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A Content Analysis of How STEM Education Researchers Discuss the Impact of their Publicly-Supported Research*

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Impact is a topic of interest among a wide range of stakeholders interested in engineering workforce development but is one in which there is a dearth of scholarship. While existing literature includes two dimensions of research impact (scientific, and societal), this qualitative study proposes and focuses on the third dimension—contextual impact. Using Toulmin's Model and the *Common Guidelines for Education Research and Development*, this study uses content analysis to explore how researchers on National Science Foundation-funded STEM education R&D projects talk about the impact of their work in abstracts ($n = 155$) with an explicit impact section; special attention is given to engineering education research. Findings reveal eight claims that are commonly discussed when Principal Investigators articulate research impact; two themes relate to how their claims are supported. The findings also indicate that the discipline associated with the study and the project focus has more to do with the types of impact PIs claim than the amount of funding awarded to the project. The proposed *SCS Impact Framework* resulted from identifying the points of alignment between PIs' perspectives on impact and existing literature. This conceptual lens describing impact in this context is useful for researchers, practitioners, and policymakers around the world interested in the scientific, contextual, and societal dimensions of engineering education R&D.

Keywords: impact; engineering education research; STEM education; National Science Foundation

1. Introduction

The most targeted investments in workforce development are in federal programs designed to increase knowledge in the STEM fields and the attainment of STEM undergraduate and graduate degrees [1]. In 2010, thirteen government agencies administered over $3 billion to support more than 200 STEM education programs across educational levels and in informal learning environments [2]. Of the thirteen agencies, the National Science Foundation (NSF) received the most funding ($1.1 billion) and administered 37 programs, the second largest number of STEM education programs within a single agency [2, p.10]. Although NSF has a relatively small budget in comparison to other federal funding agencies in the United States, it is the funding source for approximately 24% of all federally supported research projects conducted in America's colleges and universities [3].

Although NSF has well-established criteria for selecting which proposals to fund and standard processes for sharing project-related updates during the grant lifecycle, a consistent way to determine the extent to which federally funded projects are making a difference is lacking [4–7]. The current reporting mechanisms capture individual project outcomes but do not facilitate comparisons of impact across projects or over time. Without a way to characterize and ultimately evaluate the impact of NSF-funded research and education projects, it will continue to be difficult to determine the extent to which NSF's investments in undergraduate engineering education are affecting the quality of engineering education or the quantity of engineering graduates in the U.S.

Over the last decade, frameworks have been developed to characterize the impact of research in domains, such as health science research [9, 11], arts & humanities research [12], and higher education, in general [13]. These frameworks help provide a shared language and understanding of impact as researchers communicate among themselves and share impact insights with those outside the community. However, within the context of engineering education, there is no shared vocabulary for discussing the impact of research or a framework that characterizes the impact of federal investments in undergraduate engineering education research. This study begins to add to the body of knowledge by exploring how researchers on NSF-funded undergraduate STEM education R&D projects talk about the impact of their work; particular emphasis is given to engineering education research.

2. Literature review

The following section includes background information about how impact is defined in this study, highlights of existing research focused on this topic, and the gap this study seeks to fill.

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2.1 Defining "research impact"

One problem with studying impact is that there is no definitive meaning of the term, and it is oftentimes used interchangeably with other terms (e.g., outputs, third steam activities) [14, 15]. Each group's definition of impact is often influenced by motivations and priorities of key factions, which is why impact varies according to these three principal groups [14]. Existing literature includes two dimensions of research impact: scientific [16–19] and societal [16–18]; however, the authors of this study argues that there should be a third dimension. In short, research impact has three dimensions: scientific, societal, and contextual (see Fig. 1 for a definition of each). These three dimensions can be understood together in terms of their order of impact. Societal impact is an example of a first order impact, because the extent of the results is limited to conversations taking place among scholars with similar interests. Once the execution of the methods or the outcomes of a study begin to influence the context of interest, the impact of the study is extending beyond conversations among scholars; this is an example of a second order impact (i.e., contextual impact). Finally, the aggregate influence of a particular line of research on national priorities (i.e., societal impact) is a third-order impact. (Contextual impact is proposed, because the author argues that it helps bridge the gap between scientific and societal impact.)

All three dimensions of research impact are important for studying publicly-supported research and are included in what is meant by the use of the term "impact" and "research impact" in this study. Although many scholars tend to focus on the scientific impact of research (especially with regard to publications), there is a need for broader perspectives of impact that allow for a more diverse range of research outputs [20]. While the results of this study may include some insights on the scientific dimension of research impact in the context of interests, its primary focus is on the societal and contextual impact of undergraduate engineering education research since these are dimension that are severely understudied.

2.2 Existing studies on impact in STEM education

London and Cox [71] states that studying the impact of research is difficult for three main reasons: (1) issues associated with attribution; (2) issues associated with collection and analysis; and (3) issues associated with differences in interpretation. One of the main ways researchers study impact in STEM education is through the guidance of NSF's definition of "Broader Impacts" [21, 22]. NSF's Broader Impacts concerns the potential to positively influence society [23] and has been the standard for evaluating lasting change since 1997. One study found that NSF PIs were more likely to have Broader Impacts statements around increasing public scientific literacy, public engagement in science and engineering, and addressing issues of developing a diverse STEM workforce [21]. Researchers heading a project called, *Increase the Impact*, aim to improve teaching in undergraduate STEM education, focusing on propagation of educational innovations [24]. In order to investigate ways to promote the widespread use of effective teaching methods, these researchers surveyed PIs from the NSF "Transforming Undergraduate Education in STEM" (TUES) and found that PIs viewed propagation of their innovations primarily through one-way dissemination, such as publications [25]. Corresponding with this finding, the *Increase the Impact* team suggests there are four common mistakes grant projects and PIs make when propagating their educational innovations: (1) concentrating on dissemination solely through publications, (2) ignoring the literature on impact and adoption of teaching innovations, (3) focusing on product development while ignoring others factors that spread innovations, and (4) promoting

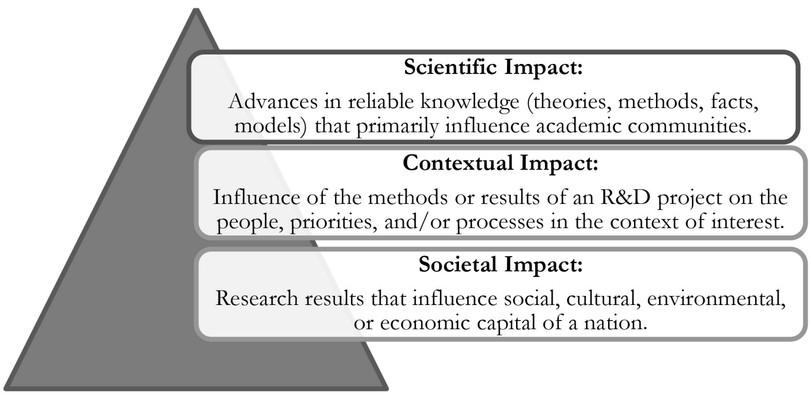

Fig. 1. Defining the Three Dimensions of Research Impact.

adoption of educational innovations only at the end of the project [26]. In response, the *Increase the Impact* team proposed a model for successful propagation of STEM education innovations that identifies three key promotional activities: (1) interactive development, (2) interactive dissemination, and (3) support of adopters. The current study extends this body of literature on STEM education by focusing particularly on engineering education research. Moreover, this study seeks to provide a framework for research impact this is not limited to the definition of a single funding agency and will be useful for a variety of stakeholders.

