

Review Article

Grand Challenges as Educational Innovations in Higher Education: A Scoping Review of the Literature

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Grand challenges are complex problems that are common to much of society, affect large populations, and may have several possible solutions. Incorporation of grand challenges into higher education courses can facilitate the development of collaborative problem-solving skills while providing relevant and practical opportunities to experience the dynamics involved in real-world work. Although grand challenges are becoming more commonly used in higher education, to date, there has been no synthesis of how grand challenges are incorporated and the learning outcomes of engaging in grand challenge work. In this scoping review, we examined and mapped the state of evidence for the use of grand challenges in higher education. We conducted the review according to the Johanna Briggs Institute methodology for scoping reviews and considered quantitative, qualitative, and mixed-methods studies as well as literature reviews, program descriptions, and opinion papers published in English without limitations on year of publication. We used a data extraction tool to synthesize and present our findings in a tabular form with accompanying narrative summaries. The results reveal a growing global interest in the use of grand challenges in higher education while highlighting a lack of rigorous empirical evidence on the impact on student learning.

1. Introduction

Today's complex workplace environments demand higher education institutions to prepare graduates who are ready to tackle society's most pressing challenges. However, present-day education may not adequately prepare students for problem-solving approaches required of our modern workforce. Implementing grand challenges within higher education courses may help prepare students to engage in innovative solutions to complex problems.

2. Grand Challenges

The concept of grand challenges was first introduced by a German mathematician in 1900, who established 23 problems to foster dialog among mathematicians, spark the development of the discipline, and focus attention on unresolved issues [1]. Different from general disciplinary

problems, grand challenges pose greater demands for coordinated and collaborative efforts [1], because they affect large populations, and cannot be effectively tackled by an individual organization, community, or discipline [2]. Fundamentally, grand challenges are global and common to much of society [1], which implies that their impact goes beyond a single discipline due to their complexity [2], long-term horizon, and wickedness [3]. Given the dynamic nature of grand challenges, it is difficult to develop simple solutions because they can take several years or decades to emerge and their impact may extend to future generations [4]. Grand challenges are often wicked in that they present large-scale common design problems that may have several possible solutions [2, 5].

2.1. Societal Grand Challenges. The distinctive feature of societal grand challenges is that they are highly significant

and potentially solvable [6]. Societal grand challenges are phenomena with global impacts such as environmental and human health [7], global hunger, urban poverty [6], climate change, ageing societies, natural resources depletion, and gender inequality [1]. These phenomena are common to various degrees across the world.

2.2. Addressing Grand Challenges. Addressing a grand challenge requires inclusive leadership that actively seeks out the ideas and input of individuals within and outside the team. Including multiple perspectives provides a better understanding of the complex components of the problem and may lead to a contemporary solution. In business, collaboration among multiple team members from different departments is a common practice to produce solutions for product or service innovation [8]. Kania and Kramer [9] argued that “collective impact initiatives depend on a diverse group of stakeholders working together, not by requiring that all participants do the same thing, but by encouraging each participant to undertake the specific set of activities at which it excels in a way that supports and is coordinated with the actions of others” (p. 40). Such an inclusive approach is crucial considering that many of the most pressing global problems involve and impact individuals from multiple locations, professions, and worldviews.

2.3. Grand Challenges as Pedagogical Innovations. Developing solutions to grand challenges as a pedagogical approach has resulted in deep learning for students [10]. Researchers found when instructors incorporated grand challenges into courses, it facilitated the development of collaborative problem-solving skills while providing relevant and practical opportunities to experience the dynamics involved in real-world work [11]. In the field of engineering, grand challenge courses have been designed to promote collaborative problem-solving skills where students need to tackle diverse engineering challenges and integrate ideas to generate a final solution which was highlighted as a critical component [12]. Promoting collaborative processes and involving multiple students to address grand challenges provided relevant and practical opportunities to experience the dynamics involved in the real-world work of an engineer [11].

Experiential learning such as grand challenge work that requires hands-on and applied learning opportunities can have a positive and powerful impact on the quality and meaning of learning experiences [13]. There is sound pedagogical evidence for incorporating experiential approaches into higher education courses. Kuh’s [14] influential research on high impact practices demonstrated that experiential learning experiences have a significant impact on students’ overall academic success. Employers often seek job applicants with leadership, communication, and problem-solving skills that can be developed through well-designed and effective experiential learning opportunities [15]. As well, the emerging field of learning neuroscience supports experiential learning as being key to long-term memory acquisition [16]. As noted by Kolb and Kolb [17], “when a

concrete experience is enriched by reflection, given meaning by thinking, and transformed by action, the new experience created becomes richer, broader, and deeper” (p. 309).

Although grand challenges are being more commonly used in higher education and have been implemented in several disciplines, Ferraro et al. [2] argued more research is needed to understand effective teaching strategies for carrying out grand challenge work, developing grand challenge solutions, and evaluating their impact. While there is emerging evidence that suggests engaging with grand challenges results in deep learning for students, the extent of evidence regarding the benefits of incorporating grand challenges into higher education learning opportunities has not yet been established. To date, there has been no synthesis of how grand challenges are incorporated and the learning outcomes of engaging in grand challenge work. The overarching objective of this review was to examine and map the state of evidence for the use of grand challenges in higher education.

2.4. Review Questions

- (1) In what contexts are grand challenges being used in higher education?
- (2) What learning objectives and assignments are used in higher education courses that incorporate grand challenges?
- (3) What types of outcomes have been reported in the literature related to the implementation of grand challenges in higher education classrooms?
- (4) What are the gaps in evidence for the use of grand challenges in higher education?

3. Methods

3.1. Design. Various systematic approaches are available for reviewing published literature. Scoping reviews are a rigorous and methodical approach to examine the extent, range, and nature of research activity in a particular field. This scoping review was conducted in accordance with Joanna Briggs Institute (JBI) methodology for scoping reviews [18] and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis for Scoping Reviews Extensions for Scoping Reviews (PRISMA-ScR) [19]. This scoping review methodology guided us to broadly examine and comprehensively and systematically map the grand challenge literature, summarize research findings, and identify gaps where further research is required.

3.2. Eligibility Criteria. For the purpose of this review, grand challenges were defined as complex problems that are common to much of society, affect large populations, and may have several possible solutions. Literature was eligible for inclusion if it focused on undergraduate or graduate students and/or instructors engaged in formal higher education settings where the application of grand challenges was integrated with or applied in the teaching and learning

TABLE 1: Search strategy in ERIC.

