDA outputs an Excel file which lists the pdf document, term it discovered, page and position of search term, and the text from as many sentences before/after the term as you tell it to pull. In this case, MAXQDA was told to pull the 20 sentences prior to the word Abstract, which pulled all text for title, author, and institution information into a cell for each paper. The "text to columns" function in Excel was then used to separate title, author, and institution information into a series of columns with data for each paper as a row in the Excel file.

Then an extensive data cleaning and reorganizing process was needed to remove data that was not included in the analysis such as emails, departments, institutional addresses, etc. and to remove rows that were instances where a paper used the term "abstract" as part of the actual paper text and thus did not pull relevant information. In addition, it was necessary to fill in information that was missing. For example, some authors included their affiliations in a separate section of the pdf and not in the title area so these pdfs were individually opened and information was copy/pasted directly into Excel. For years where all data was included in one large pdf, the page number of the word "abstract" was used to indicate unique papers and this was double checked with the table of contents to make sure that each paper in the proceedings had author and institution data. It should be noted that this cleaning process was fairly time consuming and tedious.

For completing the research areas/disciplines, the titles were uploaded into MAXQDA and specific terms were queried directly. How these terms was chosen is described in section IV Research Areas & Disciplines Analysis.

For completing grants analysis, the term "acknowledg*" was used to pull all Acknowledgement and Acknowledgments sections. (The * captures all words that start with the typed letters, capitalization does not effect the output.) Again the data needed to be cleaned to remove uses of the word acknowledge, acknowledged, within the actual paper text and/or to remove repeated pulls from the same paper. Because not all papers have acknowledgement sections there was no way to check that all acknowledgement sections were pulled. For example, one paper had an "Aknowledgement" section. This was caught because the word acknowledge was still used in the document. However, pdfs were not individually opened and checked so any acknowledgment sections which did not use the word(s) captured by the "acknowledg*" search were not included in this analysis. Once pulled into Excel, an open coding process was used where all acknowledgement sections were read and coded for: 1) did they indicate funding; 2) was the funding from the U.S. National Science Foundation (NSF); 3) if the funding was from NSF, was there a 7-digit number provided to designate this funding; 4) was the funding entity clearly an international, non-U.S. source and what country or program did this come from; 5) was the funding "Local", i.e. from a university, teaching and learning center, etc.

Of these questions, 1) Did they indicated funding was the most open to interpretation. The author used words such as "financial", "grant", "Foundation", and/or thanking a funding entity for their support as indicating funding. Thanking people, departments, or places that were not funding entities was assumed to be support of a non-financial means. For example, one paper said, "The organizers thank the Pioneers Project research team and the pioneer panelists participating in the session." This was coded as not having funding. Another said, "This work was supported by a grant from the Argosy Foundation..." This was coded as having funding, not from the NSF, not international, and not local.

III. Co-authorship Analysis

As the FIE community moves forward into new and interesting innovations, it is useful to reflect on the outcomes from partnerships and collaborations between researchers/ institutions. The author data from the FIE proceeding (2010-2019) were analyzed for the number of authors who were collaborating on papers, whether these collaborations were multi-institutional or single institution, and which institutions were most listed on FIE papers (see Table I, Table II, and Figure 1).

TABLE I
PARTNERSHIPS & COLLABORATIONS FROM FIE CO-AUTHORSHIP ON PAPERS FROM 2010-2019.

# Category	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	Percentage	Correl. w/ Year
1 Author	66	81	35	62	55	45	51	30	66	48	539	13%	-0.39
2 Authors	129	110	101	128	119	105	94	73	124	81	1064	26%	-0.56
3 Authors	119	107	72	81	133	89	104	78	116	77	976	24%	-0.23
4 and More	99	142	121	139	212	164	161	127	231	159	1555	38%	+0.55
1 Place	314	349	238	302	346	295	289	219	376	255	2983	72%	-0.19
2 Places	66	64	58	68	121	79	79	56	108	75	774	19%	+0.32
3 Places	21	22	19	28	40	20	29	18	31	25	253	6%	+0.21
4 and More	12	5	16	12	12	9	13	15	22	10	126	3%	+0.59
Total Papers	413	440	329	410	519	403	410	308	537	365	4134	100%	+0.006

A. Co-authorship Trends with Time

There were 4,134 papers in the FIE proceedings from 2010-2019. 539 of these 4,134 papers, 13%, were single author and 3,595, 87%, were collaborations of multiple authors (see Table I). Across the 10-years 26% of papers had two authors, 24% had 3 authors and 38% had 4 or more authors collaborating on the work. On average there were 3.3 authors per paper.

