Research Areas and Funding Trends through NSF Funded Awards in Engineering Education between 2012 and 2022

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Abstract— This full research paper describes the research areas and funding trends through NSF funded awards in engineering education. Engineering Education Research (EER) has traditionally spanned fives main areas of research [1] including engineering learning mechanisms, engineering learning systems, engineering epistemologies, engineering assessment and engineering diversity and inclusiveness as written by the original author. However, in a recent online content analysis of the U.S. institutions that offer engineering education academic programs or serve as engineering education research centers and research groups, we found additional areas that are missing in research. These gaps were mapped between the existing research areas and the ones advertised on institutional websites. This study considered the National Science Foundation (NSF) funded awards from the Division of Engineering Education and Centers (EEC) publicly available on the website which listed about 752 projects with a starting date between 2012 and 2022. The list of these awards was extracted from the website on August 25, 2022. These awards were mapped onto five research areas to aid in identifying unexplored and underexplored research areas. The funded awards were divided into different categories based on the labelled titles of funded awards by NSF. Additionally, this study explored the universities/organizations that had the highest number of funded awards and the highest amount of funding within this timeframe. The findings suggest a dire need for research in epistemologies, learning mechanisms, and assessments in engineering education. It sheds light on the uneven distribution of funding trends in the field of engineering education. This exploratory study builds upon the significance of the research areas in EER and funding trends for different institutions in engineering education. The paper concludes with a call for the engineering education research community to discuss ways to incorporate more research in the gap areas, equitable funding, as well as consider the possibilities for future work in engineering education.

Keywords—engineering education, research centers, learning systems.

I. Introduction

Engineering Education is a research discipline that blends engineering methods with social sciences and humanities to facilitate learning of students in acquiring engineering knowledge [2]. It puts emphasis on teaching methodologies [3], [4], assessment methods [5], learning theories and evidence-based practices [2] for engineering education and workforce ecosystems. It is a field of research that focuses on applying engineering education research to real-world learning and professional scenarios by providing evidence-based, hands-on experiences [6], incorporating technologies for instruction and learning in the classroom [7], [8], [9], [10], [11], improving engineering assessment [5], [12], promoting student-centered learning [13], and equipping them professionally [14].

In the literature, the field of engineering education is categorized into five broad research areas [1]. These areas include engineering: epistemologies, learning mechanisms, learning systems, diversity and inclusiveness, and assessment. These areas are briefly described below:

- *Engineering epistemologies:* This research area studies engineering knowledge and thinking. It seeks to understand how this knowledge is shared with the learners, what constitutes knowledge, and how it can be improved. One important aspect of engineering epistemologies is that it can consider contextual elements (social, technical, and ethical) that contribute to engineering knowledge and learning.
- *Engineering learning mechanisms:* This research area studies the learning process when acquiring, understanding, comprehending, and engineering content and materials. It makes use of social, emotional, visual, and cognitive engagement of learners as it pertains to global competencies, affective competencies, engineering fundamentals, computational thinking, leadership, innovation, and entrepreneurship, among others.
- *Engineering learning systems:* This research area builds upon instructional learning theories and uses the evidence gathered from its research to inform the development of programs, frameworks, and projects that inform effective and transformative pedagogical practices and learning strategies.
- *Engineering diversity and inclusiveness:* This research area focuses on the intellectual and societally diverse engineering communities. It aims to build effective, evidence-based strategies for including underrepresented students and faculty, understand their challenges, and broaden their participation in engineering.

- *Engineering assessment:* This research area includes how assessment can be used as a research tool by which criteria, rubric, tools, and techniques are developed, validated, and used. It puts more responsibility on educators to design evidence-based assessments for students and situates researchers as gathering evidence into frameworks for transformative student learning.

II. Motivation

This continuing exploratory study aims to build upon an earlier online content analysis [15] about the research areas in engineering education communicated on institutional websites. In the study [15], seven U.S. institutions of higher education that have engineering education research centers were studied and their research areas (as mentioned on their institutional websites) were mapped to the five primary research areas in engineering education research. The results of the study [15] indicated a dire need for research in the areas of engineering epistemologies and engineering diversity and inclusiveness. The authors wondered what specific research areas in engineering education has the National Science Foundation (NSF) funded thus far.

For this work, we focused solely on projects funded by NSF listed under the Division of Engineering Education and Centers (EEC). The aim of this exploratory study was to expand upon prior work and investigate the categories, research areas of funded projects, funded universities, and amount of funding to understand any patterns that exist in funding (or not) within engineering education research.