2.3 The research gap

While researchers in different communities that rarely connect have conducted the existing studies on research impact, there are consistencies in the dimensions of impact observed as well as in the approaches used to characterize and/or measure impact. In multiple instances, the process for developing a framework of research impact in a specific domain begins with an exploratory approach, and then the framework is validated using quantitative and/or qualitative methods [4, 11, 12]. Despite these elements of continuity, there is a gap that still exists in the literature. Within the context of engineering education, there is no shared vocabulary for discussing the impact of research or a framework that characterizes the impact of federal investments in undergraduate engineering education research. This study seeks to begin to fill this gap in the engineering education literature by exploring the perspectives of two key stakeholders (i.e., Principal Investigators [PIs] and NSF Program Officers) on what it means for a federally-funded STEM education project to have impact. An understanding of how these key stakeholders talk about impact is an important step toward the development of a conceptual framework that characterizes the impact of NSF investments in undergraduate engineering education R&D projects.

3. Guiding frameworks

Toulmin's Model [27] and the *Common Guidelines for Education Research and Development* [28] (referred to hereafter as the "Common Guidelines") are the two frameworks that will guide the data collection and analysis in this study. The *Toulmin Model* (also referred to as the *Toulmin Scheme*) [27] describes the process of defending a claim against a challenger and is a pattern that is largely independent of a particular field. This model is applicable to this study, since the primary data source that will be used in this study includes research project abstracts, narratives that include the claims researchers are making about the impact of their studies. The *Common Guidelines* [28] were developed to be used for organizational and clarification purposes by decision makers in federal agencies and grantees seeking federal funding [28]. When integrating the elements of *Toulmin's Model* [27] and the *Common Guidelines* [28], an adapted model emerges that fits the context of studying the arguments surrounding federally-funded STEM education R&D projects.

4. Research questions

The purpose of this study is to (1) explore how PIs on NSF-funded undergraduate STEM education R&D projects talk about impact and (2) compare PIs' perspectives on impact with the perspectives of Program Officers who oversee NSF's STEM education R&D programs. The following research questions guided this study:

1. What is a meaningful description of the impact of NSF investments in undergraduate STEM education R&D projects, based on PIs' perspectives?
2. What claims do PIs make about the impact of their NSF-funded projects?
3. How do PIs' perspectives of impact align with existing frameworks in the literature to form a conceptual framework that describes the impact of public investments in undergraduate STEM education R&D?

5. Methodology & guiding frameworks

This study utilized an exploratory approach where qualitative (text-based) data were collected and analyzed. Since there is little literature on research impact, in general, and this topic has not been explored extensively in the context of undergraduate engineering or STEM education research, an exploratory, qualitative study approach was an appropriate strategy for the first phase [29]. Abstracts about NSF-funded undergraduate STEM education projects are the data that were used in this study. *Mixed purposeful sampling* [30 as cited by 31, p. 237] was used to select abstracts for analysis. *Qualitative content analysis* [32–34] is the analytic technique used in this study.

5.1 Data collection

One of the largest Division of Undergraduate Education (DUE) programs was entitled, "Transforming Undergraduate Education in STEM" (TUES). Its predecessor program was called, "Curriculum, Course, and Laboratory Improvement" (CCLI). Periodically, DUE hosts a conference that all PIs on the program's active grants are encouraged to attend. The CCLI/TUES PIs conference reports from the most recent three consecutive PI conferences are publicly available online [35–37] and were downloaded in Fall 2013. The project abstracts in these three reports are the population of data from which this study's sample data was selected to address the research questions proposed in this study. Each report includes the abstracts of R&D projects presented at the conference. With little variations across reports, each abstract includes two major sections. One section includes basic project information: PI(s) name, Institution, Project Title, Project Number, Project Type, Target Discipline, and Focus. The CCLI/TUES program primarily funded four types of R&D projects. The four main project types are (1) Type 1—Exploratory, (2) Type 2—Expansion, (3) Type 3—Comprehensive, and (4) Central Resource Project. (See Section C of the 2010 TUES program solicitation online for detailed descriptions of the project types.) The eight STEM disciplines funded by DUE are (1) Biological Sciences, (2) Chemistry, (3) Computer Science, (4) Engineering, (5) Geological Sciences, (6) Mathematics, (7) Physics/Astronomy, and (8) Social Science. The five project foci specified in the CCLI/TUES solicitation are (1) Creating Learning Materials and Strategies, (2) Implementing New Instructional Strategies, (3) Developing Faculty Expertise, (4) Assessing and Evaluating Student Achievement, and/or (5) Conducting Research on Undergraduate STEM Education. In addition to basic PI and project information, the abstract template provides space for PIs to add content corresponding to six topics: goals/goals and intended outcomes, methods/methods and strategies, evaluation/evaluation methods and results, dissemination, impact, and challenges. This "impact" section is the source of the text analyzed in this study.

5.2 *Rationale for data source*

There were many reasons for using the abstracts in the CCLI/TUES PI conference reports as data (many of which are pragmatic, but some are more meaningful). Since the reports include abstracts of over 1,000 STEM education R&D projects funded by DUE, they provided a generous amount of data from which to sample. Additionally, the reports correspond to all of the CCLI/TUES PI conferences that have occurred over a five-year period; this presents a longitudinal perspective on the central topic of research impact. The last pragmatic reason is that this data is conveniently available online, and this translated to no delay in collecting data.

This is an appropriate data source given that this study focuses on engineering education research, and the CCLI/TUES program was the largest funder of engineering education research. Moreover, projects funded by the CCLI/TUES program focused on a wide range of needs and challenges that exist across undergraduate STEM education; as a result, insights about impact that result from this study have the potential to be just as broad in their applicability. Furthermore, there is an alignment between the project types, abstract elements, and the frameworks guiding this study. This alignment helped with data analysis and interpretation. Also, the abstracts are written by the PIs on CCLI/TUES projects and, as a result, provide the data that will answer the research question (on how PIs discuss the impact of their research). Moreover, the "Impact" section of the abstract includes PIs' perceptions of the *realized* impact of their project, rather than the proposed impact described in grant proposals. Impact narratives in PI conference reports are one of the few instances where the impact of a project is explicitly documented and, thus, available for study. Finally, and possibly most importantly, project abstracts are the primary source of public information about NSF-awards.

5.3 *Sampling*

Mixed purposeful sampling [31, 38] was used to select the abstracts analyzed in this study. The two sampling strategies used are maximum variation sampling and homogeneous sampling [31, 38, 39]. Maximum variation sampling is purposefully selecting a wide range of cases. For the purposes of this study, this meant selecting abstracts across conference years, project types, project foci, and STEM disciplines. The reason for sampling across STEM disciplines was because engineering is rarely discussed in isolation. On the other hand, since the focus of this study is engineering education, homogeneous sampling was also used to select a smaller set of abstracts in which Engineering was the target discipline. In total, the sample included approximately fifteen percent of the total abstracts (155 of the 1029 abstracts). Ten percent of the abstracts were selected using maximum variation sampling. An additional five percent of the total abstracts were selected based on the homogeneous sampling strategy. Although the objective was to review fifteen percent of the total abstracts, the ultimate number of abstracts was determined by the point of saturation, the point at which no new or relevant information emerged as a result of analyzing more data [39].

