



Systematic Review of NSF Virtual Reality for Education and Training Funded Projects: Implications for Researchers

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Abstract. While nearly a quarter of federally funded academic research in the United States is funded by the National Science Foundation (NSF), approximately 78% of proposals to NSF are not funded. This systematic review of NSF-funded projects that integrate virtual reality for education and training offers direction to advance research initiatives including virtual reality. Out of 605 abstracts, 160 projects funded between 2015-2022 met the inclusion criteria. Projects were coded by learning context, learning domain, subject, type of VR use, and special populations. This manuscript provides explanations about the larger categories of funded projects and provides justification for future research opportunities. This provides stakeholders insight into the shifting trends in context, learning domains, and content areas funded by NSF toward the integration of virtual reality into education and training. Among these insights, higher education contexts comprise the largest category of NSF-funded VR projects with an emphasis on engineering, computer science, and data science contexts. The most salient findings of the review of abstracts was that a majority of funded projects indicated a focus on learning outcomes in the cognitive domain (140), as opposed to the psychomotor domain (57) or affective domain (31). This is of particular interest, given the unique affordances of Virtual Reality. If VR is “the ultimate empathy machine” and the immersive nature of “learning by doing” lends itself to interactive experiences, it is likely that many VR researchers are missing out on the advantages of the most powerful aspects of the medium when leaving psychomotor skills out of their design.

Keywords: Immersive Learning, Systematic Review, Virtual Reality, Experiential Learning, Psychomotor Domain, Affective Domain, Cognitive Domain.

1 Introduction

There are many claims as to the value of integrating VR tools, such as the ability to provide new learning opportunities, replace existing methods that are expensive or ineffective, enhance existing training programs, or increase training [1, 2]. However, there is little consensus about how these tools should be integrated into classrooms and other training venues. The US National Science Foundation (NSF) invests in research to expand knowledge in science, engineering, and education, which promotes the progress of science and advances national health, prosperity, and welfare, while also securing national defense [3]. The NSF organization is a US independent federal agency created in 1950 with a \$225,000 budget, enacted a \$9.9 billion budget for 2023 [4]. Accordingly, NSF funds 24% of all federally funded academic research.

As the leading federal funder of premiere academic research, NSF receives over 40,000 research proposals every year and rigorously reviews them with a confidential merit review process designed to identify and fund proposals they expect to have the greatest possibility to be a fruitful investment of taxpayer contributions, advance science, and keep America at the cutting edge (NSF, 2023). The funding rate of NSF is about 28% of proposals; that is, 12,000 of the 43,000 proposals in 2020 were funded, leaving 32,000 proposals unfunded [3]. Given that most researchers who apply for NSF funding do not receive funding, insight into the organization's priorities and trends could inform research design and how the proposals could be better framed.

Given the significant impact the NSF has on current and future research, understanding these trends is important because they affect scientific research, ability to propel education in STEM (Science, Technology, Engineering, and Mathematics) fields, spark innovation and economic growth, address societal challenges, support collaboration, and engage the public in science communication [5]. Further, insights into the funding trends of the NSF can inform the future proposals of the 72% (or 32,000) researchers who wrote proposals for research funding but were not awarded NSF funding.

The research reported in this paper seeks to comprehend the direction of immersive technologies and advance the field of educational technology forward. As part of that process, it is essential to examine recently funded projects on the topic of VR. The purpose of this systematic review is to examine VR projects funded by the NSF within the context of education. We acknowledge that VR is defined broadly by scholars, as measured by levels of immersion and interactivity, VR ranges from 360° videos in a headset to highly immersive interactive (HII) virtual reality, in which “the user is immersed in the environment by wearing a VR headset, which blocks the view of the surrounding physical environment and replaces it with the sights and sounds of a virtual space” [2, p.75]. When using VR to go on a virtual field trip, "VR involves viewing 360° images of any environment. Each photo is a scene, which then becomes a part of a tour" [2]. It is important to note that NSF VR funded projects are not limited to these definitions.

2 Literature Review

The NSF is a primary funder of STEM education research in the United States, with an emphasis on advancing knowledge and understanding of effective STEM education practices and strategies [3]. Understanding the NSF's funding trends in STEM education research is important because it can greatly influence the focus and direction of research in this field. By aligning research proposals with the agency's objectives, researchers can increase the likelihood of securing funding and advancing knowledge [4]. While some researchers have tried to understand NSF funding trends and apply what they understand, previous related research provides only limited insights into the trends in NSF funding.