III. Methodology and Method

The study was based on a pragmatist research design paradigm in which the data extracted from NSF website was collected. The information available has been collated and interpreted to give researchers an understanding of the landscape of funding, its trends, and inherent areas of importance deemed by the funding agency. Researchers in the field of engineering education may work in a research area where they may not know if their work will be funded or not. As such, the authors' position that uncovering funding areas and trends can help provide awareness of the current funding situation to researchers and graduate students in this field.

IV. Research Approach and Design

As mentioned above, this exploration is a continuation of a previous study [15] in which seven U.S. institutions that have engineering education research centers were studied, as mentioned in Table 1. To learn more about the research areas and current research carried out by scholars within Ph.D. programs in engineering education, this research extracted the list of National Science Foundation (NSF) funded awards from the Division of Engineering Education and Centers (EEC) publicly available on the website with the start date of September 01, 2012, to August 24, 2022.

Table 1

List of Engineering Education Centers offered in U.S. Institutions [15]

University	Center	College
University of Nebraska-Lincoln	Engineering and Computing Education Core (ECEC)	College of Engineering
The University of Texas at Austin	The Center for Engineering Education	Cockrell School of Engineering
University of Texas at El Paso	Engineering Education and Leadership	College of Engineering
University of St. Thomas	Center for Engineering Education	School of Engineering
University of Tennessee, Knoxville	Tickle College of Engineering	Tickle College of Engineering
Tufts University	Center for Engineering Education and Outreach	School of Engineering
University of Kentucky	College of Engineering	College of Engineering

This timeframe was selected because the list that was present on NSF Website included the research projects in that time frame during the time of this exploratory study. The downloaded Excel sheet consisted of 752 projects. All the projects were mapped into five engineering education research areas. To support identification and explanation of the research areas, keywords based on the Engineering Education Research Taxonomy (Version 1.3, September 17, 2021) [16] was also used as a cross-reference. Categorization soon followed. There were two other columns titled 'Organization' and 'Awarded Amount to Date' that were considered to run frequency counts and summation of funded amounts.

V. Research Question

The primary research questions considered in this study are:

1. What are the top research areas and categories (as per the titles) of the funded awards under the Division of Engineering Education and Centers (EEC) by NSF between the last amendment dates of September 01, 2012, to August 24, 2022?
2. Which U.S. institutions/ organizations had the greatest number of funded awards under the Division of Engineering Education and Centers (EEC) by NSF between the last amendment dates of September 01, 2012, to August 24, 2022?
3. What is the highest amount of funding received by the U.S. institutions or organizations under the Division of Engineering Education and Centers (EEC) by NSF

between the last amendment dates of September 01, 2012, to August 24, 2022?

VI. Research & Discussion

According to NSF's website, EEC aims to work for future engineers and towards new technologies 'through transformational center-based research, research in education and inclusion, and research opportunities' for both students and faculty members [17]. Based on EEC's purpose, it is divided into four main clusters:

- Broadening participation in engineering
  - Aims to address structural inequities and biases, and to foster inclusion within engineering
- Centers and Networks
  - Aims to solve engineering grand problems through innovation and multidisciplinary collaboration
- Engineering Education
  - Aims to explore career pathways, and research on how people become engineers
- Engineering Workforce Development
  - Aims to provide hands-on research experiences and launch initiatives

The programs and initiatives included in the above-mentioned clusters within EEC are described in Table 2 below.

Table 2

Programs within four clusters in EEC

Engineering Education Centers	
Broadening participation in engineering	• Broadening Participation in Engineering (BPE) • Engineering Research Initiation (ERI) • Faculty Early Career Development Program (CAREER) • NSF INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science)
Centers and Networks	• Gen-4 Engineering Research Centers (ERC) • Industry-University Cooperative Research Centers (IUCRC) • Network for Computational Nanotechnology (NCN) • Planning Grants for Engineering Research Centers (ERC)
Engineering Education	• Engineering Research Initiation (ERI) • Faculty Early Career Development Program (CAREER) • IUSE / Professional Formation of Engineers: Revolutionizing Engineering Departments (IUSE/PFE: RED)
	• Research Initiation in Engineering Formation (RIEF) • Research in the Formation of Engineers (RFE)
Engineering Workforce Development	• Non-Academic Research Internships for Graduate Students (INTERN) Supplemental Funding Opportunities • Research Experiences for Teachers (RET) in Engineering and Computer Science • Research Experiences for Undergraduates (REU)

The research findings for this exploratory study were divided into two main categories. The first considered the research areas and expanded on the categories as per the labeled titles of NSF funded awards within EEC. The second considered the U.S. institutions and/or organizations that had the highest number of awards funded by NSF. This was followed by the highest amount of funding received by U.S. institutions and/or organizations within EEC.