5.4 *Theoretical lens*

5.4.1 *Toulmin's model*

The *Toulmin Model* (also referred to as the *Toulmin Scheme*) [27] describes the process of defending a claim against a challenger and is a pattern that is

Table 1. Alignment of Common Guidelines Framework and CCLI/TUES Project Type

Common Guidelines (Earle et al., 2013) Research Type(s)	**CCLI/TUES Program**
	Project Type
1–2: Foundational Research and Early Stage or Exploratory Research	CCLI/TUES Type 1—Exploratory
3: Design and Development Research	
	CCLI/TUES Type 2—Expansion
4–6: Efficacy, Effectiveness, and Scale-Up Research	CCLI/TUES Type 3– Comprehensive TUES Central Resource Project

largely independent of a particular field. Hitchcock and Verheij [72] succinctly describe *Toulmin's Mo*del in the introductory chapter of *Arguing on the Toulmin Model: New Essays in Argument Analysis and Evaluation*. The first step in the process is the assertion of a claim (C). In response to this claim, a questioner may ask, "What do you have to go on to make this claim?" The defender then appeals to data (D), relevant facts that are available to the defender. The challenger may then ask about how the data relates to the claim that is being made. To this, the defender may respond with a proposition, or warrant (W), that may take the form of: "Data such as D entitle one to draw conclusions, or make claims, such as C" [27, p. 98]. Toulmin's model, first published in his Uses of Argument book [27], is a commonly-used reference in the context of rhetoric, logic, debate, and argumentation. However, Toulmin's Model not only applies to standards of arguments, but to verbal reasoning in general [CITE Hitchcock]. It provides a theoretical basis for this study because it offers an explanation on the construction of arguments and generalizes beyond its original context to one in which the goal is to understand arguments researchers make surrounding aspects of their research. This model is applicable to this study since the primary data source that will be used in this study includes research project abstracts, narratives that include claims researchers are making about the impact of their studies.

5.4.2 Common guidelines for education research and development

The second framework used in this study is the *Common Guidelines for Education Research and Development* [28] (referred to hereafter as the "Common Guidelines"). A Joint Committee of representatives from the U.S. Department of Education and NSF first met in January 2011 to start the development. The guidelines were a response to a need to "establish cross-agency guidelines for improving the quality, coherence, and pace of knowledge development in science, technology, engineering, and mathematics (STEM) education" [p. 4]. These guidelines articulate the "role of various types or 'genres' of research in generating evidence about strategies and interventions for increasing student learning" [p. 7].

Since *Toulmin's Model* [27] is useful for understanding verbal reasoning, in general, and the *Common Guidelines* [28] provides additional details on the contents of the verbal reasoning found in project abstracts, an integration of the two is useful for understanding claims about research impact in the context of interest. Table 1 shows how the scope of the four Project Types aligns with the three research types in the *Common Guidelines* [28].

5.5 Data analysis

The first research question was answered using content analysis, while the second was addressed by comparing the results of the first question with the definitions of research impact in the literature. Atlas.ti, a qualitative data analysis software, was used to perform the majority of the analysis. The unit of analysis were the two sections that are most likely to contain claims about research impact: the Dissemination section and the Impact section. Abstract sections that include research "results" were not analyzed, because, although the contents could potentially be related to the project's impact, the outcomes of this analysis would have been a duplication of efforts currently being conducted by engineering education researchers developing a taxonomy of engineering education research [41].

Ideas mentioned in the literature review (i.e., the three dimensions of research impact, and the 76 impact categories in other research impact frameworks) served as *sensitizing concepts* [42] and *provisional codes* [43]. In this study, the process of coding the abstracts (in Atlas.ti) and developing the codebook (in Microsoft Word) happened in parallel. The initial coding was an exploratory analysis to get a general sense of the data [29, 47] (about one-third of the abstracts). After reading the abstract, two types of coding occurred: (1) Attribute coding and (2) Provisional or Descriptive coding [43]. In this study, the following attribute codes were assigned to the abstract: project type, project focus, and STEM discipline. Next, either provisional or descriptive codes were assigned to the ideas in the "Dissemination" and "Impact" sections of the abstract.

During the exploratory phase, Microsoft Word was used to create a duplicate codebook as codes are assigned to segments of text in Atlas.ti. This is the time during the coding process when the provisional and open codes were added to the document, sample segments of text were supplied, and coding guidelines were drafted to promote consistency in the application of codes across abstracts. Once the coding of this set of abstracts was complete in Atlas.ti, the MS word version of the codebook was used to code the second set of STEM abstracts. When necessary, new codes, examples, and guidelines were added to the codebook.

Once the coding for all of the abstracts identified in the maximum variation sampling was complete (i.e., from projects across STEM), the MS Word version of the codebook was refined, and preliminary categories were described. One of the most critical decisions that was made in revising the codebook was the creation of a category and cluster of codes for impacts that were discussed in the impact narratives but had not been realized. These changes resulted in the second version of the codebook. There was a total of 114 codes in the codebook: 19 attribute codes, as well as 95 descriptive and provisional codes. There were seven themes corresponding to the first sub-questions (about the types of claims PIs make) and three corresponding to second sub-question (about how PIs support claims about impact). An interrater reliability (IRR) check was performed before coding the engineering-only set of abstracts; the timing is consistent with Miles and Huberman's [29] recommendation to conduct the IRR testing when approximately two-thirds of the coding is complete.

5.5.1 Interrater reliability check

The F_1 score [56] is used to calculate IRR in contexts where categories are not mutually exclusive, which is the case in this study. The harmonic mean was calculated to determine the extent of agreement between the researcher and each of the two independent coders as well as between the two independent coders. The two independent coders were fellow-PhD students in the Engineering Education program, who have academic backgrounds in engineering disciplines and have been involved in the coding of at least three qualitative research projects in the past. I randomly selected seven project abstracts (based on project type, project focus, and STEM discipline) that would be coded during the IRR session. The IRR session comprised three main parts: training and practice session, individual coding, and a brief discussion on how to improve the codebook.

The IRR analysis yielded positive results. A total of 161 codes were assigned across all three coders and five abstracts were analyzed independently after the training session. There is a 12-22% difference between the F_1-scores calculated and the ideal F_1-score. As a result, modifications were made to the clarity of descriptions in the codebook based on feedback from the IRR session. These modifications led to the third version of the codebook, which included 19 Attribute Codes and 50 Provisional/ Descriptive Codes. Once modifications to the Microsoft Word version of the codebook were complete, the Atlas.ti codebook was updated to match.

5.5.2 Final round of coding

The final round of coding included two parts. In the first part, the code assignments associated with the 100 abstracts analyzed before the IRR analysis were checked and re-coded when the code assignment did not align with the codes and/or guidelines in the current version of the codebook. Next, the refined codebook was used to code the abstracts in the homogeneous sample (i.e., the engineering-only abstracts) using the same approach described above. Once all of the coding was complete, the constant comparative method was used to refine the codes one last time [39, 48]. After aligning the Microsoft Word and Atlas.ti versions of the codebook, a spot check was performed on 20 randomly selected abstracts to ensure that the segments associated with each revised code were still appropriately assigned.

5.5.3 General descriptive statistics & Interpreting the qualitative results

Atlas.ti's analysis tools were used to generate a co-occurrence table; this data was used to describe how often the themes occur in relation to one another. Additionally, Microsoft Excel was used in this study to generate descriptive statistics surrounding the themes that resulted from the analysis. In this study, the codes corresponding to the themes that emerged from the coding analysis were compared with the three definitions of research impact and the dimensions of impact in existing research impact frameworks [4, 8, 11, 12, 19, 57–59].