Researchers currently read books and articles seeking clarity on “What do grant reviewers really want, anyway?” [7] and attend workshops in which NSF Program Officers explain how to write and submit a proposal. These approaches are not based in data on what is actually being funded, instead it is based on the NSF calls for proposal (CFP). NSF provides insights about funded projects through NSF’s award search, a database that includes information on all current and past NSF grants. NSF-supported training materials recommend researchers begin here when doing “grant reconnaissance,” before writing a proposal. Similarly, a recent analysis of over 7.4 million words covering 19,569 proposals found that the writing style (i.e., increased length and complexity) of NSF abstracts correlates with increased funding [7]. When compared to the National Natural Science Foundation of China, NSF relies more on multi-program funding across different fields [8]. The NSF is organized into seven directorates that oversee many organizations and programs [4].

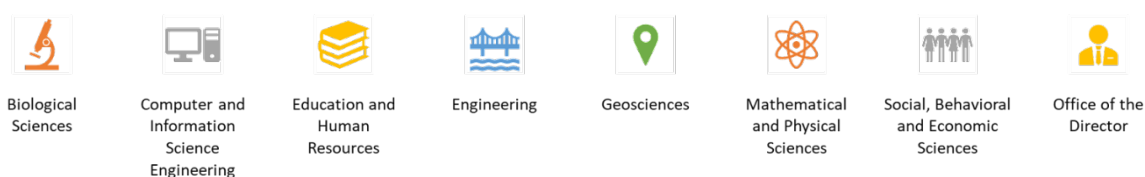


Fig. 1. Directorates of the US National Science Foundation.

Given NSF’s standing as top research funder for education research, it is also of particular importance to tenure-track faculty. This is evidenced by a recent study that revealed that securing grant funding is an element in a majority of tenure criteria [9]. This study detailed that 26 of 49 (53%) of assistant professors' tenure criteria lists grant funding, is also within the criteria for 50/79 (63%) of associate professors, and 56/83 (67%) of criteria for professor promotion and tenure.

To illustrate the need for this research, to our knowledge, no study has examined VR funded NSF projects, especially with an intention to move the field of educational technology forward to build upon and contribute in new ways to the larger issues at the forefront of innovative research. Providing researchers with clearer pathways, possibilities, and an understanding of significance to leading academic scholars, such as those at the NSF, could help advance education more expeditiously.

This systematic review addresses the following research questions:

1. Between January 2015 and February 2022, what has NSF funded on the topic of VR for education and training, according to learning context, learning domain, subject, type of VR use, and special populations?
2. What are the implications and opportunities for future research and funding that are emphasized in VR in education research based on what is being funded and gaps in funding for Virtual Reality for education and training by NSF between January 2015 and February 2022, according to learning context, learning domain, subject, type of VR use, and special population?

3 Method

This study follows the 2020 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement guidelines [10], which include a content analysis of the extracted data. NSF funded grants were identified using the NSF award search, limited to the time between January 2015 and February 2022, using the search terms “virtual Reality” + Education and “Virtual Reality” + training. For each funded grant, we retrieved the abstract, title, start date, NSF directorate, NSF organization, NSF program, the organization that received the funding, the US state in which the recipient is located, and the funding amount.

3.1 Search Strategy and Selection Process

The search was conducted on February 28, 2022. The search was conducted on the NSF Awards Search Advanced page (NSF Award Search: Advanced Search.) and included expired and active awards. The search term was “virtual reality” (including the quotation marks). The search of NSF-funded abstracts between January 2015 and February 2022 resulted in 605 awards. Of those (active and expired awards), 21 were duplicates, and 460 were excluded for the following reasons: did not involve substantive use of VR, was not focused on education, or some combination of these. The remaining 160 grants were analyzed as described below (see fig. 1).

Each record was independently reviewed by two members of the research team. Notion was selected as the software management tool to abstract and organize data.