In terms of institution, 72% of papers had authors who were all at the same institution, and 28% were collaborations where authors were from different institutions with 19% being from two places, 6% from 3 places, and only 3% from 4 or more places. Of the papers with multiple institutions, it was significantly more likely for a majority of authors to be from the same institution and only one or two of the authors to be from a different institution than for all authors to be from separate institutions. For example, while there were 1,555 papers where 4 or more authors collaborated on the paper, there were only 126 papers where authors from 4 or more intuitions collaborated on the paper.

These data show that the FIE community relies heavily on author collaborations/partnerships to accomplish research goals since only 13% of papers are single author. It also shows that most, 72%, author collaborations happen via partnerships at a single institution, which suggests that intra-institution collaborations are most important for publication productivity. However, while the within institution collaborations are clearly very important for publication productivity in the FIE community, there are cross-institution interactions that are driving research productivity, as measured by authorship, and these cross-institution collaborations are increasing with time.

Multiple author partnerships of 4-and-More authors and multiple institution partnerships on papers were seen with increased frequency over the 10-year period. Single institution, and author collaborations of 1, 2 and 3 people decreased over this time period. This is documented in Table I through the reported positive and negative correlations between author and year and the correlations between place and year for the difference categories of 1, 2, 3, and 4-and-More.

In addition, Figure 1 displays trends with time toward larger author collaborations on papers. A linear fit for this graph gives an increase of 7.3 papers per year for 4-and-More authors and a corresponding decreases in 1, 2, and 3 author collaborations. The institutional collaborations data shows similar results. Single institution papers (1 Place) trend down by 3.2 papers a year and multi-institution collaborations (2, 3, or 4-and-More Places) trend up. (Note: the total number of papers a year showed no overall trend up, or down, across this 10-year period, see Table 1 total papers correl. w/ year of +0.006. So, the number of authors/places on a paper do not provide independent variables. Also, because single institution papers are much more numerous than multi-institution papers, a graph with time is not included for Place.)

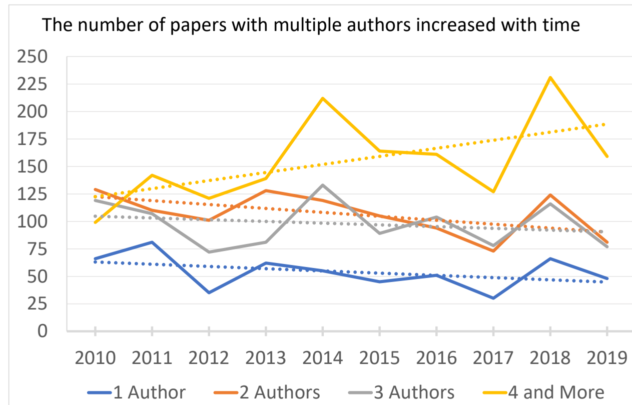

Fig. 1. Increased Collaboration by Author Number with Time on FIE Papers

B. Institutions Participating in FIE Authorship

In terms of institutions that participated, data on the places that collaborated on each paper were collected together and cleaned to align the institutional names as much as possible. For example, "Virginia Technic Institute and State University", "Virginia Tech", and "Virginia Tech State University" were all cleaned into just *Virginia Tech*. Each collaborating place was counted once per paper regardless of the number of authors from this institution who participated. This gave 1,628 unique names of institutions that were associated with 5,881 instances of places participating in these 4,134 papers.

Purdue University was the most represented with someone from this institution participating as coauthor in 367 different papers, or 8.9% of published work in this 10-year time frame. Virginia Tech was next with 151 papers or 3.7% of the publications, and Arizona State University had 127, or 3.1% of papers. Table II has the data for all 20 of the top institutions which are spread geographically over the whole U.S. and in a couple other countries. In total these 20 institutions accounted for 25.8% (1,520 of the 5,881 instances) of places participation. These are for the most part universities with graduate programs, research focus, and/or strong engineering