#	Query	Results
S1	TI ((Grand or global or societ* or world) N1 challenge*) OR KW ((Grand or global or societ* or world) N1 challenge*) OR AB ((Grand or global or societ* or world) N1 challenge*)	841
S2	TI (challenging N1 (“social problem*” or “global problem*” or “world problem*”)) OR KW (challenging N1 (“social problem*” or “global problem*” or “world problem*”)) OR AB (challenging N1 (“social problem*” or “global problem*” or “world problem*”))	8
S3	TI “integrate module*” OR KW “integrate module*” OR AB “integrate module*”	4
S4	TI “big idea*” OR KW “big idea*” OR AB “big idea*”	486
S5	TI Hackathon* OR KW Hackathon* OR AB Hackathon*	11
S6	DE “Problem Solving” AND (DE “Social Problems” OR DE “Social Change” OR DE “Global Approach” OR DE “Science and Society” OR DE “World Problems”)	1,146
S7	S1 OR S2 OR S3 OR S4 OR S5 OR S6	2,478
S8	DE “Higher Education” OR DE “Postsecondary Education” OR DE “Universities” or DE “Colleges”	492,640
S9	DE “Graduate Study” OR DE “Postdoctoral Education” OR DE “Doctoral Programs” OR DE “Graduate Students” OR DE “Masters Programs”	35,506
S10	DE “Undergraduate Students” OR DE “College Students” OR DE “College Freshmen” OR DE “Undergraduate Study”	139,647
S11	DE “College Faculty” OR DE “College Instruction”	53,752
S12	DE “Educational Research” OR DE “Professional Education”	64,232
S13	TI (undergraduate* or graduate* or doctoral* or student* or professor* or instructor* or faculty or “preservice teacher*” or “pre-service teacher*”) OR KW (undergraduate* or graduate* or doctoral* or student* or professor* or instructor* or faculty or “preservice teacher*” or “pre-service teacher*”) OR AB (undergraduate* or graduate* or doctoral* or student* or professor* or instructor* or faculty or “preservice teacher*” or “pre-service teacher*”) OR KW (academic or “higher education” or universit* or college* or postsecondary or post-secondary) OR KW (academic or “higher education” or universit* or college* or postsecondary or post-secondary)	776,672
S14	TI (academic or “higher education” or universit* or college* or postsecondary or post-secondary) OR KW (academic or “higher education” or universit* or college* or postsecondary or post-secondary) OR AB (academic or “higher education” or universit* or college* or postsecondary or post-secondary)	471,711
S15	S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14	1,033,468
S16	S7 AND S15	1,696
S17	Narrow by Language: English Excluded dissertations, books	1,538

process to identify potential solutions. Primary research studies including qualitative, quantitative, and mixed-methods studies were eligible. In addition, literature reviews as well as text and opinion papers that met the inclusion criteria were considered. Only studies written in English were included due to difficulty in obtaining foreign language studies and the lack of language capabilities of the team.

We excluded dissertations, books, book chapters, book reviews, websites, and conference abstracts that did not include a full-text paper. Literature studies that focused on K-12 students or educators were also excluded. Literature studies that included grand challenges in higher education teaching and learning but did not attempt to identify a solution were also excluded.

3.3. Information Sources and Search Strategy. We followed the JBI scoping review method which includes a three-step search strategy. First, an experienced health sciences librarian conducted an exploratory search of the truncated phrase “global challenge*” in a multidatabase search on the EBSCO platform. The four databases searched simultaneously included: Academic Search Complete, CINAHL, ERIC, and GeoRef. The exploratory search helped to identify key studies, relevant keywords in the titles and abstracts, as well as the subject headings. This analysis informed the development of a draft search in ERIC, the prime education database. The draft search was piloted to ensure that all key

studies were retrieved. The second step included finalizing the ERIC search strategy (Table 1), which was then adapted for all other databases, taking into account database syntax and thesaurus. In order to conduct a thorough investigation into grand challenges in postsecondary environments, both disciplinary and interdisciplinary databases were searched from inception until May 3, 2020. Disciplinary databases searched include the following:

- (i) EBSCO databases: Business Source Complete, CINAHL Plus with Full Text, Education Research Complete, Environment Complete, ERIC, GeoRef, SocINDEX with Full Text, and Social Work Abstracts
- (ii) OVID databases: MEDLINE, Embase, and APA PsycINFO
- (iii) ProQuest databases: Sociological Abstracts
- (iv) Other databases: Compendex and IEEE Xplore

Interdisciplinary databases searched included Academic Search Complete (EBSCO), Scopus, and Web of Science. Relevant sources of unpublished studies and grey literature were searched including American Educational Research Association, Annual Conference on Higher Education Pedagogy, Association for the Study of Higher Education, Canadian Society for the Study of Higher Education, EuroSoTL, Higher Education Research and Development Society of Australasia, International Society for the Scholarship of Teaching and

Learning, Lilly National Conference on College and University Teaching and Learning, Midwest SoTL Conference, Society of Teaching and Learning in Higher Education, SoTL Commons, SoTL in the South Conference, and Symposium on Scholarship of Teaching and Learning. Finally, the third step involved snowball searching, where the references and cited bys of included studies were screened for additional studies.

3.4. Source of Evidence Selection. Following the search, all identified records were exported and uploaded into Covidence (Covidence, Melbourne, Australia) and were then deduplicated using Covidence's deduplication function. We conducted pilot testing on a random sample of 25 titles/abstracts and the team screened this sample using our predefined inclusion criteria. We discussed any discrepancies and clarified the inclusion and exclusion criteria to ensure consistency across the team. Once we achieved greater than 75% agreement across team members, all titles and abstracts were screened by two independent reviewers for assessment against the inclusion criteria. A third reviewer resolved conflicts in the title and abstract review. Literature studies that met the inclusion criteria were retrieved in full and assessed in detail by two independent reviewers against the inclusion criteria. Full-text studies that did not meet the inclusion criteria were excluded, and reasons for exclusion were provided. Disagreements that arose between two reviewers were resolved by a third reviewer.

3.5. Data Extraction. We used a descriptive analytical method to extract contextual information from included literature. The review team developed a data extraction tool that we continually updated as new key findings emerged. We piloted the data extraction form on a random sample of 10 included articles to ensure consistency amongst the review team. Each included article was extracted by one team member using a standardized data extraction tool and was then verified by a second reviewer. Weekly meetings were held amongst team members to determine consistency in approach to data extraction. The data extracted included year, authors, publication title, journal, country, institutional affiliation, discipline, context/population, course description, course objectives, grand challenge topic, course assignments, study characteristics, and key findings in relation to the review questions. Any disagreements that arose between the reviewers were resolved through discussion and/or a third reviewer.

3.6. Data Synthesis. Our synthesis included quantitative analysis using a simple numerical count and qualitative analysis using narrative synthesis in alignment with the objective of this scoping review. Article characteristics, grand challenge courses, and studies related to grand challenges in higher education were summarized in table formats. Narrative summaries were also conducted to add depth to the synthesis.

4. Results

After screening 8945 citations and 558 full-text papers, 55 papers met the inclusion criteria and were included in this scoping review ($n = 55$). The flow of data through our review is depicted in Figure 1.

Table 2 displays the characteristics of the literature. The majority of literature came from the United States ($n = 40$, 72.7%) followed by the United Kingdom ($n = 5$, 9.1%). Prior to 2010, there were only 4 articles published on the use of grand challenges in higher education; however, the numbers have been climbing since, with 10 articles (18.2%) published in 2019 alone. The majority of literature focused on multidisciplinary teams of higher education students ($n = 26$, 47.3%), followed by engineering students alone ($n = 18$, 32.7%). Most of the grand challenge literature focused on undergraduate students ($n = 36$, 65.5%) followed by a mix of both undergraduate and graduate students ($n = 10$, 18.2%), then graduate students ($n = 9$, 16.4%). Almost every article included a description of a grand challenge course ($n = 54$, 98.1%), while only 25 articles (45.5%) included program evaluation or study data.