5.6 Acknowledging bias

I (the researcher conducting this study) hold B.S. and MS degrees in Industrial Engineering and at the time of conducting this study, was a PhD in Engineering Education. My academic background in Industrial Engineering undergird my research interests in studying systems-level issues and also facilitates a systems engineering approach to solving problems (i.e., understanding the individual components in socio-technical systems, how they fit & work together, and pursuing actions to enhance the overall system's efficiency). Lastly, I have conducted three mixed methods during consecutive interns in NSF's Division of Undergraduate Education [60–62]. An example of my bias might include expecting systems-level impact from an individual project where a more modest expectation is more reasonable. I monitored these biases and was intentional about engaging in research activities that should increase confidence in the results; examples of this includes keeping reflective notes, engaging in inter-rater reliability analysis, and triangulating results using methods that involve other STEM education researchers.

6. Results

6.1 Making claims about impact

Using qualitative investigation, the second research question, "What claims do PIs make about the impact of their NSF-funded projects?," was explored. When discussing impact of a research project, PIs tended to make claims about eight thematic ideas: (1) conducting research, (2) research- and education-focused developments, (3) disseminating research findings and propagating developments, (4) influence on individuals and/or communities, (5) influence on environmental/structural decisions/metrics, (6) scope of influence, (7) symbols of impact, and (8) unrealized impact (see Table 2).

6.1.1 Conducting research

When given an opportunity to discuss the impact of their work, PIs make claims about people involved in conducting the study, and claims related to the major steps of the research process in their impact narratives. References are usually made to collaborators on the project, undergraduate student researchers, graduate research assistants, and post-doctoral research staff. Making claims regarding conducting research also includes connections between the current study and existing literature or work that serve as a motivation for the study. This may also include connections to prior research and developments that serve as the foundation for the current work. Highlights of current research activities are other discussion topics associated with this theme. Impact narratives may also include a succinct statement on the key research findings, with emphasis on the new contribution to the body of literature. Lastly, impact narratives sometimes mention the submission of applications for additional funding and/or references to securing funding to continue the study. Provided is a quote from an abstract that provides evidence in support of this theme; the code among those assigned that corresponds to this theme is **bold**.

> Project Attributes: Central Resource Project | Engineering | Conducting Research on Undergraduates in STEM Education
>
> "The project has already helped and will continue to build a community of engineering education scholars by training and mentoring twelve graduate and post-doctoral researchers in both qualitative and quantitative data collection and analysis. . ."
>
> Assigned Codes: **Parties Involved in Conducting Research;** Influence of Research on STEM Education Researchers and/or Research Community

6.1.2 Research- and education-focused developments

There are three types of research-focused developments: text-based entities, discussion-based entities, and facilities or technology developed primarily for the purpose of conducting research. Examples of each of these may include the establishment of a new

Table 2. Summary of the Types of Claims PIs Make about Impact

Theme	Description
Conducting Research	Claims about people involved in conducting the research and the major steps in the research process.
Research- and Education-focused Developments	Claims about the development of artifacts that imply permanence and sustainability of the research topic beyond the current study, and tangible, educational materials informed from the current study.
Disseminating Research Findings and Propagating Developments	Claims about how research findings and/or educational developments are being shared with other researchers and/or practitioners.
Influence on Individuals and/or Communities	Claims about ways in which individual or communities of learners, instructors, or researchers are being affected by the outcomes of the study.
Influence on Environmental/ Structural Decisions, Metrics	Claims about how insights from the current study inform administrative decisions that ultimately influence the actions of others, and how the current study contributes to assessments and/or metrics of interest to administrators.
Scope of Influence	Claims about the span associated with their project outcomes.
Symbols of Impact	Claims about the receipt of public affirmation as a result of connections to the current study.
Unrealized Impact	Claims about activities, events, and outcomes that have not yet happened, but are either future plans or anticipated outcomes that will be realized at a later time.

scholarly journal or an annual research symposium focused on a niche research area as well as the installation of a new research center dedicated to specific research areas. Additionally, impact narratives also include claims about the development of tangible, educational materials that were informed from the current study and designed to benefit individuals (e.g., learners, instructors) or groups in an educational setting. This includes curricular and pedagogical materials as well as resources for training instructors. Technology developments and instruments purchased (e.g., lab equipment) for educational purposes are also included among the examples of education-focused developments. Consider the following quote from an abstract as an example.

> Project Attributes: TUES Type II | Physics/Astronomy | Conducting Research on Undergraduates in STEM Education
>
> "The curriculum is in use at our institution and has been tested at a handful of pilot sites. As noted above, our materials are available to potential adopters as well."
>
> Assigned Codes: **Curricular materials, training resources, and pedagogy;** Curricular changes

6.1.3 *Disseminating research findings and propagating developments*

When PIs discuss the ways in which they are sharing research findings and propagating their education- and research-focused developments, they make claims about the mediums used to circulate the findings, along with activities and outcomes surrounding propagation. The mediums used to disseminate research findings are text-based and/or discussion-based mediums. Examples of text-based mediums include conference proceedings, journal publications, and research briefs. Discussion-based mediums include sharing research findings during a conference presentation or by participating in an expert panel discussion. Another form of disseminating research findings includes sharing insights informed from research in various venues for teaching and training (e.g., workshop, seminar, consulting, demonstrations at a research conference). Oftentimes, the audience for the text- and discussion-based mediums is the same: STEM education researchers and/or practitioners.

In addition to discussing mediums and venues for disseminating research findings, PIs discuss ideas related to developments resulting from their study. These topics include highlights of current activities they are engaged in to propagate developments—such as activities that contribute to the establishment of partnerships, marketing and commercialization of materials, and instituting mailing lists to keep track of educators and/or vendors who have expressed interest in their developments when they become available. Provided is a quote from an abstract that provides evidence in support of this theme; the code among those assigned that corresponded to this theme is **bold.**

> Project Attributes: TUES Type II | Research/Assessment of Research | Assessing Student Achievement
>
> "To date, more than 15 peer-reviewed conference presentations; several posters; 1 publication; 2 under review; 2 in preparation by team members. Several campus visits and workshops."
>
> Assigned Codes: **Text- and/or Discussion-based Mediums; Dissemination via Venues for Teaching, Training;** Highlights of Current Activities; Quantifying Outcomes

6.1.4 *Influence on individuals and communities*

When given an opportunity to discuss the impact of their work, PIs make claims about ways in which individuals or communities of people are affected by outcomes of the current study. The individuals most commonly mentioned are learners, instructors, and researchers. As it relates to learners, PIs may make claims about how participation in an experience associated with the current study leads to the development and application of knowledge, skills, and ways of thinking relevant to STEM concepts and careers. It also includes undergraduate students' changes in interest in pursuing graduate studies, as well as improvements in STEM literacy among those who participate in outreach activities associated with the current study.

When making claims about instructors, PIs assert that participation in a set of activities contributes to the development and application of knowledge, skills, and ways of thinking surrounding improved pedagogical practices. The activities include attending a workshop hosted by the PI's research team, or joining a virtual network designed by the PIs' research team to facilitate interactions among instructors and to exchange resources. The latter of these two activities (i.e., providing a virtual venue) is an example of how PIs make claims about their influence on a community of instructors.

The last category of individuals that are commonly referenced in impact narratives are researchers. Researchers may include undergraduate researchers, graduate student research assistants, post-doctoral researchers, and faculty in higher education. When mentioning these groups, PIs discuss ways in which participation in the current study is contributing to the development of new data collection and analysis skills or influencing the quality of the research-related documents (e.g., grant proposals, research publications). PIs also make claims about the development or expansion of the research community who share interests in their area of expertise. This theme also captures instances where teaching- or learning-related insights resulting from the current study serves as the basis for a new set of research-focused activities/projects.