TABLE II
INSTITUTIONS WITH THE MOST PAPER AUTHORSHIP FOR FIE 2010-2019

Institution	Coauthor #	% of Papers
Purdue University	367	8.9%
Virginia Tech	151	3.7%
Arizona State University	127	3.1%
Penn State	77	1.9%
Rochester Institute of Technology	59	1.4%
Texas A & M University	59	1.4%
Olin College of Engineering	58	1.4%
University of Illinois Urbana-Champaign	55	1.3%
University of São Paulo, Brazil	55	1.3%
Gannon University	54	1.3%
University of Virginia	53	1.3%
The Ohio State University	51	1.2%
Iowa State University	50	1.2%
Uppsala University	47	1.1%
Utah State University	47	1.1%
Michigan Technological University	44	1.1%
Rose-Hulman Institute of Technology	44	1.1%
Clemson University	42	1.0%
Georgia Tech	40	1.0%
University of San Diego	40	1.0%
Total	1,520	25.8%

programs. Thus, it is not surprising that these institutions have high participation. However, noting the institutions external to the U.S. and the geographic spread is interesting and may be useful for students looking for programs of study and/or faculty looking for job placements or potential collaborators. Additionally, while these 20 institutions represent a chunk of the participation in FIE, it is important to note that there are over 1500 other places from which people are contributing with 80 additional institutions averaging at least yearly participation. Here are the additional institutions that participated in 20 or more papers, listed in order of the number of papers they participated in: National Distance Education University UNED, Federal University of Amazonas, University of Colorado Boulder, IUPUI, University of Washington, Bucknell University, Universidad Politécnica de Madrid, University of Texas El Paso, Drexel University, James Madison University, University of Michigan, Colorado School of Mines, Miami University, Ohio Northern University, Universitat Politècnica de Catalunya - BarcelonaTech, Embry-Riddle Aeronautical University, North Carolina State University, Oregon State University, South Dakota School of Mines and Technology, Stanford University, United States Coast Guard Academy, Worcester Polytechnic Institute, Brandeis University, Rowan University, University of Pittsburgh, and University of Vigo.

IV. RESEARCH AREAS & DISCIPLINES ANALYSIS

The titles for all 4,134 papers underwent a lexical search in MAXQDA for specifically chosen terms. Table III shows a breakdown of the terms and number of papers which included these terms in their titles. The terms were chosen with two goals in mind: 1) to determine the relative emphasis of the proceedings on certain disciplines, student levels, or areas of study; 2) to look for trends in research areas or themes that might be of interest to the community. For this second goal, a bottom up, thematic analysis approach was used, i.e. the data, not the researcher, determined the themes/terms to be investigated. Section C details this methodology.

A. Relative Mentions of Engineering Disciplines

To investigate the relative focus of engineering disciplines the titles were directly searched for the terms Electrical Engineering, Mechanical Engineering, Civil Engineering, Industrial Engineering, Biomedical Engineering, and Chemical Engineering. There were respectively 30, 12, 14, 5, 4, and 8 papers that included these in the titles. In addition, the terms Material Science and Computer Science/Computer Engineering were used to query these disciplines with 6 and 179 papers that used these terms in their titles respectively. In contrast to these relatively small numbers of papers, 1,357 papers, 32%, use the term engineering somewhere in the title.

This suggests that many studies are, or believe their work to be, generally applicable across the engineering disciplines. In addition, these numbers suggest that there are unequal amounts of education research being presented at FIE from the different engineering disciplines, and that these do not strictly follow the number of engineering jobs in each discipline, which has civil engineers accounting for the most jobs of any engineering field at 274,000, followed closely by mechanical engineers at 264,000, and industrial engineers at 229,000 as of 2014 [13]. In addition, these numbers suggest that outreach to biomedical, chemical, and industrial engineering might be good methods for expanding participation in FIE. However, it should be noted that there are complex reasons for why a researcher may/may not involve a certain course or discipline in their research and these researchers may/may not choose to describe the research with the discipline as part of the title. Thus, while these differences are suggestive of variations in disciplinary participation, they do not tell a complete story.

B. Relative Mentions of Course or Student Level

To investigate student and/or course level, the terms K-12, K12, High School, Middle School and Grade School were searched together with 129 titles indicating work at the precollege level. 152 papers use the terms freshman, freshmen, first year, or first-year with an additional 100 papers using the term introductory vs. 69 papers using the terms senior or capstone in their titles. 191 papers use the word undergraduate and 58 papers use the word graduate. 116 papers use the words faculty, teacher, instructor, or teaching assistant. These numbers show that the FIE proceedings include work across the spectrum of engineering education course level, but seem to have a focus on undergraduate and beginning course work.