Multiple categories of grand challenges were addressed in the literature, the majority of which discussed sustainability issues and food and water insecurity. The topic of environmental sustainability encompassed a variety of challenges from sustainable agricultural practices to environmental health risks, such as soil erosion [20], creating sustainable energy required for developing affordable renewable energy sources, such as solar power [21]. For instance, Heinricher and colleagues [22] described a grand challenge that explored how to power up the world where the focus was on designing future energy-efficient homes and vehicles, such as green roofs and hydrogen cars. Other projects aimed at mitigating climate change through pollution sensors or carbon dioxide sequestration [23]. However, some of the major challenges in developing countries include food and water insecurity, and higher education students sought to combat these issues through the reduction of food waste and river cleaning robots [22, 23]. In addition, world health grand challenges encompassed a wide variety of topics from advancing health informatics to engineering better medicines and improving resource allocation between hospitals [21, 24]. Some developing countries struggled with mosquito-borne illnesses, such as malaria, and therefore, students were given the opportunity to develop solutions through the use of drones at California State University [25]. Other than preventing health risks, grand challenges also focused on improving urban infrastructure through sustainable cities and communities as well as strived to attain world peace through the prevention of nuclear terror and mitigating global violence [21].

Table 3 displays the summary of the grand challenge courses described in the literature. More than half of the courses ($n = 28$, 51.8%) included multidisciplinary (or interdisciplinary) learning as their primary course objective. Encouraging students to think and plan collaboratively, being part of an interdisciplinary team, along with the promotion of interdisciplinary knowledge, was recognized

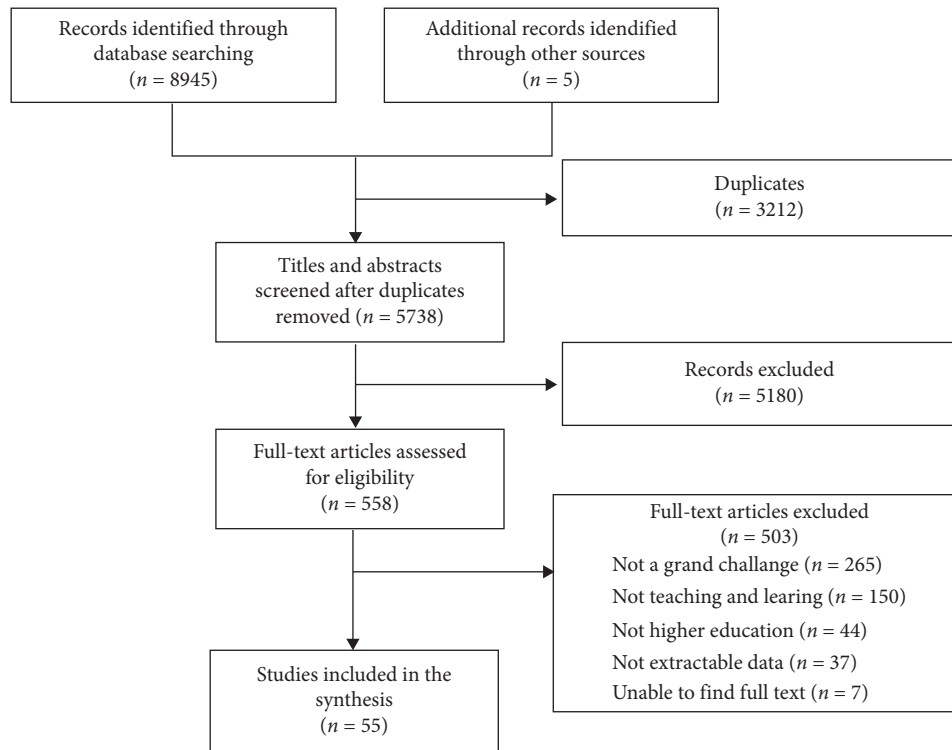


FIGURE 1: PRISMA flow diagram.

as a consistent objective in the courses. Many of the courses ($n = 16$, 29.6%) mentioned preparing students to develop innovative solutions to global problems while promoting the concept of sustainability as their major course objective [26, 46]. Enhancing the problem-solving skills of the students with evidence-based learning concepts was recognized as another common course objective ($n = 11$, 16.6%) in the literature discussed. This included an improved ability to identify and understand the problem, work and plan around the available resources, and eventually develop viable solutions.

More than half of the articles ($n = 28$, 51.8%) mentioned some type of student professional development as a common course learning objective. Equipping the students with enhanced professional skills and promoting their career readiness was identified as a major aim. Improved communication skills [39], leadership [49], teamwork [67], and superior critical and strategic thinking abilities [22, 43] were the common listed professional skills in the course objectives. Furthermore, refining the systems and entrepreneurial thinking of students [55] to make them more competent and competitive globally was listed as another common course objective. A few courses mentioned improved subject knowledge and modifications in the educational curriculum as their course learning objective [62].

Table 4 displays the summary of the grand challenge course assessments used in the grand challenge courses. The majority of courses included the use of design thinking projects ($n = 48$, 88.9%) and presentations ($n = 26$, 48.1%) as course assessments. Design thinking projects included problem-solving to propose creative solutions. Presentations

took place within a course, at conferences, and as part of hackathons or competitions allowing students to demonstrate their knowledge to peers, students, instructors, and stakeholders. A few courses also mentioned the use of essays or reports ($n = 13$, 24%) and active discussions ($n = 11$, 20.3%) as course assessments. These assessment tools promote the development of transferable professional skills among students including verbal and written communication, leadership, critical thinking, and adaptability.

Table 5 displays an overview of the studies on the use of grand challenges in higher education classrooms. Students perceptions, opinions, and preferences in relation to grand challenge courses were most commonly explored ($n = 12$, 48%) [25, 28, 39, 45, 51, 57, 61, 63, 66–68, 72]. Eight studies (32%) aimed to assess students learning and knowledge development from participation in a grand challenge course [25, 28, 39, 40, 43, 62, 64, 66]. Skills development was explored in six studies (24%) [35, 44, 59, 61, 63, 67] while five studies ($n = 20$) focused on evaluating the grand challenge courses themselves [20, 24, 30, 38, 67]. Only two studies (8%) focused on evaluating outputs of the grand challenge course and the impacts they may have on problem-solving attempts [31, 36].

Of the 25 studies identified in this review, the majority ($n = 10$, 40%) were mixed-methods studies most commonly using surveys, focus groups, and interviews. Eight studies used qualitative methods only including focus groups, interviews, and reflective assignments (32%), and six used quantitative surveys (24%). One study included data on students' perceptions of a course without indicating how data were collected [45].

TABLE 2: Literature characteristics.