The funded awards have been divided into five award instruments as mentioned in the Excel sheet downloaded from NSF website. These are reflected in Table 3 below.

Table 3

Categorization into Research Areas

Award Instrument Type	**#**
Standard Grant	547
Continuing Grant	176
Intergovernmental Personnel Award	4
Fellowship Award	1
Cooperative Agreement	23
Uncategorized	1
Total	**752**

A. Research Areas & Categories for NSF funded awards

The funded awards have been divided into five main research areas including engineering learning systems, engineering diversity and inclusiveness, engineering learning mechanisms, engineering assessment, and engineering epistemologies [1]. As summarized in Table 4, the funded projects by NSF under the division of EEC as listed on their website and their respective research areas are as follows:

Table 4

Categorization into Research Areas

Category/Research Areas	**#**
Engineering Learning Systems	324

Engineering Epistemologies	50
Engineering Learning Mechanisms	76
Engineering Assessment	78
Engineering Diversity and Inclusiveness	220
Other	4
Total	**752**

The 'Other' category includes those awards that were labelled as 'Intergovernmental Personnel Award' under 'Award Instrument' column in the Excel sheet but did not include any other information making it difficult to properly place them. Engineering epistemologies can be clearly seen as an underexplored and less funded research area in Table 4. This finding resonates with previous studies [15], [18] that also indicated low attention being given to this research area in engineering education. As shown in the above table, the top three areas include engineering learning systems (324), engineering diversity and inclusiveness (220) and engineering assessment (78).

The engineering learning systems, which is the most funded area (324 projects) of research by NSF include structures that are brought together to formulate frameworks, programs, and projects. It aims to promote research activities and ensure that the people involved in these projects will have a better understanding of the practices in engineering and will do research in those areas under expert leadership. This research area considers instructional culture, institutional infrastructure, and organizational schemas to create a better working and learning environment for engineering students. According to NSF's Strategic Plan for FYs 2018 to 2020, there were three goals to be achieved. One of the goals was to expand knowledge in science, engineering, and learning [19]. One of the objectives in this goal was to advance knowledge through investments in ideas, people, and infrastructure. The funding of REU, RET, IUCRC sites, and engineering research centers as shown in Table 3 reflects the fulfillment of this goal but also indicates the interest that NSF takes in funding these projects.

EEC have funded awards that belong to different categories. These categories are indicated as a prefix to the title for most of the awards. Across all research areas, the types of grants were tabulated, and Table 5 shows a breakdown by categories of the funded awards. These numbers have been collated by counting the number of each category in the list of funded awards.

Table 5

Overall Breakdown of Engineering Education Research

Serial No.	Categories within EEC	Count
1	Broadening Participation in Engineering (BPE)	11
2	Faculty Early Career Development Program (CAREER)*	30
3	Collaborative Research	99
4	Design and Development	8
5	Engineering Research Centers	27
6	Industry-University Cooperative Research Centers Program (IUCRC)*	154
7	Industry-University Cooperative Research Centers Program (IUCRC) Planning Grant	16
8	IUSE / Professional Formation of Engineers: Revolutionizing Engineering Departments (IUSE/PFE: RED)	12
9	Planning Grant	47
10	Research/Research Initiation	63
11	Research Experiences for Teachers (RET) Site	47
12	Research Experiences for Undergraduates (REU) Site	145
13	Research in the Formation of Engineers (RFE)	4
14	Workshops	13
15	Other**	76
Total		**752**

* Indicates that these programs are NSF-wide programs [20]
** Includes those funded awards with no label/category indicated

It should be noted that there were about 17 funded awards under the category of REU Sites that were additionally titled Collaborative Research in the extracted excel file from NSF website. Hence, they were grouped under REU Sites. The highest number of awards were in the category of Industry-University Cooperative Research Centers Program (154) followed by Research Experiences for Undergraduates (REU) Site (145) and Collaborative Research (99). The IUCRC funded awards consists of projects in different phases (Phase I, II & III). All these projects have been accumulated in this category except for the IUCRC Planning Grant that has been considered as a separate category. The academic institutions that have been funded in this category (IUCRC) include, in no order, Purdue University, Virginia Tech, Worcester Polytechnic Institute, The Pennsylvania State University, Colorado School of Mines, Georgia Institute of Technology, University of Florida, Case Western Reserve University, Washington State University, University of California San Franciso, Texas A&M University, Arizona State University, Columbia University, and Indiana University amongst others. The three categories with lowest funded awards were Research in the Formation of Engineers (RFE) (4), Design and Development (8), and Broadening Participation in Engineering (BPE) (11).