3.2 Initial Documentation

For every grant that was assessed, we examined the abstract, which was the sole description of the project that was accessible to the public and could potentially clarify its substance and methodologies. We extracted study characteristics and conducted a content analysis to define emerging themes to synthesize findings. Each author extracted an initial 30 abstracts to identify a coding frame. With an initial coding criteria established, two authors coded another 50 projects, with a third solving discrepancies. This replication test improved validation and an extension of the initial coding frame. The coding frame that emerged included learning context, learning domain, subject, type of VR use, scientific contribution, and special populations. The remaining abstracts were coded by two authors, with an even distribution by authorship.

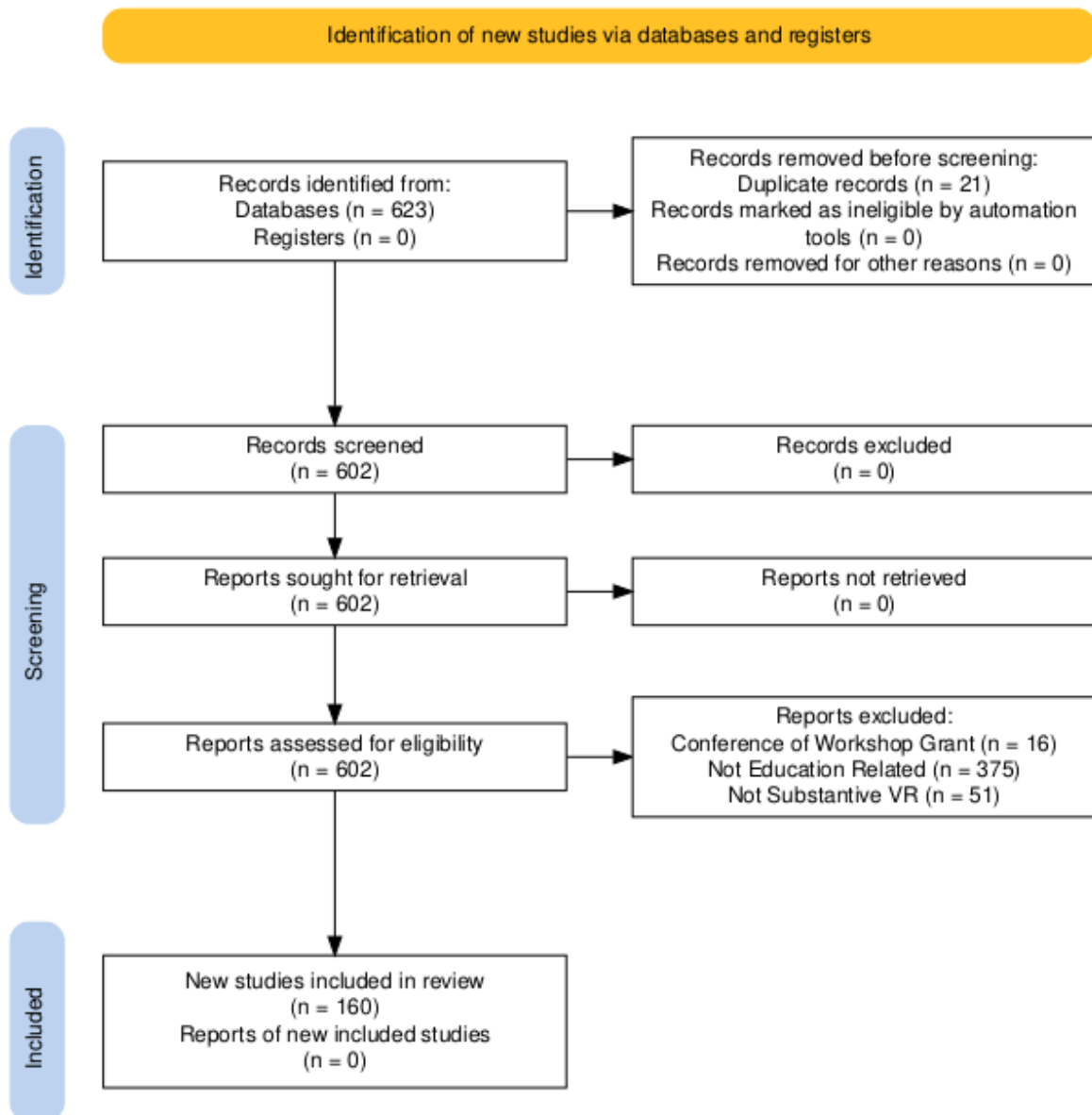


Fig. 1.: PRISMA Flow Diagram of VR Funded Projects.