The last collection of ideas that correspond to claims regarding influence on individuals and/or communities are claims about direct personal, professional benefits to instructors and/or researchers. This includes, but is not limited to, expansions in the number of contacts in the PIs' professional network as a result of conducting research or hosting a training session for faculty. It also entails claims about how the inclusion of research activities in faculty's promotion and tenure package contributed to positive professional outcomes for the individual. One example of this idea is provided below.

> Project Attributes: TUES Type III | Engineering | Implementing Education Innovations
>
> ". . . Through invited presentations at conferences, workshops, and a variety of academic institutions, the PI has established well over 200 contacts from dozen of engineering programs across the country."
>
> Assigned Codes: Dissemination via Venues for Teaching, Training; Affirmation from within the Academic Community; **Direct Personal, Professional Benefits to Instructors, Researchers;** Institutional Scope; Geographic Scope

6.1.5 Influence on environmental/structural decisions/metrics

PIs make claims about ways in which their research informs administrative decisions, which ultimately influence the actions of others—either at the PIs' home institution or elsewhere. Curricular changes such as modifications to an existing course, new course offerings, and changes in the set of courses students are advised to take are examples of influences on the educational environment. Informing or enacting new policies by participating in policy-related discussions at local- or national-level gatherings is another way that PIs influence the decision making process. This theme also captures claims about how adding the PIs' research project to their promotion and tenure package affects administrators' decisions.

Furthermore, this theme also includes ways in which the current study influences assessments and/or metrics of interest at the level of the undergraduate departments. This may include how the current study highlights latent environmental/structural issues that need to be addressed. It also includes claims about how the research insights affect aggregate student outcomes—such as enrollment, retention, and "Drop, Fail, Withdraw"-rates within an undergraduate STEM education department. Lastly, the impact narrative may reference instances where inclusion of research data or findings contributed to an accreditation evaluation. Provided is a quote from an abstract that provides evidence in support of this theme; codes among those assigned that corresponded to this theme are **bold.**

> Project Attributes: TUES Type II | Computer Science | Creating Learning Materials and Teaching Strategies
>
> "CS1 enrollment doubled after integration of course in freshman program. . . ."
>
> Assigned Codes: **Department-level Assessments and/or Outcomes;** Curricular Materials, Training Resources, and Pedagogy; Quantifying Outcomes

6.1.6 Scope of influence

Across many impact narratives, PIs make claims about the span associated with their projects outcomes. Span may be geographic, disciplinary, or institutional in scope. References to states in the United States and use of the term "international" are words that suggest geographic scope. Highlighting other disciplines involved in the study besides the specific target discipline serve as an indicator of disciplinary scope. Citing the names of other institutions using the R&D resulting from the study is what is meant by institutional scope. Scope of influence may also include span via target populations. This might include the use of terms like "at risk" students, underrepresented minorities, and women as qualifiers of the types of learners affected by the study. Finally, this theme also captures scope in the form of non-academic partnerships—with vendors, industry, or professional societies—usually for the purpose of advancing the dissemination of research findings or propagation of research developments. What follows is a quote from an abstract that references dimensions of the scope associated with this theme.

> Project Attributes: TUES Type III | Interdisciplinary | Developing Faculty Expertise
>
> "To date, more than 350 institutions in 45 states 13 foreign nations have been intensively involved. In the last three years, participants estimate their efforts have impacted 145,000 students. . . ."
>
> Assigned Codes: Influence of Training on STEM Education Instructors and/or Community of Instructors; **Geographic Scope; Institutional Scope;** Less Specific; Indirect or Expected Outcomes

6.1.7 Symbols of impact

At times, PIs make claims about the forms of public affirmation they have received as a result of the research they have conducted. Such affirmations vary depending on whether it comes from within the academic community or from outside. In most cases, the symbol is bestowed on the PI by other experts in the research community because of their unique contribution to the body of knowledge or perceptions of the extent to which their work advances the discipline. By doing such, those affirming the research bolster its credibility and visibility.

The forms of affirmation that come from within the academic community are often in the form of receiving special recognition/awards, being labeled an exemplar, leader, or fellow, or being asked to give a keynote address related to the PIs' area of expertise. These are all symbols that carry significance among the members of their research community. Examples of the forms of affirmation that come from outside the research community may be in the form of press coverage, news media reports, featured stores on television or in written publications, or having a project featured in the NSF Highlights. (The NSF Highlights are a source of information about NSF investments in R&D projects stored on the NSF intranet. NSF Program Officers submit "highlights" to the internal database at will. Each highlight is a brief summary of the funded project, along with its transformative results or outcomes.) Provided is a quote from an abstract that provides evidence in support of this theme; the code among those assigned that corresponded to this theme is **bold.**

> Project Attributes: TUES Type I | Biological Sciences | Implementing Educational Innovations
>
> "The impact that this project has had on students has been positive and we have been successful in achieving our goals for them based on gains in the classroom, from survey results and CAT gains. Each of the classes has generated research-quality data for the collaborating research faculty. Some of the data have resulted in a research publication with the students as authors. The success of our project has been recognized nationally and within our department with several faculty members approaching us with ideas for future-based classes."
>
> Assigned Codes: Influence of Teaching on STEM Learners; Quantitative Evaluation and/or Metrics; Highlights of Research Findings; Parties Involved in Conducting Research; Text- and Discussion-based Mediums; Geographic Scope; Institutional Scope; **Affirmation from within the Academic Community**

6.1.8 Unrealized impact

The final type of claim PIs make when discussing the impact of their work is claims about unrealized impact. These are claims about activities, events, and outcomes that have not yet happened but are either future plans or anticipated outcomes the PI expects will happen at a later time. This includes three types of ideas. One set of ideas is future plans to conduct research, create developments, disseminate findings, or propagate developments. A second set of ideas includes indirect and/or expected outcomes. More specifically, these are claims that create links between direct project outcomes and secondary, or tertiary outcomes that may or may not have been realized yet. Oftentimes, this is discussed in form of a chain of events that ultimately leads to effects on student learning.

Sometimes, claims are made to describe anticipated outcomes in conjunction with references to an anticipated geographic span of influence. In some cases, PIs posit that the findings of their work have implications for teachers and learners on a national or international level. However, this is usually limited to a non-specific use of the term national or international, and often does not include a detailed explanation of how and where the implications will take effect. In a few instances, PIs also connect their project outcomes to societal-level impact constructs of interest—such as workforce development, technological literacy of citizens, or the economy.

The third type of idea associated with this theme are indeterminate outcomes: statements of admission that the impact is "unclear", "hard to determine", or "yet to be determined." One last example of an abstract that includes evidence to support this theme is provided below.