Characteristic	<i>n</i>	%
<i>Country</i>		
USA	40	72.7
United Kingdom	5	9.1
Australia	4	7.3
Netherlands	3	5.5
Brazil	2	3.6
Canada	2	3.6
Sweden	2	3.6
China	1	1.8
Denmark	1	1.8
Italy	1	1.8
Luxembourg	1	1.8
Singapore	1	1.8
Switzerland	1	1.8
Tanzania	1	1.8
<i>Year</i>		
Pre 2010	4	7.3
2010	3	5.5
2011	3	5.5
2012	1	1.8
2013	4	7.3
2014	3	5.5
2015	3	5.5
2016	7	12.7
2017	7	12.7
2018	9	16.4
2019	10	18.2
2020	1	1.8
<i>Discipline</i>		
Multidisciplinary	26	47.3
Engineering	18	32.7
Chemistry	2	3.6
Social Work	2	3.6
Biology	1	1.8
Biotechnology	1	1.8
Business	1	1.8
Geoscience	1	1.8
Global Health	1	1.8
Political Science	1	1.8
Social Science	1	1.8
<i>Grand Challenge Topics</i>		
Environmental Sustainability	26	47.3
Sustainable Energy	18	32.7
Climate Change/Global Warming	16	29.1
Food Insecurity	16	29.1
Water Insecurity	16	29.1
World Health	15	27.3
Sustainable Cities and Communities	8	14.5
World Peace	8	14.5
Poverty	7	12.7
Waste Management	6	10.9
Quality Education	5	9.1
Housing Crisis/Homelessness	4	7.3
Improving nutrition	4	7.3
Political Participation/Social Justice	4	7.3
Natural Disasters	4	7.3
Sustainable Transportation	4	7.3
Increasing Exercise/ Obesity	3	5.5
Sanitation in developing countries	3	5.5
Population Growth/Immigration	2	3.6

TABLE 2: Continued.

Characteristic	<i>n</i>	%
Family Violence	1	1.8
Gender Inequality	1	1.8
Reducing Drunk Driving	1	1.8
Refugee Crisis	1	1.8
<i>Students</i>		
Undergraduate students	36	65.5
Undergraduate and Graduate Students	10	18.2
Graduate Students (Masters and PhD)	9	16.4
<i>Types of literature</i>		
Course descriptions	54	98.1
Studies	25	45.5
Quantitative studies	6	24
Qualitative studies	8	32
Mixed methods studies	10	40
Unclear	1	4

Country: some literature had more than one country affiliation. Grand challenge topics: some literature looked at multiple grand challenge topics. Types of literature: some literature included both course descriptions and studies.

The authors reported on four main outcomes: (1) course satisfaction, (2) perceptions of the design thinking process, (3) perceptions of interdisciplinary group work, and (4) skill and knowledge development. In general, students were satisfied with grand challenge courses, course material, and course delivery [24, 25, 28, 45, 64, 67, 68]. The process of working on design thinking projects focused on broad ideas that could be tailored to individual interests aimed at proposing innovative solutions and providing relevant and valuable real-world learning experience for many students [20, 28, 30, 31, 36, 40, 44, 45, 51, 59, 61, 62, 66–68]. However, some challenges to integrating design thinking projects were noted. Some students felt deficient in design thinking skills and wanted better preparation in design skills [30, 39]. Other students struggled with ambiguous learning objectives, unclear structure, face pace, and lack of concrete solutions [20, 24].

A number of authors reported on perceptions of interdisciplinary teamwork ($n = 10$, 40%). In general, students appreciated the interdisciplinary team collaboration [28, 30]. One study reported that students with positive attitudes towards group work showed greater learning gains throughout the course [43]. In other studies, students noted that interdisciplinary learning helped prepare them for the real world of work and collaboration while offering valuable new perspectives, ideas, and knowledge to develop successful solutions to grand challenges [31, 63]. In another study that reported on instructor perceptions, the teaching faculty found interdisciplinary team-teaching rewarding and felt that it enriched the class, amplified each other's teaching abilities, and supported professional skills development related to teaching and learning [30]. However, teamwork was not without its challenges. Gillet [38] noted that some teams were challenged with managing schedules or personal conflicts, while Gosselin and colleagues [39] reported that the multidisciplinary aspect created challenges in achieving course learning goals.

The authors also reported on students' knowledge and skills development. Increased content knowledge was

discussed in six studies [25, 28, 30, 66–68], while others discussed how students gained a more holistic and systemic understanding of grand challenge topics [35, 57, 63, 67, 68]. Although an increase in student self-confidence and competence was observed in three studies [44, 61, 67], students in another study noted, due to the interdisciplinary nature of the learning, they did not perceive they gained specialized knowledge in their main fields of study [57].

Although quality appraisal is not conducted as part of scoping review methodology [18, 19], there are some important issues related to study quality that require further consideration. First, the diversity of methods, study designs, and reporting mechanisms made the identification of meaningful comparisons across the included studies difficult. Some studies did not include clear objectives and/or clear descriptions of data collection and analysis methods. The quantitative studies consisted only of cross-sectional descriptive surveys with the majority applying nonvalidated questionnaires that included very little methodological detail. The lack of description of the study details reduced our ability to generate an in-depth understanding of the impact of grand challenges in the higher education classroom. Overall, the generalizability of the studies included is limited.

5. Discussion

We undertook an extensive review of the grand challenge literature in higher education from inception to 2020. To the best of our knowledge, this is the first scoping review exploring the current state of the use of grand challenges as pedagogical innovations in higher education. A detailed review of 55 eligible articles revealed the contexts in which grand challenges are being used, common learning objectives and assignments used in grand challenge course work, outcomes related to the implementation of grand challenges in higher education classrooms, and gaps in the evidence to date. The results reveal a growing global interest in grand challenges in higher education while highlighting a lack of rigorous empirical evidence on the impact on student learning.

TABLE 3: Summary of grand challenge courses.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Apelian (2015) [26]	USA, Worcester Polytechnic Institute	Engineering	First-year undergraduate engineering students	<p>To learn the concept of sustainable development, climate change, energy sources, food and water issues, housing, health, and transportation concerns</p> <p>To approach these issues proactively and develop ecologically sound solutions</p> <p>To practice all aspects of college writing and project development</p> <p>To learn the importance of engaging different disciplinary perspectives</p> <p>To learn to formulate researchable questions based on multiple sources</p> <p>To participate in classroom debates and discussions on complex issues of sustainable development and contribute to teamwork</p>	<p>Essays</p> <p>Active discussions</p> <p>Design thinking project</p> <p>Presentation to a public forum in the form of posters and 4-minute video clips of the value proposition of their proposed solutions</p>
Becerik-Gerber (2018) [27]	USA, University of Southern California	Arts, Business, Cinematic Arts, Computer Science, Communication, Engineering, Journalism, and Medicine	26 students representing 14 disciplines	<p>To learn how to design products, services, and technologies with a human-centered approach to help solve the needs of people in the midst of global crises</p> <p>To learn about the process of product innovation, prototyping, fabrication, and building sustainable business models</p>	<p>Design thinking project</p>