Note: Prisma diagram generated by Prisma diagram generator [11].

3.3 Exclusion Criteria

The following section details the exclusion criteria for the review. Exclusion criteria are specified conditions or factors that disqualify prospective subjects from study participation. For this study, the following operational definitions are provided for each exclusion criterion:

The first criterion pertains to the relevance of the subject matter, specifically, whether it is education-related or not. For the purposes of this study, the term Not Education Related refers to any research, initiative, or project that does not have a primary or significant focus on learning, teaching, curriculum development, or other educational practices and policies. In other words, if the subject matter does not involve the process of educating or learning in some capacity, it is considered not education-related and is therefore excluded from this study.

The second exclusion criterion is Not substantive VR. In the context of this study, "VR" refers to Virtual Reality, a simulated experience that can be similar to or completely different from the real world. The term "substantive" refers to something having a firm basis in reality and therefore important, meaningful, or considerable. For this study, "Not substantive VR" refers to projects, initiatives, or studies that either do not use

virtual reality technology in a significant way or use it in a way that lacks depth or meaningful impact. Any research or initiative that does not involve substantial use of virtual reality technology is excluded from this study.

The third exclusion criterion, Workshop/conference grant (e.g. doctoral consortium) refers to funding specifically dedicated to workshops, conferences, or similar events. In this context, a doctoral consortium would be an academic conference for PhD students to present and receive feedback on their work (i.e., poster, roundtable, and paper presentations).

In accordance with each exclusion criteria, each included project was coded according to the following:

1. Learning Context (PreK, elementary, middle grades, high school, higher education, job training, rehabilitation, informal)
2. Subject
 - a. We used the College Board college major list used by the SAT and added the topic “diversity,” referring to the content of the VR experience [12].
3. Learning Domain (cognitive, affective, psychomotor) Based on Bloom’s Taxonomy [13].
 - a. Cognitive (Mental skills /knowledge)
 - b. Psychomotor (Manual or physical skills)
 - c. Affective (Skills that foster appropriate emotional responses /Attitude)
4. Type of VR Use (new platform, new content, use existing content)
5. Special Populations (gender, race, ethnicity, learners with a specified disability)
6. When coding, no new tags were added. To group categories for syntheses, we deleted the category for “Interdisciplinary” and we combined “Theory and Religious Vocations” with “Philosophy and Religion”.

4 Results

The systematic review of NSF award abstracts for grants that supported virtual reality for education or training between 2015 and 2022 began with 623 records. After 21 duplicates were removed, 602 remained for analysis by the research team. Given our purpose of looking at education and training virtual reality projects funded, studies that were not primarily education-related were excluded. For example, NSF grant #1636992, which was for the development of a body suit for VR, was excluded. Additionally, many grants have an educational component in their dissemination plans, but we excluded these grants if the primary focus of the grant was not education. For example, NSF grant #2047793 includes the educational component of disseminating “research and educational outcomes to a wide audience, including K-12 students, professionals, and the public using Virtual Reality-based and simulation platforms,” but the primary focus of the grant is the development of traffic management systems. Thus, this grant was not included.

Table 1: Excluded grants and reason for exclusion.

Doctoral Consortium or Conference Grant	13
Doctoral Consortium or Conference Grant, not education-related	3
Not education-related	380
Not substantive VR	46
Total	442

4.1 Included Studies and Characteristics

After removing the grants that did not meet our criteria, 160 relevant awards remained. Encompassing the 160 abstracts, the most common scientific contribution is to enhance and improve the learning experience by leveraging VR technology. Some specific areas of contribution include improving STEM education and teaching, improving job training and language learning, enhancing physical therapy and rehabilitation, improving understanding of student experience and metacognitive skills, and developing best practices for integrating VR into geoscience education.

Type of VR use, learning domain, and award instrument are detailed in Table 2. As evidenced, VR is primarily being used to generate new content, with a focus on cognition, primarily through a new standard grant.

Table 2. Type of VR Use, Learning Domain, and Award Instrument.