> Project Attributes: TUES Type II | Engineering | Creating Learning Materials
>
> "Over the past years, several state-of-the-art laboratories and new courses have been developed by the NSF grant. Creation of the Internet-based laboratories significantly contributes to the development of technologically literate students and workforce that could be in great demand not only in the tri-state area but also nationwide. Information-based technology has become the new realm of manufacturing and mechanical engineering technology graduates. The NSF project helps the AET program to prepare faculty and students to: apply discipline-specific theory, conduct experiments, and use real world experience to interpret, analyze, and solve current and emerging technical problems. Annual workshop has been held for faculty development. The successful implementation of the NSF project is crowned by the Applied Engineering Technology program's successful accreditation by the TAC of ABET. The AET program was granted accreditation and the ABET evaluation team found no deficiencies, concerns or weaknesses. The NSF project has been well-performed by the PIs as planned in the early stage."
>
> Assigned Codes: Instruments, Technology used for Educational Purposes; Influence on STEM Learners; MISC—Reference to Societal Level Impact; Geographic Scope; **Indirect or Expected Outcomes;** Influence of Training on STEM Instructors and/or Communities of Instructors; Affirmation from within the academic community; Department-level Assessments and/or Outcomes

6.2 Supporting claims about research impact

Themes related to how PIs support claims about the impact of their work were also examined. Data were analyzed to explore how PIs qualify and back their

Table 3. Summary of Ways PIs Support Claims About Impact

Theme	Description
Clarifying Claims Using Degrees of Specificity	The use of more or less specific language when discussing claims about impact. Examples of more specific language include quantifying project outcomes, and using qualifying term to describe the extent of impact. Examples of less specific language are succinct, broad, vague ideas that could easily describe a variety of projects.
Supporting Claims by Establishing Credibility and/or Relevance	References to ideas that suggest reasons why the reader should perceive the study as trustworthy and/ore closely related to the priorities of the STEM education discipline associated with the project.

claims, irrespective of the types of impact being discussed. Two themes describe the mechanisms PIs used to support their claims; they include (1) clarifying claims using degrees of specificity and (2) supporting claims by establishing credibility and/or relevance. See Table 3 for an elaboration on these two themes.

6.3 Descriptive statistics surrounding results on making and supporting claims

A total of 1,454 codes about making and supporting claims were assigned to texts in the 155 abstracts reviewed in this study. Each code maps to one of the 10 themes about making and supporting claims about impact. Fig. 2 shows the proportion of claims discussed in abstracts. The three themes that account for the largest proportion of claims that are made about impact are (1) claims regarding disseminating research findings and propagating developments; (2) claims about unrealized impact; and (3) claims about influence on individuals and/or communities. On the other hand, there are fewer instances of claims about influence on environmental/structural decisions, metrics; and claims about symbols of impact are practically negligible when looking across abstracts.

The data shows that there are instances when the average number of claims does not vary much by project type, but there are instances when there are noticeable differences. The two themes with the highest total average (i.e., dissemination of research findings and propagation of developments and unrealized impact) are also the two most often mentioned in Type I and Type II projects. The same is true for the two types of claims that are mentioned the least often (i.e., symbols of impact and influence on environment/structural decisions, metrics). The deviation from the highest and lowest overall sum occurs with the Type III and Central Resource Project (CRP) projects. For Type III, influence on individuals and communities along with education- and research-focused developments are mentioned just as often as unrealized impacts. For CRP projects, dissemination of research findings and propagation of developments are not among the claims mentioned the most often; rather, conducting research is the claim mentioned most often. Similarly, for the two types of claims mentioned the least often across abstracts (i.e., symbols of impact and influence on environment/structural decisions, metrics), Type III abstracts have even fewer claims regarding conducting research than influences on environmental/structural decisions, metrics. Furthermore, the CRP

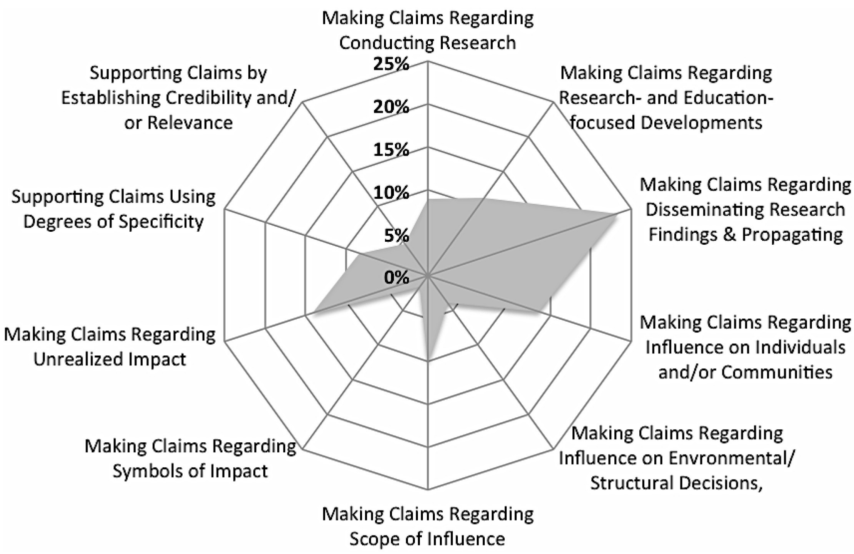

Fig. 2. Proportion of Themes Discussed in Abstracts (N = 1454 code assignments across 155 abstracts).

Table 4. Summary of Themes Most Commonly Mentioned in Abstracts, by Project Focus

Most Commonly Mentioned Themes					
	Project Focus				
Rank	**Implementing Educational Innovations**	**Developing Faculty Expertise**	**Assessing Student Achievement**	**Creating Learning Materials**	**Conducting Research on Undergraduate STEM Education**
1	Claims Regarding Influence on Individuals and/or Communities	Claims Regarding Unrealized Impact	Claims Regarding Disseminating Research Findings and Propagating Developments	Claims Regarding Disseminating Research Findings and Propagating Developments	Claims Regarding Disseminating Research Findings and Propagating Developments
2	Claims Regarding Scope of Influence	Claims Regarding Influence on Individuals and/or Communities	Claims Regarding Unrealized Impact	Claims Regarding Unrealized Impact	Claims Regarding Unrealized Impact
3	Claims Regarding Disseminating Research Findings and Propagating Developments	Claims Regarding Disseminating Research Findings and Propagating Developments	Claims Regarding Conducting Research	Claims Regarding Research- and Education-focused Developments	Claims Regarding Influence on Individuals and/or Communities

projects did not include any claims regarding symbols of impact.

When comparing claims made by projects receiving the largest funding (CRP) to projects with the smallest funds (Type I), there are a few notable differences. Type I project abstracts tend to include five types of claims more often than CRPs: claims regarding dissemination of research findings and propagation; unrealized impact; influence on individuals and/or communities; scope of influence; and symbols of impact. On the contrary, CRP projects mention claims about conducting research more often than Type I projects. The two project types are comparable in the average number of claims about research- and education-focused developments, and influence on environmental/structural decisions, metrics. The differences in claims made are less apparent when comparing Type II and Type III projects.

With three exceptions, the three themes most commonly mentioned in the abstracts (i.e., disseminating researching findings and propagating developments; unrealized impact; and influence on individuals and/or communities) are consistently among the most commonly mentioned across project foci (see Table 4). The first exception, claims regarding scope of influence, is second among the most commonly mentioned in projects focused on Implementing Educational Innovations. The second exception, claims regarding conducting research, is third in the list of the most commonly mentioned themes for projects that focus on Assessing Student Achievement. The third exception, claims regarding education-and research-focused developments, is among the most commonly mentioned in projects focused on Creating Learning Materials. For all five project foci, the two least commonly mentioned claims are claims regarding influence on environmental/structural decisions, metrics and claims regarding symbols of impact (see Table 5). Finally, analyzing the average number of impact claims based on disciplinary differences leads to other patterns in the data as well. See Table 6 for a summary of the average number of claims mentioned in each abstract based on discipline. On average, PIs reporting on Engi-

Table 5. Summary of Themes Least Commonly Mentioned in Abstracts, by Project Focus