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Berger (2013) [28]	USA, Simmons College	Biology, Chemistry, Economics, Education, English, Management, Math, Nursing, Nutrition, Physical Therapy, Political Science, Public Health, Social Work, and Sociology	Sophomores from a private women's liberal arts institution	<p>To grasp key concepts, principles, and theories relating to the complexities surrounding food</p> <p>To understand the critical social issues such as food insecurity, sustainability, and social justice</p> <p>To understand the critical technical issues such as food safety, production, and distribution</p> <p>To evaluate available information in order to target and define a specific issue</p> <p>To address a specific global issue related to food and design and develop a local solution</p> <p>To become more empowered to take the lead in learning and become better at risk-taking in learning environments</p> <p>To work effectively in a team</p>	<p>Group discussion</p> <p>Presentation</p> <p>Pretest-posttest</p> <p>Self-reflection</p> <p>Journal reflection</p>
Bernal (2013)	USA, Rose-Hulman Institute of Technology	Engineering and Science	Undergraduate Engineering and Science students	<p>To develop feasible concepts for solar energy collection</p> <p>To develop a problem statement and report findings</p> <p>To conduct competitive benchmarking to determine how their alternatives fair in response to current products</p> <p>To build a prototype and analyze results</p>	<p>Oral exams</p> <p>Presentation</p> <p>Peer evaluation</p> <p>Design thinking project</p>
Brewer (1993) [29]	USA, University of California	Biology	Biology students	<p>To develop a model for the global carbon cycle</p> <p>To develop an outline for human implications of global climate change</p>	<p>Presentations</p> <p>Group discussions</p> <p>Design thinking project</p>

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Cohen (2009) [30]	USA, Eugene Lang College of Liberal Arts at The New School	Environmental Studies, Design and Liberal Arts	Undergraduate students	<p>To provide students with the knowledge of systems thinking, including the life cycle of materials and products</p> <p>To better appreciate the value of diverse human and natural systems</p> <p>To introduce basic ecological concepts related to the sustainable food system, including energy consumption, organic cultivation, farmland conservation, and food security</p> <p>To appreciate the role of design in critical and strategic thinking</p> <p>To develop an ability to translate quantitative information into visually and verbally coherent presentations and to make an argument visually and in written form</p> <p>To provide a clear understanding of mapping, including the development of concept maps that isolate, visualize, and represent in various formats ecological phenomena at an urban scale</p> <p>To help students develop skills to explore the dimensions of a problem, identify alternative solutions, and develop a prototype or visual campaign to advance a proposed solution; and the skills to work collaboratively, including distribution of tasks according to skill level, interests, and leadership capabilities</p>	Presentations Design thinking project

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Dean (2017) [31]	AUS, University of Technology Sydney	Architecture, Landscape, and Nursing	Undergraduate third-year and postgraduate students	To develop researched landscape-focused architectural solutions for refuge spaces To explore the relationship between the built and natural spaces	Design thinking project Poster presentation
Flammia (2011) [32]	USA, University of Central Florida	Biology, Digital Media, Economics, English, History, Information Technology, Nursing, Politics, Science, Social Science, and Technical Communication	Undergraduate students	To gain a fuller understanding on a particular grand challenge topic and develop a small local project to address one aspect of the topic	Design thinking project
Fomich (2018) [33]	USA, The Ohio State University	Engineering	Undergraduate students	To apply knowledge of mathematics, science, and engineering To design a system, component, or process to meet desired needs To function on multidisciplinary teams To identify, formulate, and solve engineering problems and use techniques, skills, and modern engineering tools necessary for engineering practice To develop an understanding of professional and ethical responsibility To communicate effectively To understand the impact of engineering solutions in a global and societal context To recognize the need for, and an ability to engage in lifelong learning and develop knowledge of contemporary issues	Design thinking project Executive summary report

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Forbes (2018) [34]	USA, University of Nebraska-Lincoln	Agribusiness, Economics, Engineering, Fisheries, History, Hydrology, Journalism, Math, Prehealth, Science, Technology, and Wildlife Biology	Second-year undergraduate students	<p>To explain fundamental hydrologic concepts and use this knowledge to engage in scientific practices including posing and answering scientific questions</p> <p>To explore hydrologic phenomena, analyzing and making inferences from data, and determining validity of conclusions</p> <p>To engage effectively in principled analysis of and reasoning about sociohydrologic systems, including their scientific, ethical, social, economic, cultural, and civic dimensions, to make informed decisions about water resource use</p>	<p>Student discussions</p> <p>Presentation of infographics to scientists, policymakers, and educators at a global conference</p>
Fortner (2016) [20]	USA, Wittenberg University, Virginia Tech, Santa Rosa Junior College	Agriculture, Ecological Sciences, Environmental Sciences, Geology, and some Non-Science majors	Undergraduate students	<p>To develop a plan for sustainable soil management in one or more agricultural settings using geologic data</p> <p>To predict agricultural challenges that might result from climate change</p>	Creation of a fact sheet
Fortuin (2013) [35]	NLD, Wageningen University	Economics, Humanities, Natural Sciences, Social Sciences, and Technology	BSc and MSc environmental science students	<p>To holistically develop an understanding of the environmental issues</p> <p>To identify, understand, appraise, and connect disciplinary knowledge</p> <p>To reflect on the role of science in solving environmental problems</p>	<p>Scientific report</p> <p>Design thinking project</p> <p>Reflection papers</p>
Gama (2018) [36]	BRA, Federal University of Pernambuco CAN, McGill University	Computer Science and Information Systems	Undergraduate students	<p>To find ways to grow quality vegetables in a domestic environment</p> <p>To predict and identify possible sources of fire in private rural estates</p>	Design thinking project

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Gardner (2010) [37]	USA, New York University	Social Work	Masters students	<p>To assess the community well-being of low-income urban residents</p> <p>To develop, analyze, and propose policies, programs, and services that support the needs of vulnerable community members</p> <p>To promote a broader, more critical understanding of the multiple and interacting factors that negatively affect poor individuals and families in urban communities</p>	<p>Essays</p> <p>Poster presentation</p>
Gillet (2019) [38]	USA, University of Michigan	Management and Education (multidisciplinary)	Undergraduate students	<p>To build global competence and career readiness skills for young people in the United States and across the Middle East and North Africa (the MENA region)</p>	<p>Design thinking project</p> <p>Video presentation of the suggested entrepreneurial solutions</p>
Gosselin (2016) [39]	USA, University of Nebraska-Lincoln, The University of Utah, West Chester University, Metropolitan State University	STEM-Science, Technology, Engineering, Math, and some non-STEM disciplines (interdisciplinary)	Undergraduate students	<p>To explain water projects to nontechnical people and assess implications of technical and nontechnical water project solutions and decisions in a societal context</p> <p>To develop effective communication with others to develop, judge, and recommend multiobjective solutions to water resource challenges</p> <p>To think critically and analytically across disciplinary boundaries about connections between natural, social, and economic systems</p> <p>To make informed decisions and ethical choices by actualizing sustainability as a system dependent on both fact and value</p>	<p>Papers and Essays</p> <p>Design thinking project</p>
Griffin (2011) [40]	USA, University of Nebraska-Lincoln	Political Science	Upper-level undergraduate students	To design a solution to a political or social problem	<p>Design thinking project</p> <p>Presentations</p> <p>Essays</p> <p>Reflections</p>