C. Relative Mentions of Select Research Areas

Research areas were queried based on two methods. First, themes the author saw from reading a subset of the titles were identified. The author only searched themes that could be meaningfully queried from a few terms and that would be meaningful given those terms. For example, Assessment/Evaluation/Impact can be easily queried and was identified as a common theme in the titles; however, these terms were not seen as useful for indicating the kinds of research being published in FIE proceedings. Second, the MaxDictio function in MAXQDA was used to gather word

TABLE III
USING KEYWORD QUERIES OF PAPER TITLES TO INVESTIGATE STUDIED POPULATIONS AND RESEARCH THEMES

Terms	# of Papers
Studied Course or Student Level	
K-12, K12, High School, Middle School, Grade School	129
Freshmen, Freshman, First(-)Year, Introductory	252
Senior, Capstone	69
Faculty, Instructor, Teacher, Teaching Assistant	116
Education Technology Focus	
Online, On-line, Distance, MOOC	163
Computer, Programming	448
Software, Mobile Application(s), App(s)	181
Technology, Virtual, VR	162
A Few Investigated Research Areas	
Broadening Participation & DEI terms	197
Curriculum, Curricula	125
Lab*	163
Engineering Design	60
Game, Gamification	133
Total Distinct Papers Captured with these terms	1,760 (42.6%)

frequencies from all 2010 and 2015 papers. Illuminating search terms were chosen from this list of common words (see Table III for results). The ten most common words in these titles were: engineering, learning, student(s), course, education, using, design, teaching, programming, and computer.

As might be expected, given the focus of the conference, there were several papers titles that use words associated with educational technology. 163 papers use the words online, online, distance, or MOOC in their titles, 161 use the term software, with an additional 20 using the terms mobile application(s) or app(s). 97 papers use the word technology in their title and 69 used the word virtual or VR [9], [14], [15].

197 papers used the terms: minorit*, girls, women, gender, diversity, equity, inclusion, retention, persistence, Black, or Hispanic in their titles suggesting that these papers are addressing broadening participation and/or diversity, equity, and inclusion in a course or program [10]. 163 papers use lab* (where the * allows for any set of letters to follow in the word), 125 use the words curriculum or curricula, 133 use game or gamification and 60 used "Engineering Design". These different searches, reported on in Table III account for 1,760 of the papers or 42.6%. (Note: there is some overlap in the reported searches so the "Total Distinct Papers" in Table III is how many distinct papers were captured by these terms but does not equal the sum of the above data.)

It should be noted that the themes in Table III are are not all, or even a majority, of the research being published in the FIE proceedings. Nor is it the author's goal to suggest that these research areas/themes are more important than other research objectives. Only that these were some of the themes seen. In addition, there were many interesting details to what was, and what was not, present in these searches; however, it is not the goal of this paper to document all such findings.

V. FUNDING ANALYSIS: FUNDING RATES WITH TIME

Data from the funding analysis for the FIE and PERC proceedings is shown in Table IV, V, and Figure 2, 3. There are several aspects of this data to consider. In the following sections, funding rates for FIE, trends with time, and comparisons of these with the PERC and CSCL and ICLS proceedings are presented and discussed.

A. FIE Funding Rates and Trends with Time

For FIE proceedings papers from 2010-2019, there were 4,134 total papers in this 10-year period. 2,155 had acknowledgement sections or acknowledgments in the article. 1,412, or 34% of papers, acknowledged some source of funding. 753 papers, 18% of papers overall, acknowledged the U.S. National Science Foundation (NSF) for funding (see Table IV). Additionally, 53% of the acknowledged funding credited NSF as one of the funding sources, 30% of acknowledged funding came from international funding agencies, and 12% of acknowledged funding from a "Local" source such as a university, department, or teaching center. While these three "sources" are not mutually exclusive, i.e. a paper can be funded by NSF, an international agency and a local source at once, these over laps were fairly rare. Thus, these three sources of funding account for 96% of all acknowledged funding.

Considering funding across the 10 years, there is a significant overall decrease in the percentage of papers reporting funding (see Figure 2). The average reported funding rate for FIE papers was 40% for years 2010-2013 but only 31% for years 2017-2019. A t-test shows this difference is significant at $p < 0.05$ with a 1.6 effect size. In addition, the rates of NSF funding mirror this overall decrease in funding acknowledged in the proceedings papers with both showing a yearly decrease of 1.4%. In contrast, rates of funding internationally have a small but steady increase of 0.5% a year over this window. This change is consistent with the increase in international participation at the FIE conference in this time frame.