As per NSF's website, it offers research opportunities for researchers to broaden participation in engineering and promote equity through research, planning and conference grants, mentoring hubs, and centers [21]. This study found that specifically BPE funded awards were 11 out of 752 projects. However, there were projects in other categories (besides BPE) where the focus was to uplift underrepresented minority groups, to promote equity, and support women in engineering. This is

also evident by looking at Table 2 in which diversity and inclusiveness as a research area is second most funded in the list of funded awards by NSF during the years 2012 and 2022. This research area is a strategy to promote and advance scientific research, learning and innovation by providing equal opportunities [22]. Ventures like NSF Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES) [23] are also indicative of the importance that this funding agency puts to promote inclusion and equity.

Considering Section B in research findings, it is seen that the Industry-University Cooperative Research Centers Program (IUCRC) by NSF, which is a foundation wide activity/program, has the highest number of funded awards (154). If the IUCRC Planning Grants are also considered, then the number goes even higher. The mission of IUCRC is to bring together innovators in industry, academic institutions, and government agencies to collaborate in making high-impact breakthroughs in research, foster a global leadership in engineering innovation, and mentor an engineering workforce that can be prepared for the future challenges [24].

It can also be seen that 'Collaborative Research' is also included as one of the top listed funded awards. The idea of collaborative research is to involve researchers in different institutions who are working on a similar project. This reflects an effort by NSF in improving collaborative research which may include cross-disciplinary and inter-disciplinary research. Additionally, engineering education as a discipline offers fluidity and acceptance from all engineering backgrounds [25]. As mentioned earlier, it should be noted that the awards included in the category of Research Experiences for Undergraduates (REU) Sites also had about 17 awards that were labelled as 'Collaborative Research'. This type of research brings in innovation and ideas from multiple perspectives and may lead to convergence research. In the national report published by NSF titled "Leading the World in Discovery; and Innovation; STEM Talent Development; Delivery of Benefits from Research", it mentions about the case of urgency to do convergence research, quoting it as a 'potent force', to bring together a combine array of perspectives and techniques to find solutions to challenging research questions [26]. Convergence research is also considered as inter-disciplinary research. It appears that NSF is promoting collaborative research as a response to this urgency.

In recent years, the demand for STEM capable workers has continued to increase [22], [23], [24, p. 13, p. 24]. However, it is surprising that only about 11 of 752 awards specifically focused on workforce development. The projects belonging to CAREER category (30 funded awards) also indicate NSF's interest in funding STEM Workforce by supporting early career faculty members who show potential to serve in an academic role by leading in innovation and research [25]. It is also worth noting that only a few awards (less than ten) were specifically focused on student success, well-being, mental health, and ethics in engineering. This indicates a dire need to put emphasis on these categories in engineering education research.

B. Name of U.S. Institutions/Organizations funded and Amount of Funding by NSF

The downloaded Excel file from NSF website had information about the U.S. institution or organization name for each funded award. These awards have been given to two hundred and ten (210) U.S. institutions/organizations. The name of the U.S. institutions that received ten or more awards have been listed in Table 6.

Table 6

Select U.S. institutions and number of NSF funded awards from September 1, 2012, to August 25, 2022

Serial No.	University/Institution	# of awards
1	Virginia Polytechnic Institute and State University	28
2	The Pennsylvania State Univ University Park	23
3	Purdue University	23
4	Arizona State University	18
5	The Ohio State University	17
6	University of Illinois at Urbana-Champaign	16
7	University of Florida	14
8	Georgia Tech Research Corporation	13
9	Texas A&M University	12
10	Iowa State University	12
11	Florida International University	12
12	North Carolina State University	12
13	University of Texas at Austin	11
14	Clemson University	10

The top three U.S. universities that had the highest number of funded awards are Virginia Polytechnic Institute and State University followed by the Penn State University and Purdue University as shown in the above table. Out of the total U.S. universities/organizations (210) that secured funding from NSF, about 58% of these funded awards went to R1 Doctoral Universities with a 'Very High Research Activity' as per Carnegie Classification of Institutions of Higher Education [32]. Out of these R1 Doctoral Universities, 77% of these awards were awarded to 'Public' universities while the other 23% were secured by 'Private not-for-profit' universities as per Carnegie Classification of Institutions of Higher Education. The amount of funding (in US dollars) that the U.S. institutions or organizations received has also been collated from the excel sheet. The universities/organizations that received most funding to the date for the awards have been listed in Table 7.