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Grose (2014) [21]	USA, Arizona State University, Bucknell University, Rose-Hulman Institute of Technology, Bucknell University, Duke University	Engineering	Undergraduate students	To design, build, and test materials that can help the developing world	Design thinking project Essays Presentations Reflections
Hogfeldt (2019) [41]	SWE, KTH Royal Institute of Technology TZA, University of Dar es Salaam	Engineering	Undergraduate and graduate students	To apply design thinking methodology to address water and sanitation issues	Design thinking project Presentations
Hasan (2017) [42]	AUS, University of Wollongong	Computer Science, Green Information Systems, and Information Communication Technology	Professors, undergraduate, postgraduate students, and representatives from local businesses	To identify a problem, define the obstacles in reaching a solution, design, develop, and demonstrate a solution, and communicate findings	Design thinking project
Hecht (2014) [23]	USA, Massachusetts Institute of Technology Media Lab iNOVATION and Engineering colleges, India	Engineering	Undergraduate and graduate students, high school students, technology professors, entrepreneurs	To build and test prototypes of hardware, sensors, and mobile apps for surge population attendance in advance of Kumbh Mela Festival	Design thinking project
Heinricher (2008) [22]	USA, Worcester Polytechnic Institute	Aerospace Engineering, Biology, Biomedical Engineering, Chemical Engineering, Chemistry, Civil Engineering, Computer Engineering, Electrical Engineering, and Mechanical Engineering	First-year undergraduate students	To engage with current events, societal problems, and human needs To engage in critical thinking, information literacy, and evidence-based writing To develop effective teamwork, time management, organization, and personal responsibility skills	Report writing Presentations Group discussions Miniprojects “Adventure assignments”
Holzer (2016) [43]	CHE, Ecole Polytechnique Fédérale de Lausanne, Université de Lausanne, ITA, University of Ferrara	Engineering, Science, and Social Science	First-year undergraduate students	To show the links between technological solutions and societal issues To guide future scientists and engineers to become responsible citizens, and develop critical thinking around global issues	Design thinking project Presentation Self-reflection Posters
Jahan (2019) [44]	USA, Rowan University	Engineering (integrates engineering and humanities/social sciences content)	69 first-year undergraduate students	To engage in project-based learning using a living organism To learn about engineering fundamentals and core concepts from humanities	Design thinking project Presentations Classroom-based discussions

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Johannes (1996) [45]	NLD, University of Technology Eindhoven	Engineering		To emphasize interdisciplinary work and promote cooperation within a group To acquire and apply a systematic approach to problem-solving	Design thinking project
Jonker (2019) [46]	NLD, Institute for Management Research, Nijmegen School of Management, Radboud University Nijmegen	Business	Graduate students and third-year undergraduate students	To learn about sustainability concepts from a management and business perspective	Design thinking project Learning portfolios
Judge (2020) [47]	USA, Roger Williams University, University of Rhode Island, Northeastern University, GNCB Consulting Engineers, United States Naval Academy, University of Massachusetts	Architecture, Ecology, Landscape, Engineering, Physical Sciences, and Social Sciences	Graduate students	To bridge the gap between research and practice regarding the design of resilient infrastructure for coastal adaptation To develop a resilience-improving hybrid structural/social/ecological infrastructure design for a particular site	Design thinking project Presentation
Kienzler (2017) [24]	GRB, King's College, London USA, George Washington University	Social Sciences	Undergraduate students	To gain and create knowledge about specific global health-related challenges To acquire tangible and transferable skills being a part of the course To define global health and how it might be secured To understand the knowledge-to-action gap in different fields of global health and the strategies that aim to close it To develop skills needed to critically evaluate initiatives and identify the role of key stakeholders in shaping them To demonstrate the value of interdisciplinary approaches to global health To use methodological and epistemological tools in the production of global health research	Essay Infographic Poster Public presentation

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Kim (2018) [48]	USA, Purdue University, John Hopkins University	Engineering	Undergraduate students	To develop a problem statement by identifying explicit and implicit goals, determining the constraints involved in a given problem, and considering multiple perspectives regarding the design scenario to help eliminate any perceived assumptions that unnecessarily limit the problem-solving process To plan and manage a design project by applying a variety of project management strategies	Design thinking project Concept map Presentations
Knudson (2011) [49]	USA, University of California	Anthropology, Chemistry, Community Development, Design, Ecology, Education, Engineering, Environmental Resources, Geography, Physics and Soil Science	Graduate students	To develop environmental leaders through a professional development mentoring program	Design thinking project Presentations
Leon (2015) [50]	USA, Emory University	Global Health	First-year students of Master of Public Health	To integrate core public health disciplines into team-based problem-solving around authentic global health challenges	Written reports Class discussions Presentations
Lim (2016) [51]	AUS, Griffith University GRB, University of Dundee	Law, Natural Sciences, and Social Sciences	Graduate students	To bring together expertise from the natural and social sciences To link priorities and preferences expressed by decision-makers with regard to issues concerning the environment, land and natural resource use, and livelihood	Design thinking project Class presentations
Nagarajan (2019) [52]	USA, Bowling Green State University AUS, Monash University	Chemistry	Undergraduate students	To educate students on the principles and importance of green chemistry, circular economy, recycling, and life cycle analysis	Design thinking project
Nichols (2019) [53]	USA, South Dakota State University	Agriculture, Arts, Sciences, Biological Sciences, Education, Engineering, and Human Sciences	Undergraduate students	To support interdisciplinary undergraduate research experiences	Design thinking project Presentations

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Nitkin (2016) [54]	USA, Simmons College, Worcester State University		Sophomore level	To understand the local and global social, economic, political, and cultural dynamics related to a societal challenge, as well as the strengths and weaknesses of existing responses to the problem To develop organizational and communication skills needed to work effectively in teams To formulate creative and actionable solutions to the challenge	Design thinking project Presentations
Nurius (2017) [55]	USA, University of Washington, University of Illinois, Boston College	Social Work	Undergraduate and graduate students	To develop entrepreneurial thinking and leadership skills and practice these skills inside and outside of the classroom with diverse, interdisciplinary teams	Design thinking proposal
Piens (2015) [56]	USA, Rose-Hulman Institute of Technology	Engineering, Humanities, and Social Sciences	Undergraduate students	To develop and design a project for Haiti disaster relief addressing the housing crisis	Design thinking project
Radberg (2018) [57]	SWE, Chalmers University of Technology	Civil Engineering, Energy, Environmental Studies, Maritime Engineering, Physics, and Technology Management	Masters students	To describe critical sustainability challenges, their connection with, and effect on industrial and societal actors To reflect on the challenges of policy implementation for sustainable development To apply a systems perspective to meet sustainability challenges and apply practical methods and tools for sustainable product development and design	Design thinking project