Least Commonly Mentioned Themes					
	Project Focus				
Rank	**Implementing Educational Innovations**	**Developing Faculty Expertise**	**Assessing Student Achievement**	**Creating Learning Materials**	**Conducting Research on Undergraduate STEM Education**
7	Claims Regarding Influence on Environmental/ Structural Decisions, Metrics	Claims Regarding Influence on Environmental/ Structural Decisions, Metrics	Claims Regarding Influence on Environmental/ Structural Decisions, Metrics	Claims Regarding Influence on Environmental/ Structural Decisions, Metrics	Claims Regarding Influence on Environmental/ Structural Decisions, Metrics
8	Claims Regarding Symbols of Impact	Claims Regarding Symbols of Impact	Claims Regarding Symbols of Impact	Claims Regarding Symbols of Impact	Claims Regarding Symbols of Impact

Table 6. Summary of Themes Most & Least Commonly Mentioned in Abstracts, by STEM Discipline

Claims Regarding. . .	Rank	Highest Two Disciplines	Rank	Lowest Two Disciplines
Disseminating Research Findings and Propagating Developments	1	Social Science		
	2	Interdisciplinary		
			9	Biological Sciences
			10	Mathematics
Unrealized Impact	1	Physics/Astronomy		
	2	Research/ Assessments of Research		
			9	Interdisciplinary
			10	Computer Science
Influence on Individuals and/or Communities	1	Geological Sciences		
	2	Biological Sciences		
			9	Research/ Assessments of Research
			10	Physics/Astronomy
Research- and Education-focused Developments	1	Interdisciplinary		
	2	Social Science		
			9	Mathematics
			10	Research/ Assessments of Research
Conducting Research	1	Research/ Assessments of Research		
	2	Interdisciplinary		
			9	Social Science
			10	Mathematics
Scope of Influence	1	Social Science		
	2	Research/ Assessments of Research		
			9	Chemistry
			10	Interdisciplinary
Influence on Environmental/ Structural Decisions, Metrics	1	Physics/Astronomy		
	2	Interdisciplinary		
			9	Biological Sciences
			10	Mathematics
Symbols of Impact	1	Social Science		
	2	Geological Sciences		
			9	Research/ Assessments of Research
			10	Mathematics

neering, Geological Sciences, and Computer Science projects tend to include the same number of claims in each abstract. Abstracts about Social Science projects tend to include more claims about impact than PIs reporting on Mathematics projects. Social science and Interdisciplinary projects include the most number of claims about dissemination of research findings and propagation of developments and research- and education-focused developments.

6.4 Alignment of themes and existing literature on research impact & SCS impact framework

Guided by Toulmin's Model [27] and the Common Guidelines [28], a content analysis of what PIs describe in the Dissemination and Impact section of project abstracts was conducted in order to answer the third research question, "How do PIs' perspectives of impact align with existing impact frameworks found in the literature to form a preliminary description of the impact of NSF investments in undergraduate STEM education projects?" Some findings are consistent with the current literature on research impact, and others are unique contributions to the scholarly discussion on this topic. The author proposes the following definition of impact in light of existing literature and the findings of this study. *Impact is a time-sensitive interpretation of the extent to which a series of interactions have led to incremental and transformative change in and beyond the context in which the*

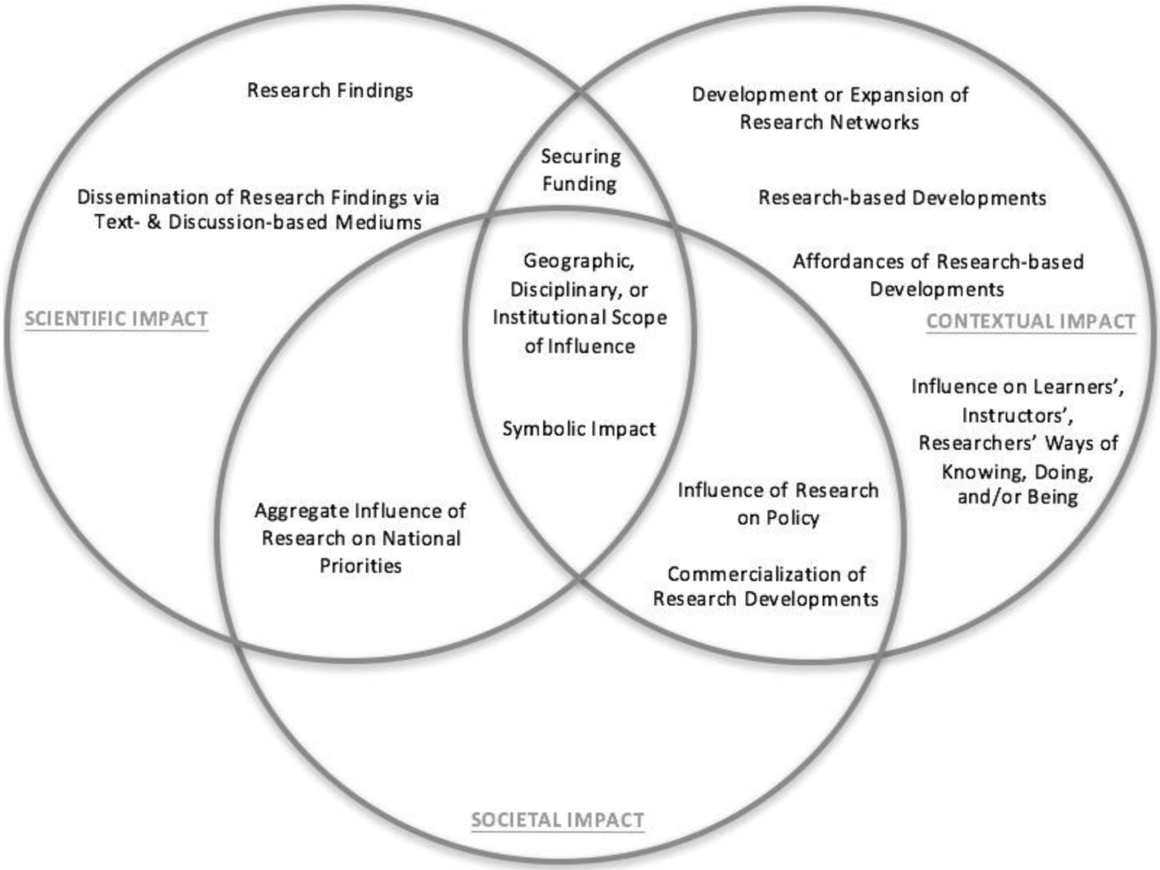

Fig. 3. SCS Impact Framework.

change originated. Within the context of research, impact has three dimensions: scientific, contextual, and social. Fig. 3 illustrates the overlap of abstract themes with existing literature on research impact via the SCS Impact Framework.

One idea related to *claims regarding conducting research* aligns with the most familiar dimension of research impact (i.e., scientific). When PIs highlight unique contributions to the body of literature, this is an expression of the study's scientific impact. With the exception of the framework developed for informal science education projects [4] and focused primarily on societal impacts [63], every framework included in the literature review includes a construct of related to advances in knowledge [8, 11, 12, 19, 57, 58, 59]. There are many points of continuity between the forms of impact mentioned in existing literature and ideas supporting the theme *claims regarding education- and research-focused developments.* More specifically, most of the existing frameworks reference the creation of tangible artifacts, instruments or products meant to be most useful to researchers and practitioners in the domain associated with the research that led to the development [8, 11, 19]. As it relates to ideas supporting *claims regarding disseminating research findings and propagating developments*, there are two areas of overlap with studies that have already been done. Disseminating research finding through text- and/or discussion-based mediums is part of advancing reliable knowledge: scientific impact. Ideas related to *claims regarding influence on individuals and/or communities* are significant in this context, because they are directly connected to the mission of the university—the setting where learners, instructors, and most STEM education researchers converge.