B. Comparisons with Similar Proceedings

For PERC proceedings from 2010-2019, there were 918 papers in this 10-year period. 745 had acknowledgements. 612, or 67% of papers, acknowledged some source of funding. 489 papers, or 53%, acknowledged NSF funding. Additionally, 80% of the acknowledged funding was credited to NSF. Outside of NSF the PERC community is funded by institutional, local, and/or state grants as the next most common funding

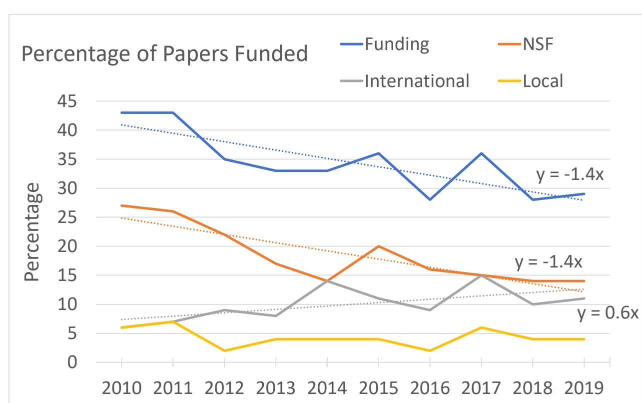

Fig. 2. Shows the decrease in FIE funding across the 10-year window

TABLE IV
FUNDING ACKNOWLEDGED IN FIE & CONTRIBUTED PERC PAPERS FROM 2010-2019.
% OF PAPERS FUNDED = # W/ FUNDING/ # OF PAPERS; % OF FUNDING BY NSF = # W/ NSF FUNDING/ # W/ FUNDING

FIE Papers from 2010-2019	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Avg	Total
# of Papers	413	440	329	410	519	403	410	308	537	365	413	4,134
# w/ Acknowledgments	225	233	162	191	286	224	205	169	274	186	215	2,155
# w/ Funding	176	190	115	134	170	146	113	110	153	105	141	1,412
# w/ NSF Funding	112	114	73	70	71	79	64	46	74	50	75	753
# of Unique NSF Funds	114	109	83	78	70	96	61	44	100	49	80	614
% of Papers Funded	43%	43%	35%	33%	33%	36%	28%	36%	28%	29%	34%	–
% of Funding by NSF	64%	60%	63%	52%	42%	54%	57%	42%	48%	48%	53%	–
% of Funding by International Agencies	14%	16%	24%	25%	42%	31%	34%	43%	36%	38%	30%	–
% of Funding by Local Means	14%	16%	5%	13%	14%	11%	8%	15%	14%	13%	12%	–
PERC Papers from 2010-2019	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Avg.	Total
# of Papers	67	72	95	84	70	93	97	115	113	112	92	918
# w/ Acknowledgments	57	61	75	67	54	78	71	91	96	95	75	745
# w/ Funding	50	52	62	58	42	66	53	73	81	75	61	612
# w/ NSF Funding	35	41	51	46	32	49	45	59	62	61	49	489
# of Unique NSF Funds	31	53	44	46	44	50	52	56	61	62	48	285
% of Papers Funded	74%	72%	65%	69%	60%	71%	54%	63%	72%	67%	67%	–
% of Funding by NSF	76%	83%	85%	79%	76%	76%	85%	81%	77%	81%	80%	–

sources at 69 instances, or 11%, of funding mentions, and there are only small, less than 5%, of funding to the PERC proceedings community from international sources such as Technological-140 grants (14 mentions) and 19 mentions of other granting agencies in various countries.

Contrasting this with FIE statistics, there are a few clear differences. First, the FIE community is considerable larger than the PERC community. The FIE proceedings had on average 413 papers a year while the PERC proceedings, which grew considerably during the ten year window investigated, had only 92 papers a year on average. This is 4.4 times the number of participants in FIE by paper.

Second, the FIE community is considerably more international than the PERC community. 30% of acknowledged funding for the FIE proceedings was from international funding agencies/entities where as the PERC proceedings has $< 5\%$ of funding acknowledged from international sources. This most likely reflects the different natures of the conferences and therefor the proceedings rather than an overall difference in disciplinary practice between the two communities. FIE is a more international conference with a meeting held in 2014 in Madrid. PERC, on the other hand, is held in conjunction with the American Association of Physics Teachers meeting and is always held in the U.S. This international aspect to FIE has the benefit of diversifying the portfolio of funding and thus the community can better weather reductions in funding from any one source and/or changes in agency priorities. However, it also means that conference attendees must travel internationally, and the impact Covid-19 will have on these conferences moving into the future is as yet unclear.