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Reichmanis (2017) [58]	USA, Georgia Institute of Technology	Biochemistry, Chemistry, Engineering, and Material Science		To understand how chemicals can be used/ integrated into products to achieve the best benefit to customers while minimizing life cycle sustainability impacts To make decisions taking into account life cycle thinking and systems analysis	Design thinking project
Richards-Kortum (2012) [59]	USA, Rice University	Engineering	Undergraduate students	To use the engineering design process to develop innovative technologies addressing global health challenges	Design thinking project Presentations
Rodríguez (2019) [60]	USA, University of Illinois, University of Nebraska-Lincoln, Iowa State University, University of California, North Carolina State University, University of Minnesota, Northern Arizona University, University of Louisiana, Johns Hopkins University	Biological Sciences, Engineering, Physical Sciences, and Social Sciences	Graduate students	To ask transdisciplinary questions across disciplinary boundaries to build on existing sources of knowledge and to understand and design innovative solutions	Design thinking project
Sienko (2013) [61]	USA, University of Michigan, Humboldt State University	Engineering	Fifteen students from Mechanical Engineering, Biomedical Engineering, and the School of Information	To focus on technologies that are designed to prevent, diagnose, or treat the top ten leading causes of death in low-income and middle-income countries, as well as maternal and infant health	Group report Class discussions
Tandon (2017) [25]	USA, California State University	Engineering and Science	Undergraduate and graduate students	To promote engineering education in the context of mosquito-borne illnesses, a relevant real-world problems	Design thinking project Presentations

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Telenko (2016) [62]	USA, Georgia Institute of Technology SGP, Singapore University of Technology and Design LUX, Université du Luxembourg USA, Massachusetts Institute of Technology	Engineering		To understand the engineering subject fundamentals To reflect, observe and hypothesize, and assess contexts, opportunities, and needs To ideate and abstract using multiple representations To make decisions for open-ended, design problems and creatively utilise resources within a complex system	Design thinking project
Trowbridge (2018) [63]	USA, Arizona State University	Engineering	First-year engineering students	To develop talent, multidisciplinary, viable business/ entrepreneurship, multicultural, and social consciousness competencies needed to solve global challenges	Design thinking project Digital portfolios Reflection
Udugama (2018) [64]	DNK, Technical University of Denmark Universitetsparken, University of Copenhagen GRB, Newcastle University	Biotechnology	Postgraduate students	To learn cutting edge, industrially relevant knowledge about industrial scale bio-based production processes To build relevant soft skills To facilitate working in a multicultural and multidisciplinary group	Design thinking project

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
White (2018) [65]	USA, no specific institution listed	Engineering	Mechanical Engineering doctoral candidate, along with 15 new university first-year students	<p>To explore how engineering solutions can be used to support the basic human needs of the world's population</p> <p>To understand how engineering solutions are impacted by the surrounding economic, environmental, and societal context</p> <p>To explore how engineering solutions may impact global society and how culture and political philosophies impact the appropriateness and sustainability of engineering solutions</p> <p>To explore the influence of a given culture on the engineering solutions used in that culture</p> <p>To design and implement engineering solutions addressing the needs, both from a practical and cultural perspective, of a range of communities including those that are currently disadvantaged</p>	Service learning Reflections Discussions
White (2017) [66]	USA, University of New Hampshire, University of Arizona, University of Dubuque University of Nebraska, University of California	Geosciences	Undergraduate students	<p>To introduce the interdisciplinary science needed to understand the Critical Zone (CZ) of earth</p> <p>To examine geosciences-related grand challenges facing society, especially soil and ecosystem services</p> <p>To address interdisciplinary problems by using data visualization and analysis skills with authentic data</p> <p>To incorporate systems thinking by employing examples and activities that demonstrate the connection between water, air, soil, and organisms in biogeochemical processes</p>	In-class discussions Presentations Essay and report writing

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
White (2014) [67]	USA, Worcester State University, Simmons College	Communications, Lab Science, Liberal Arts, Library Science, Mathematics, Management, Nursing, Nutrition, Science, Social Work, and Sociology	Undergraduate students	To acquire a working knowledge of the global social problem, including an understanding of local and global social, economic, political, and cultural dynamics and existing responses To develop the practical organizational, technical, research, and communication skills to work effectively and efficiently in teams To formulate creative and actionable solutions to address the global social problem	Design thinking project
Wilson (2019) [68]	USA, University of Denver Graduate School of Social Work, Colorado State University School of Social Work	Business, Computer Science, Education, Engineering, International Studies, Psychology, and Social Work	Interdisciplinary team of faculty, graduate students, and community member	To encourage students and community members to come together to brainstorm to develop innovative solutions to address homelessness	Design thinking project Presentations
Wobbe (2010) [69]	USA, Worcester Polytechnic Institute	Engineering and Technology	First-year students	To develop information literacy, effective writing, and speaking skills, while working in teams	Design thinking project
Wyrick (2016) [70]	USA, West Virginia University, Statler College of Engineering and Mineral Resources	Civil Engineering		To develop a sense of how to identify and act on opportunity To develop a multicultural and international perspective to comprehend the impact of working with people and society	Design thinking project

TABLE 3: Continued.

First author (year)	Country and institution	Discipline	Students	Course learning objectives	Course assessments
Zou (2015) [12]	Hong Kong, China, Center for Engineering Education Innovation, the Hong Kong University of Science and Technology	Engineering	Freshmen from all backgrounds	To apply an integrated learning approach to learn about energy To enhance critical thinking and problem-solving skills To introduce a multidisciplinary view to understand energy and its sensible usage To introduce the relationship between energy and society To tackle the complexity of energy through multiple disciplines including basic sciences, social sciences, economics, and technology	Design thinking project
Zuin (2019) [71]	BRA, Federal University of Sao Carlos GBR, University of York	Chemical Engineering	First-year undergraduate students	To develop a way to extract valuable products from orange waste using chemistry concepts and methods	Design thinking project

Note: countries are identified using the ISO alpha 3 codes.

The most common grand challenge topics were focused on sustainability, climate change, and food and water insecurity. This may be due to the wide variety of topics related to environmental sustainability including agriculture, soil, and land use to reducing global environmental footprints, biofuel use, and ecological restoration. As well, sustainability topics have increasingly multifaceted characteristics, as they encompass a wide range of sectors in society from government policies and economics to public health and security [28]. A variety of disciplines are able to participate in grand challenges centered on sustainability as they incorporate diverse issues on preserving the environment and supporting development in a society.

Despite the variety of disciplines identified as engaging in grand challenge work, many disciplines remain under-represented in grand challenge literature to date. For instance, healthcare disciplines were present in some of the multidisciplinary groups involved in grand challenges; however, there was a distinct lack of literature that focused on grand challenges specific to healthcare disciplines, such as nursing. Additional grand challenges that target real-world societal issues might benefit disciplines that work consistently in teams and high-stress environments, such as those in healthcare professions. Disciplines such as political science that are involved in government policies may benefit from the implementation of additional grand challenges in higher education curricula, to build critical collaboration and problem-solving skills required in developing and changing public policies. Furthermore, many potential

grand challenge topics were not discussed in the literature. For example, the education discipline could target interventions on bullying or information; communication and technology disciplines could strive to ensure the safe use of artificial intelligence in common technology.

Incorporation of interdisciplinary learning was commonly discussed as a course learning objective and in the research findings. As suggested by Ivanitskaya et al. [73], interdisciplinary learning can create knowledge that is “more holistic than knowledge built in discipline-specific studies” (p. 97). By incorporating interdisciplinary perspectives into the learning process, students can acquire knowledge about various methodologies, theories, paradigms, and concepts from multiple disciplines and evaluate their thinking processes against perspectives offered by different disciplines [73]. Furthermore, opportunities to engage in interdisciplinary problem-solving can help students explore and develop solutions in a synthesized manner while also building personal and professional skills [74].