Claims regarding influence on environmental/structural decisions, metrics relates to how research may influence administrative decisions or metrics of interest. Although focus on metrics is not captured, some aspects of this theme connect with existing studies on how research informs policy at various levels [11, 12, 19]. Additionally, ideas supporting *claims regarding symbols of impact* is consistent with the symbolic impact mention in the framework on the impact of science [19]. The last two of the eight types of claims PIs tend to make in impact narratives that are absent in the literature are *claims regarding scope of impact* and *claims regarding unrealized impact*. To the extent that stakeholders would perceive the span of reach as a valid form of impact, this finding is a unique contribution to the literature on the impact of research. Based on these alignments with existing literature, the *SCS Impact Framework* includes broad constructs (i.e., scientific, contextual, and societal impact) and concrete details that presents a preliminary description of the impact of undergraduate STEM education R&D.

7. Discussion

The ideas in the two frameworks that were used to guide the qualitative analysis [27, 28] served as sensitizing concepts; more specifically, they provided ideas on what to expect in terms of how researchers may construct arguments about impact and what type of evidence may be associated with certain types of research. Although existing literature on the use of Toulmin's model discussed its limitations in terms of using it to evaluate arguments [64, 65, 66], it was a useful analytic tool for trying to understand PIs' verbal reasoning surrounding the impact of their work. This was one of the first scholarly studies on the realized impact of a collection of NSF-funded projects; it relied on small sections of project abstracts in the conference report of a particular NSF program, because it is highly accessible. To the extent that is it is true that one of the best sources of information on the impact of projects in which millions of taxpayers' dollars are invested is buried in small sections of project abstracts in the PI conference reports of some NSF programs, this may imply that impact is largely invisible from the current reporting processes and speaks to the urgent need for improved infrastructure.

What PIs discuss are a breadth of topics ranging from research activities, research outputs, and influence on populations. One example of an idea that is not discussed, however, is the negative impact of a project. Moreover, in some ways, these findings support the idea that impact is commonly used interchangeably with terms like outputs and outcomes [14, 15]. The lack of focus and coherence in the ideas that are discussed may also provide evidence in support of the idea that researchers may really struggle with knowing how to communicate the impact of their work or evaluate the contents of Broader Impact statements in NSF proposals [67].

One of the most surprising themes that emerged from the current study was *unrealized impact.* Although the ideas supporting this theme are not consistent with any of the dimensions of impact mentioned in existing research impact frameworks, it does help shed light on how researchers may think about research impact. Given how frequently this theme appeared in the sample of abstracts reviewed, it seems as if PIs are so certain about what might potentially happen in the future that they see no problem with reporting it as impact now; said differently, PIs may perceive that there is no need to distinguish between realized impact and expected/anticipated impact. As this scholarship on impact continues to grow, it will continue to be difficult to make proper attribution if claims about realized and unrealized impact are made together and are oftentimes indistinguishable.

The descriptive statistics show how often different types of claims are mentioned based on the project type, focus and STEM discipline. This data shows that there were few notable differences in the types of claims PIs make when comparing across projects with different levels of funding. Part of the reason for this may be because the differences in impact may not occur until many years or decades after the project is completed [68]. The research findings also indicate that the project focus and discipline seem to have more influence on the types of impacts that are observed than the amount of funding award (at least in the early stages of the project). Additional studies are needed to explore the extent to which this finding is consistent across programs and to trace the impact of projects after the grant lifecycle, since a longer horizon will provide more time for the differences impact to be evident.

7.1 Implications for policy and practice

One of the notable implications of this work is it provides a starting point for NSF to develop a reporting structure that would allow program officers and the wider STEM education community to get better data—and ultimately, a better understanding—of what it means for a research project to have impact. Provided are guidelines for PIs to consider when writing about the impact of their NSF-funded projects:

1. Use the *SCS Impact Framework to* discuss the scientific impact of the study by highlighting advances in knowledge, or ways in which the current study clarifies existing ways of thinking about a topic. Limit generic references to mundane steps in the research process and lists of publications resulting from the study.
2. Use the *SCS Impact Framework to* discuss the societal impact of the study by making connections between the outcomes of the current study and national priorities and/or salient discipline-specific issues (e.g., increasing the quantity of engineering graduates and improving the quality of undergraduate engineering education).
3. Apart from mentioning the outcomes of the

study, use the *SCS Impact Framework to* discuss the contextual impact of the study by mentioning the unique ways people (e.g., learners, instructors, administrators, networks of researchers, parents, industry partners), priorities (e.g., effective teaching, meaningful learning) and processes (e.g., in classrooms, departments, institutions) are affected by the outcomes of the study.

4. Make concrete statements about the impact of your work and briefly mention evidence that supports the claims.
5. Make clear distinctions between realized and anticipated impacts.

7.2 Study limitations and future research directions

One, the data used in this study originally comes from a context where PIs were reporting project outcomes to the agency funding their research. Another limitation of this study is associated with the primary data source in this study: project abstracts. Third, the data included in this study is only from one NSF program, and the goals of this particular program could have implications on the research impact that is observed. Lastly, the resulting description of research impact may or may not capture the research impact of a project that occurs beyond the life of the grant.

Apart from using project abstracts as data for analyzing research impact, other documents that might be useful include program objectives mentioned in grant solicitations; grant proposals, annual reports, and final reports of expired research projects voluntarily shared by PIs; research briefs, executive summaries, and other short synopsis of research written for lay audiences; and media reports that highlight research projects. Other methods to consider include other qualitative approaches (e.g., grounded theory), quantitative methods (e.g., correlational studies), other mixed methods research designs, and computational approaches (e.g., data mining) [31, 47, 69, 70]. Another way to gauge how impact is defined may be to ask the STEM education research community to identify what they think has been the most impactful projects and why. Lastly, future studies that trace the impact of research beyond the grant cycle are vital to understand the immediate and long-term impact of a project.

8. Conclusion

This study provides a synthesis of the fragmented scholarship of impact, such as highlighting proposed dimensions of impact and ordinal levels of impact, to form a unified starting point for the conversation on this topic and builds on this body of knowledge. Current findings highlight eight themes of impact that describe undergraduate STEM education R&D projects, and two themes related to how PIs support their impact claims. This study found variations in PIs' impact claims across STEM disciplines and proposes a preliminary description of what impact looks like in the specific context of engineering education through previous frameworks of scientific, contextual, and societal impacts. In revealing various themes of impact discussed by PIs in their research, the findings suggest continuing to pursue the goal of investigating the multifaceted, complex dimensions of impact *are* and to develop a valid conceptual framework to facilitate a shared understanding of what impact means in this context.

The SCS *Impact Framework* proposed in this study may be useful to guide policy administrators and STEM education researchers worldwide in examining impact of R&D projects. In the short term, it might be useful for funding agencies to provide PIs with more guidance on the types of information to include in an impact narrative. Improving the quality of information PIs include in projects abstracts is critical to advancing transparency about NSF's investments in undergraduate STEM education and possibly reducing criticisms of publicly-support R&D. A disconnect between researchers and stakeholders of publicly funded research is apparent and needs to be scaled or broken down as we attempt to be more efficient in the use of taxpayers' funds allocated to engineering education research. Such a pursuit is necessary as we seek to support studies that lead to notable impacts on the number, quality, and diversity of engineers equipped to address society's most pressing social and technological needs.

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