Third, the PERC proceedings is significantly more likely to acknowledge funding support than the FIE community. Only 34% of papers in the FIE proceedings acknowledge funding compared with 67% of papers in the PERC proceedings. While it is likely this difference is a reflection of the different natures of these two conferences more than a commentary on funding for the physics education discipline over the engineering & computer science education disciplines, it is a notable difference.

To give additional context to these differences between the FIE and PERC proceedings communities, results from a similar funding analysis of the CSCL and ICLS proceedings from 2010-2018 that the author completed are useful to consider [11]. This showed that 661 of the 2,502 papers, or 26%, of papers acknowledged funding from these two communities, which generally represent the Learning Sciences. These ICLS and CSCL proceedings also come from a larger and more international community, where approximately 40% of acknowledged funding came from international sources. So, it may be that FIE has more in common with ICLS/CSCL than with PERC despite the apparent greater overlap in disciplinary interests between engineering education and physics education.

VI. SOURCES OF ACKNOWLEDGED FUNDING

As mentioned above, over all 34% of papers acknowledged funding. Of this funding, 53% was credited to NSF, 30% to international agencies, 12% to “Local” sources, and the final 4 to 5% from a variety of foundations, businesses, associations, or other U.S. agencies. However, it can be useful to know the exact sources of this funding either from a policy perspective in understanding the financial stability of the field and/or from a research perspective in wondering what would be good places for a researcher to apply for grant money. The details of these sources are discussed in the next section.

A. *Sources of Funding within the National Science Foundation*

53% of acknowledged funding was credited to NSF and 614 unique 7-digit award codes were pulled from 753 different papers. 595 of these codes generated award matches from the NSF award database search [16]. This created an output Excel file which gave NSF Directorate, NSF Division, and Program(s) which funded each award among other data. Table V and Figure 3 show the directorates that provided these awards. Education and Human Resources (EHR) was by far the most common NSF Directorate with 54% of awards coming from these programs. Next most common was the Engineering

TABLE V
DIRECTORATES FOR THE GRANTS ACKNOWLEDGED IN FIE & PERC PAPERS FROM 2010-2019

	FIE		PERC	
Directorate	# of Grants	Percent	# of Grants	Percent
CISE	68	11%	3	1.2%
EHR	331	54%	205	80.1%
ENG	178	29%	4	1.6%
GEO	4	0.7%	0	0.0%
MPS	9	1.5%	31	12.1%
O/D	2	0.3 %	1	0.3%
SBE	3	0.5%	1	0.3%
N/A	19	3%	10	4%

Computer and Information Science and Engineerign (CISE); Education and Human Resources (EHR); Engineering (ENG); Geosciences (GEO); Mathematical and Physical Sciences (MPS); Office of the Director (O/D); Social, Behav., & Economic Sciences (SBE); (N/A) No such grant # exists in the awards search.

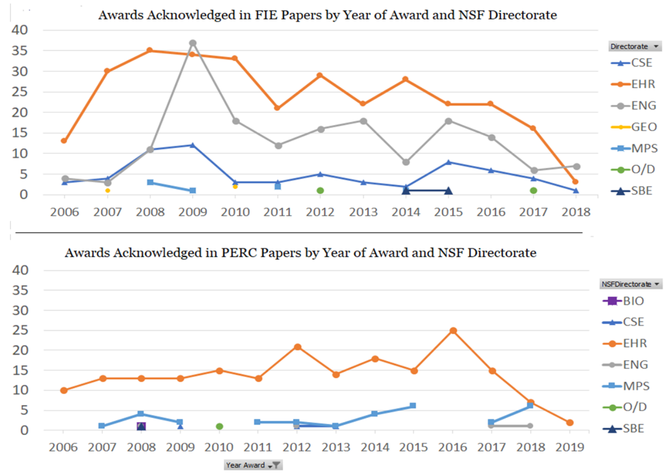

Fig. 3. Grants Acknowledged by Year of Award and NSF Directorate

directorate (ENG) with 29% and then the Computer and Information Science and Engineering (CISE) is next with 11% of the awards. These are perhaps not surprising given that FIE is a conference for education research in Engineering and Computer Science. Comparing this with PERC proceedings shows that the acknowledged FIE award set is much more spread out across NSF directorates, division, and programs.