Type of VR Use	<i>n</i>	Learning Domain	<i>n</i>	Award Instrument	<i>n</i>
New Content	89	Cognitive	140	Standard Grant	150
Not Stated	46	Psychomotor	57	Continuing Grant	40
New Platform	38	Affective	31	Cooperative Agreement	3
Uses Existing Content	23			Fellowship Award	2
New Theoretical Model	7				

When more than five codes in each category appear, we report the top five in narrative format and include full details in the figures.

Higher education contexts comprise the largest category of NSF funded VR projects (see Figure 3). All of these funded projects sought to improve teaching and learning pedagogy and practices within the context of higher education. Content analysis revealed an emphasis on engineering, computer science, and data science contexts, with a focus on cybersecurity education, and the design of immersive environments to improve data visualization and STEM learning.

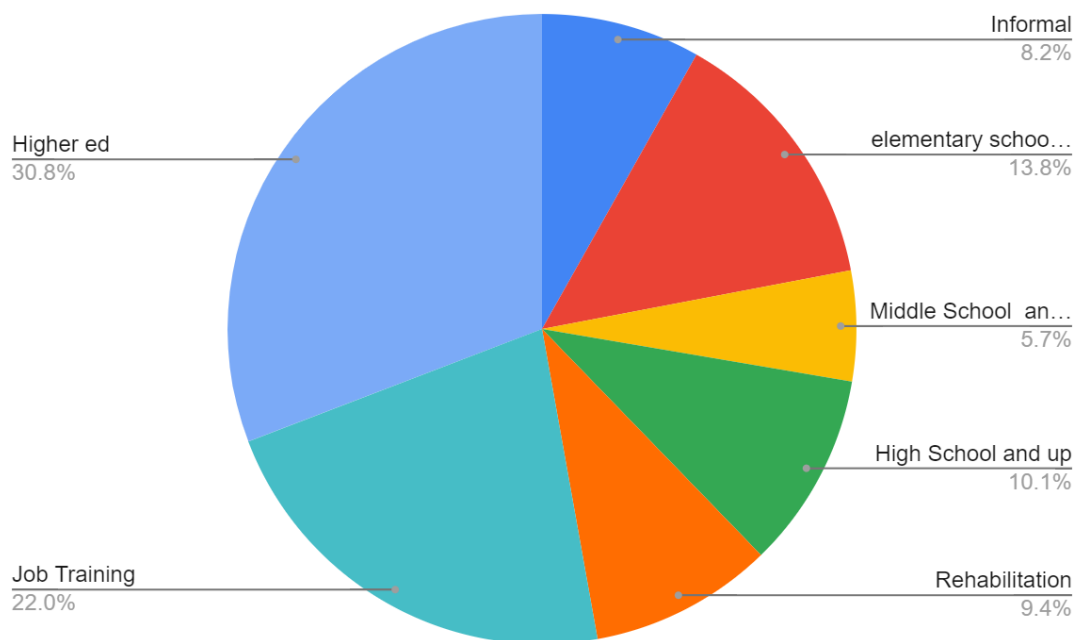


Fig. 3. VR Funded Projects by Context.

Several projects aim to improve accessibility and inclusivity in higher education through the use of VR. For example, one project adapts VR hardware for wheelchair users and creates an immersive archaeology class, offering fieldwork experiences that might otherwise be inaccessible. Another project proposes to develop virtual teaching spaces and personalized learning environments to reduce barriers for junior colleges, fostering collaboration, partnerships, and knowledge dissemination to enhance technical education programs.

Furthermore, the integration of VR in STEM education is a prominent focus of several NSF projects. These initiatives leverage data science to correlate student performance in VR lessons with their classroom performance, refining the VR pedagogy and improving learning outcomes. Moreover, the projects aim to address the shortage of cybersecurity education and research in VR, generate model-based systems for engineering education, and infuse Industry 4.0 concepts into engineering design and manufacturing through the use of VR and AR technologies.

The top five most funded subjects include Physical Sciences ($n = 17$), Engineering, Mathematics and Statistics, Physical Sciences: ($n = 11$), Health Professions ($n = 10$), Teacher Education ($n = 7$), and Engineering Technologies ($n = 7$). A majority of NSF funding for educational content in VR is focused on scientific, technical, and

vocational subjects, with minimal funding for the social sciences and the humanities. The top five subject categories were the physical sciences (n = 37), engineering (n = 25), math and statistics (n = 22), engineering technologies (n = 21), and health professions (n = 18). By contrast, non-scientific subjects were awarded many fewer grants, with the top subjects in these categories being teacher education (n = 14), psychology (n = 6), social sciences (n = 5), history (n = 2), and communication and journalism (n = 2).