Table 7

Highest funding amount received by universities/organizations from September 1, 2012, to August 25, 2022

Serial No.	University/Institution	Count	Amount Funded
1	Purdue University	23	$63,117,715
2	North Carolina State University	12	$40,560,524
3	University of Illinois at Urbana-Champaign	16	$40,424,786
4	University of Texas at Austin	11	$39,798,386
5	University of California-Los Angeles	4	$37,938,769
6	Arizona State University	18	$37,895,393
7	Rice University	5	$30,518,529
8	Georgia Institute of Technology	13	$29,390,792
9	Texas A&M University	12	$27,351,718
10	American Society for Engineering Education	6	$24,379,018

It can be observed that the highest amount of funding from September 1, 2012, till August 25, 2022, has been awarded to Purdue University followed by North Carolina State University and University of Illinois at Urbana-Champaign. The amount of funding for all 752 awards by NSF in the excel sheet for a list of funded awards between 2012 and 2022 totaled $695,416,064. It should be noted that these funded awards had varied start dates. There were four projects that had their beginning date in 2012 and were 'cooperative agreements' awards. However, the statistics indicate that there is still an uneven distribution of awards and funding as some universities receive significantly higher amounts of funding than others. Funding awarded was as low as $20,000 to the University of Memphis (data not included in Table 7). It is also worth noting that universities like Purdue University and Virginia Tech, being pioneer universities in engineering education, have higher number of awards while other universities with increasing commitments to and/or departments of engineering education like Georgia Tech and University of Florida are also climbing up the ladder in engineering education research.

It is important for researchers to pay attention to the broader research areas, and funding distribution and dissemination within engineering education research. This is because as faculty, scholars, and graduate students work on projects that belong to these research areas and categories, they should be aware of the funding trends as they anticipate funding from funding agencies.

VII. Limitations

There were a few limitations in this study. Firstly, the data that was extracted from EEC on NSF website belonged to a specific time frame. The breakdown of research areas identified in this research is reflective of this data only. However, the focus was on EEC as these projects may primarily derive from engineering education researchers and may be a better representation of the research and funding trend in this field. The funding awards varied in their start dates, and the funding amount reflects that amount awarded from the start date till August 25, 2022. The authors recognize that there are other divisions within NSF and other federal agencies that could be further explored. Future work will explore funding in other agencies and divisions.

VIII. Conclusions & Future Work

In this online content analysis, the data was extracted on August 25, 2022, from NSF website for a list of funded awards between September 01, 2012, to August 24, 2022. The list consisted of about 752 projects that were put together and mapped to five research areas within EER. This study identified the prevalent research areas of awards, most funded categories within EEC, universities/organization with highest number of awards, and highest amount of funding to universities/organizations in engineering education research in extracted data. The goal of the study was to understand the trends that exist in funding within EER by NSF as a highly competitive agency.

The top two funded research areas included engineering learning systems, and engineering diversity and inclusiveness. The top three categories in the funded awards included Industry-University Cooperative Research Centers Program (IUCRC), Research Experiences for Undergraduates (REU) Sites and Collaborative Research. Additionally, Virginia Tech, Penn State, and Purdue University had the highest number of awards. The most funding was secured by Purdue University.

The overall results indicated a lack of funded awards that fell under the category of engineering epistemologies, engineering mechanisms and engineering assessment. It is pertinent to draw focus and attention to other engineering education research areas. This is because engineering epistemologies offer how the knowledge and teaching of engineering is communicated and shared with students. It reflects how knowledge can be applied in real-world scenarios within social contexts to approach and solve problems. Engineering assessment should be a more funded research area as it is directly linked with the pedagogical practices and how performance should be measured in the classroom. Similarly, engineering mechanisms also directly correspond to how teaching practices and methodologies can be made effective to improve students' learning and understanding of engineering concepts. Hence, more funding should be granted to these research areas.

This research study gives faculty members, graduate students and scholars, departments, and research centers in the

discipline of engineering education the opportunity to determine the funded research areas and work on specific problems that support engineering knowledge and learning within engineering education research. It is a source to identify the lacking research areas in engineering education and how more work can be done in those areas. Future work includes considering other divisions within NSF, widening the time frame for data collection, making policy recommendations to improve research in underexplored research areas, and developing strategies to support those areas.

IX. Declaration

Author Contributions

Gadhaun Aslam conceptualized the idea, conducted data collection, data analysis, interpreted results, and wrote the article. Dr. Idalis Villanueva Alarcón conceptualized the idea with the first author and refined the research idea, supervised the research and data analysis, assisted with the interpretation of results, and contributed to editing and direction of the article.

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