Given the 331 awards from EHR (54% of all NSF funding mentions), a majority of these awards, 231 or 70%, were from the Division of Undergraduate Education. The programs IUSE* and S-STEM featured on 212 of the Division's awards, ECR (on 8 awards), and NOYCE (2). The Division of Research on Learning (DRL) had 43 acknowledged awards, i.e. 13% of the awards from EHR. The programs that funded FIE work from DRL were ECR* (26 awards: 17-REAL & 9-ECR), DRK-12 (5), ITEST (5), AISL (2), and others (5). The Division of Graduate Education had 35 awards acknowledged, 11% of EHR awards. These programs were CYBERCORPS: Scholarships for SER (18 awards), GRFP (10), GRAD TEACHING FELLOWS IN K-12 (3), IGERT (1), and mixed funding (3). Finally, 22 awards, 7% of EHR funding, were from the Division of Human Resource Development programs ECR* & ADVANCE* (11), CREST (4), HBCU-UP (5), and two other programs. (Note: Some programs no longer exist at NSF. For these awards, the current funding program that is most similar was identified and these awards were grouped together under this. CCLI and TUES awards were all listed under IUSE as an example. Where this was done a * is used. Also, acronyms were used to conserve space. If a reader is unfamiliar with the acronym, a Google search of the acronym and NSF should find the relevant program webpage and provide information about the kinds of research this program might support.)

178 awards, 29% of funding from NSF, came from the Directorate of Engineering (ENG). 159 of these awards, 90% of the acknowledged funding from this directorate, came from the Division of Engineering Education and Centers. The programs Research in the Formation of Engineers, RFE, provided most of these awards at 130 acknowledged awards. Other programs that were listed for these acknowledged awards numbers were Broadening Participation in Engineering (8 awards), RET (5), PFE/RED-IUSE (4), Eng Workforce Development (3), and others. Also, the Division of Civil, Mechanical and Manufacturing Innovation (CCMI) gave 7 awards. The Division of Industrial Innovation and Partnerships provided 6 awards, several of which were from the SBIR program. The Divison of Chemical, Bioengineering, Environmental and Transport Systems (CBET) had 2 awards, and the Division of Electrical Communications and Cyber Systems had 3.

The Directorate for Computer and Information Science and Engineering (CISE) was the third most in grants with 68 or 11% of the funding from NSF. The Division of Computer and Network systems had the majority of these grants with 44. These came from programs such as Broadening Participation in Computing (16 awards), Special Projects-CNS (6), STEM+C (7), REU (3), Secure and Trustworthy Cyberspace (3), Broadening Participation in Computing Alliance Program (3), and others. The Division of Computing and Communication Foundations, CCF, was listed on 12 of these awards from programs such as REU (4), ITEST (2), and several other programs. Division of Information and Intelligent Systems was listed on 8 awards for programs such as ITEST (2), REU, S-STEM, and Human Centered Computing among others.

These are the main funding programs as reported from the awards search. However, these are not the only funding programs at NSF; indeed, several programs that had small numbers of awards were not mentioned here for brevity. In addition, efforts were made to collect and simplify the program data reported, especially where multiple programs were listed on one award, this further shortened the number of funding programs reported here. Thus, this data should not indicate to a reader that only a few programs would fund researchers in the FIE community. Nor are these programs necessarily the best programs for faculty to apply for funding from. NSF funding programs and priorities change with time as described in the solicitations and these funding announcements are what a PI should use to determine where their research/project idea fits with a program. Finally, these data are awards only and say nothing about the numbers or places where FIE researchers have applied for funding. So, just because a large number of awards are from a certain program does not mean that this program necessarily has a higher rate or likelihood of funding.

B. International Funding Sources

30% of funding acknowledged in the FIE proceedings came from international funding agencies. There were several commonly mentioned funding sources such as the Brazilian National Research Council (CNPq), Coordination for the Improvement of Higher Education Personnel (CAPES), European Commission, Japan Society for the Promotion of Science (KAKENHI), eMadrid Excellence Network, Spanish Ministry of Economy and Competitiveness, German Federal Ministry of Education and Research (BMBF), Irish Research Council, National Natural Science Foundation of China, etc. Because it was unlikely for international funding to be reported with a unique award id, it is difficult to know how many different instances of support there were. However, the number of times each of these agencies was mentioned was documented.