Table 3. NSF Directorates Funding of VR for Education and Training.

Education and Human Resources (EHR)	64
Computer and Information Science and Engineering (CISE)	34
Engineering	34
Geosciences	11
Social, Behavioral, and Economic Sciences	5
Mathematical and Physical Sciences	3
Biological Sciences	3
Office of the Director	6
	160

Table 4. NSF Top 5 Organizations Funding of VR for Education and Training.

Division of Undergraduate Education (DUE)	39
Industrial Innovation and Partnerships (IIP)	27
Division of Information and Intelligent Systems (IIS)	24
Division of Research on Learning in Formal and Informal Settings (DRL)	13
Division of Computer and Network Systems (CNS)	8

Table 5. NSF Top 12 Programs Funding of VR for Education and Training.

Advanced Tech Education Prog	16
SBIR (Phase I and Phase II)	15
I-Corps	12
FW-HTF/Convergence Accelerator Futr Wrk Hum-Tech Frntr	11
IUSE	10
HCC-Human-Centered Computing	8
Hist Black Colleges and Universities & Hispanic Serving Inst.	7
Cyberlearn & Future Learn Tech	5
RSCH EXPER FOR UNDERGRAD SITES	4
AISL (Advancing Informal Science Learning)	4
ECR-EHR Core Research	4
Major Research Instrumentation	4

Grants focusing on special populations (gender, race, ethnicity, disability) made up 34% of the funded proposals (n = 54). VR projects for education and training focusing on underrepresented groups (identified in proposals as underrepresented, indigenous, Latinx, HBCU students, or women) (n = 31) are a large focus of NSF funding. Special populations focused on autism spectrum disorder (n = 9) emphasize rehabilitation and on the job training, followed by elementary and high-school settings. With the ASD (Autism-Spectrum Disorder) population, VR is being used as a tool to teach and enhance social-emotional skills of individuals with developmental disabilities, as well as to provide a platform for medical rehabilitation. These projects aim to provide a realistic and practical learning environment, while also addressing the needs of individuals with developmental disabilities and

neurodegenerative diseases. The VR environments are designed to promote the transfer of skills from the virtual environment to real-life scenarios that individuals regularly encounter. One such project, called vSocial, uses an immersive VR medium to connect children with ASD from different geographical regions for online social training. The project aims to bridge the knowledge gap between online social training and real-world social skills for students with ASD, by using a networked immersive VR system. Similarly, another project implements innovative therapy for children with attention deficit on the autism spectrum. Virtual reality technology is used to create "impossible experiences," which are experiences that cannot be created in the real world, to address the attention deficits of some children with autism. The system employs eye-tracking data and physiological signals to detect the user's attention and remove distractions from the virtual environment. The system then gradually restores the distractions and reinforces the desired behaviors. Another project involves the development of a software suite of modular web applications to guide medical rehabilitation from neurodegenerative diseases, which could also be used to help people with ASD. The technology uses gamification, incentivization, and machine learning, integrated with mobile games, to provide a more engaging and interactive experience for patients.

Table 6. Special Populations (top 5).

Underrepresented	31
Autism Spectrum	10
Rural	7
Hearing-Impaired	4
Other Disabilities	4

5 Discussion

Where previous research that is tangentially related focused on NSF funding amounts (Huang et al., 2016; Markowitz, 2019), it is our understanding that this is the first review study to analyze NSF funded VR abstracts for their characteristics, with the intention of acknowledging the funder's foci in regard to population, context, and NSF programs. As researchers with a focus on immersive technologies to advance learning, we are aware of the competitive nature of NSF funding. To better understand the landscape and help other scholars be more successful at obtaining funding, we sought to investigate what projects are funded with a focus on VR in education.

While 129 of the 160 articles included mentioned STEM, this systematic review of the abstracts provided a deeper delineation of the focused areas of STEM. This demonstrates a trend that one would expect, the NSF favoring science. This also represents a possible gap in the VR for education and training, as relative to scientific and technical subjects, VR application in fields such as the humanities and social sciences are minimal in number. Similarly, this demonstrates a space for more interdisciplinary work utilizing emerging technologies, such as VR to advance social science or humanities while also advancing basic science and learning sciences.