Because the PERC Proceedings have so few international participants, let alone acknowledged funding, a comparison could not be made between these communities. However, the analysis completed for ICLS and CSCL proceedings could be usefully compared with the FIE results [11]. There were 2,502 total submissions to the ICLS and CSCL proceedings from 2010-2018, with 661 (or 26% of total papers) acknowledging funding. 48% of funding acknowledged came from NSF and roughly 40% from international sources. 16%, 104 mentions, of funding for this proceedings was from Europe with the European Commission playing a large role in this funding. 14%, 94 mentions, was from Asia with the Japan Society for the Promotion of Science and the Ministry of Education in Singapore playing large roles. Also, Canada's Social Sciences and Humanities Council funded 26 or roughly 4% of funding acknowledgements. Israel via the programs LINKS, I-Core, and the Israel Science Foundation had 20 papers acknowledging awards or 3% of funding, and finally, Australia's Australian Research Council had 2.4%, 16 mentions. It is interesting to note that while the FIE conference appears to have a similar rate of international funding as the two Learning Science conferences. The FIE conference has strong participation from Brazil that was not seen in the learning science conferences.

VII. Discussion of Error

Due to the extensive cleaning for both the author data and the funding data that occurred as part of this analysis, it should be assumed that there is error in these reported values. An attempt was made to estimate the error in the data by completing a randomized sample recheck of a small number of papers. The function Randbetween was used in Excel to identify a set of papers which would be rechecked for correct compilation of author and funding data. 30 papers were checked for funding mistakes. There were zero errors identified in the coding of whether the paper had funding, if the source of funding was NSF, international, or local. This puts the error in funding at less than 1/30, 3%, by paper or 1/120, 0.8%, by each code category. Similarly 30 papers were checked for author mistakes. In this there was one error identified in that an institution for one of the papers was missed. Again this is 1/30, 3% error, or 1/152, 0.6%, by entries of authors and institutions on these 30 papers. This error was corrected in the data and the overall error was deemed acceptable. Because FIE papers do not have a standardized display for author information, it was not surprising that error was found in this part of the analysis. Use of a cover page with agreed upon author information, placement, and style would have simplified this analysis greatly and reduced analysis error.

VIII. Conclusions & Future Work

To provide insight into the FIE community's history, a text-based analysis of all FIE proceedings between 2010 and 2019 is provided that identifies patterns of author and institutional collaboration on FIE papers, research and disciplinary themes from paper titles, and the sources of acknowledged funding.

Results from the author analysis suggest that research productivity may be enhanced through more inter-institutional collaboration since relatively few papers leverage these kinds of partnerships. These results also suggest that there are research areas/disciplines of interest to FIE constituents that have been less investigated in the past ten years and these areas might be open for study. For example, there was relatively less work found at the senior undergraduate and graduate levels than at the introductory level, and relatively little work that focused on biomedical, chemical, and industrial engineering. Engaging with these faculty could broaden FIE participation and improve the instruction in these courses.

Results on funding data show that there are many programs where FIE participants have found funding. However, it was observed that the work presented in FIE shows a much lower funding rate than the PERC community at 34% of papers acknowledging funding as compared to 67%. However, it does show a larger funding rate than the ICLS and CSCL proceedings which had 26% of these papers acknowledge funding. The NSF is the most common source of funding to this community with 53% of all funding acknowledgments. There are many programs and division that provide this funding from three main directorates at NSF: Education and Human Resources; Engineering, and Computer and Information Science; and Engineering. In addition to NSF, there are many sources of funding from agencies outside the U.S. that in total account for 30% of the funding to this community.

These data also show that FIE has a diverse community across the U.S. and abroad. There were over 1500 unique institutions from which more than 7000 different authors contributed work from 2010 to 2019. In addition, there is an increasing trend in larger, and in multi-institutional, collaborations. While the community is broad, it should be noted that much of the FIE authorship comes from large universities with well known engineering or technology programs (see Table II). This suggests these places are key to community engagement.

With the Covid-19 pandemic still ongoing and recovery of research and instruction an aspiration, it may be interesting to follow this data over in the next few years to see if there is impact on funding and research outputs visible in the FIE proceedings. While it is hoped that the ongoing efforts by community members to maintain productivity and student support, will mitigate issues to the extent that nothing can be seen in the publication record; it may be of interest to consider this analysis over the next few years.

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