5.1 Included Studies and Characteristics/Excluded Grants by Exclusion Criteria

The most common reason for exclusion from the systematic review was "not substantive VR," as this category emerged as many proposals mentioned virtual reality, but did not intentionally specify the type of VR device, hardware or software, and also failed to explain implementation. This did create some limits to some of the conclusions that could be drawn from our systematic review.

The results regarding the type of VR used and the learning domain should be of interest to VR researchers. Virtual reality is known to provide affordances particularly useful for psychomotor skills, affective, cognition, and higher order thinking skills [14]. However, the majority of the funded projects do not indicate in their abstracts any intention to go beyond the acquisition of basic cognitive skills. This indicates an underutilization of the affordances of VR.

Another telling finding in the data is the prevalence of VR research in the content areas of the Physical sciences. This is noteworthy, as there are very few affordable tools currently available that can be used in VR to teach even though it's very difficult to find VR to teach physical sciences. This raises questions as to why the interventions and strategies being researched are not commonly available to the public. Is this an indication of research that does not yield actionable research findings, or is this a problem with the research to citizen pipeline?

5.2 NSF Organization/ Directorate

The fact that 82.5% of NSF funding researching virtual reality for education came from three of the seven directorates. The Education and Human Resources (EHR) directorate led funding of VR research for education and training (n = 64), followed by Computer and Information Science and Engineering (CISE) (n = 34), and Engineering (n = 34) directorates. This aligns with objectives of these directorates. Education and Human Resources (EHR), recently renamed to STEM Education (EDU), has a mission to support excellence in U.S. STEM education in the preparation of a diverse workforce of well-prepared scientists, engineers, technicians, mathematicians, and educators.

5.3 Study Limitations

Study limitations acknowledge that only NSF abstracts were included in the analysis, as they are the only part of the proposal available in the NSF award search, which could leave some elements that were more deeply discussed in the full proposal out of this analysis. For instance, the analysis of the reported type of VR use, indicated that 22% of proposals did not indicate the type of VR use. Unfortunately, it is impossible for any research team to access and analyze the full proposals to investigate if full proposals had more details about the type of VR specifications and detailed uses.

Another limitation of the study is the narrow scope of VR projects instead of all immersive technologies. While it would be interesting to explore the trends of all immersive technology used for education and training, the search criteria for this study was very specifically looking at VR. This was driven by the very specific questions of VR support after the emergence of virtual reality as a commercially available tool in 2015.

5.4 Study Implications

Practical implications include the ability for scholars to identify areas of need and ideas for integrating VR, so that they can write a robust and high-quality grant proposal. We suggest the NSF incorporate discrete categories for special populations to ensure that various terms (e.g., underserved, under-resourced, marginalized, minoritized, etc.) are used consistently and that it is possible to track funding allocation by special population. Existing research has demonstrated disparities in research funding [15], likelihood to seek funding [16, 17], and research activity [18]. Disparities in research activity are directly connected to disparities in funding. Without adequate funding, researchers face limitations in conducting their work due to lack of infrastructure, inability to engage in networking activities, and lack of staffing and other support [19]. The authors of this systematic review intend to provide these deep insights to be leveraged by individuals who may not have experience with NSF funding or insights from academic colleagues into successfully writing grant proposals.

5.5 Future Research

The purpose of this study was to provide guidance for research opportunities through the lens of funding trends and gaps in the research. Specifically, to guide scholars in understanding what NSF funds and where, to gain a sense of what is significant to the funders. In addition to the research here providing guidance to scholars interested in work related to virtual reality for education and training, our methods can be replicated to provide anyone looking to better understand the trends and gaps in their research area for NSF or any other agency with publicly available databases of funded projects.

6 Conclusion

Understanding the NSF's programs and initiatives can potentially be transformative as part of a researcher's career and research aspirations. Understanding NSF funding trends and priorities can help researchers discover funding opportunities, foster collaboration, access resources and facilities, engage in professional development, and impact broader impacts. In addition to the contributions this systematic review provides for researchers, the approach and outcomes can be useful for NSF personnel when considering how funding is distributed and to address any inequitable gaps that may exist.

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