Klaassen [75] evaluated the nature of interdisciplinary learning and factors to be considered when integrating interdisciplinary opportunities into the curricula. The choice of problem, level of interaction between different disciplines, and constructive alignment were identified as important variables to be considered. Designing group assignments that require collaborative and multidisciplinary research and developing problems and questions that are identified in conjunction with key stakeholders were identified imperative in promoting interdisciplinary learning [76, 77]. These

TABLE 4: Grand challenge course assessments.

First author (year)	Active discussions	Design thinking projects	Essays or reports	Infographics	Learning portfolio	Oral exams	Peer evaluation	Posters	Presentations	Pre-post tests	Reflections
Apelian (2015) [26]	x	x	x					x	x		
Becerik-Gerber (2018) [27]		x									
Berger (2013) [28]	x								x	x	x
Bernal (2013)		x				x	x		x		
Brewer (1993) [29]	x	x							x		
Cohen (2010) [30]		x							x		
Dean (2017) [31]		x						x			
Flammia (2011) [32]		x									
Fomich (2018) [33]		x	x						x		
Forbes (2018) [34]	x			x					x		
Fortner (2016) [20]			x								
Fortuin (2013) [35]		x	x								x
Gama (2018) [36]		x									
Gardner (2010) [37]			x					x	x		
Gillet (2019) [38]		x		x							
Gosselin (2016) [39]		x	x								
Griffin (2011) [40]		x	x				x		x		x
Grose (2014) [21]		x	x						x		x
Hagfeldt (2019) [41]		x							x		
Hasan (2017) [42]		x									
Hecht (2014) [23]		x									
Heinricher (2008) [22]	x	x	x						x		
Holzer (2016) [43]		x	x					x	x		x
Jahan (2019) [44]	x	x							x		
Johannes (1996) [45]		x									
Jonker (2019) [46]		x			x						
Judge (2020) [47]		x							x		
Kienzler (2017) [24]			x	x				x	x		

TABLE 4: Continued.

First author (year)	Active discussions	Design thinking projects	Essays or reports	Infographics	Learning portfolio	Oral exams	Peer evaluation	Posters	Presentations	Pre-post tests	Reflections
Kim (2018) [48]	x	x					x		x		x
Knudson (2011) [49]		x							x		
Leon (2015) [50]	x		x						x		
Lim (2016) [51]		x							x		
Nagarajan (2019) [52]		x									
Nicholas (2019) [53]		x							x		
Nitkin (2016) [54]		x							x		
Nurius (2017) [55]		x									
Piens (2015) [56]		x									
Radberg (2018) [57]		x									
Reichmanis (2017) [58]		x									
Richards-Kortum (2012) [59]		x							x		
Rodríguez (2019) [60]		x									
Sienko (2013) [61]	x	x									
Tandon (2017) [25]		x							x		
Telenko (2016) [62]		x									
Trowbridge (2018) [63]		x			x						x
Udugama (2018) [64]		x									
White (2018) [65]	x										x
White (2017) [66]	x		x						x		
White (2014) [67]		x									
Wilson (2019) [68]		x							x		
Wobbe (2010) [69]		x									
Wyrick (2016) [70]		x									
Zou (2015) [12]		x									
Zuin (2019) [71]		x									
Total	11	48	13	3	2	1	3	5	26	1	8

TABLE 5: Overview of studies about the use of grand challenges in higher education courses.

First author (year)	Study aims	Study design	Participants	Results
Berger (2013) [28]	<p>To measure the extent students increased their content knowledge</p> <p>To explore the extent students felt they learned content knowledge</p> <p>To examine students' opinions regarding gains from participating in the <i>World Challenge</i> course</p>	Multimethods case study including pretest-posttests, personal reflections, and final debriefings	14 students, 6 faculty members, and 4 teaching assistants from Biology, Chemistry, Economics, Education, English, Management, Math, Public Health, Nursing, Nutrition, Physical Therapy, Political Science, Social Work, and Sociology	<p><i>Students</i></p> <p>Statistically significant difference in mean content knowledge scores between pretest and posttest ($p = 0.000$)</p> <p>Appreciated the team collaboration, research process, progress made, and support from the faculty and TAs</p> <p>9 of 14 students strongly agreed they were satisfied with the course</p> <p>All students strongly agreed the classes stimulated to intellectual engagement with course material</p> <p><i>Faculty</i></p> <p>Strengths of the course were student participation, progress on proposing innovative solutions, and providing a rigorous and fun learning environment</p> <p>Most faculty were engaged with and satisfied with the course and plan to incorporate more problem-based, student-centered learning into their courses</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Cohen (2010) [30]	To evaluate the success of the <i>Designing the Sustainable Foodshed</i> course	Multimethods case study including surveys of the students, subjective evaluation of the students' progress, and comments received by external reviewers about the students' interim and final products	25 undergraduate students from Design, Environmental Studies, and Liberal arts	<p>Students</p> <p>A majority of students had positive responses to working in groups and working on the design thinking project. The grand challenge topic was described as interesting, enlightening, broad enough to tailor it to your interests, and brought up a relevant and pressing contemporary issue that should be taught on a university-wide scale.</p> <p>Students expressed an interest in having more knowledge about sustainability and better preparation in design skills.</p> <p>Not surprisingly, the design students wanted more instruction in food systems while the liberal arts students felt deficient in design skills.</p> <p>Faculty</p> <p>Students were engaged in class throughout the semester, acquired a solid understanding of sustainability and food systems issues, and quickly learned how to integrate visual design techniques into their projects.</p> <p>Teaching as a team was rewarding and enriched the class, individual teaching abilities, and professional skills.</p>
Dean (2017) [31]	To explore the potential for authentic, interdisciplinary, collaborative learning to enhance educational and social outcomes for health, architecture, and landscape architecture students	Qualitative study using focus groups for data collection and program/project evaluation	15 nursing students, 10 architecture students, and 12 landscape students	<p>Students favoured authentic, "real-life" projects and learned about feelings and attitudes as well as knowledge.</p> <p>The interdisciplinary learning prepares students for the real world of work and collaboration offered valuable new perspectives, ideas, and knowledge.</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Fortner (2016) [20]	To explore students perceived strengths and weaknesses of <i>A Growing Concern: Sustaining Soil Resources Through Local Decision Making</i> course	Qualitative study: focus groups with students	35 students across 3 institutions Ecological sciences, agriculture, geology, environmental sciences, and some nonscience majors	Students perceived the strengths of the course to be interactivity/hands-on, learned content, open-ended inquiry, quantifying the complex problems of erosion Students perceived the weaknesses of the course to be ambiguity of learning objectives, unclear structure, lack of personal relevance, fast pace, and lack of concrete solutions
Fortium (2013) [35]	To identify the cognitive interdisciplinary skills that enhance students' ability to understand complex environmental problems and develop sustainable solutions To explore how education in environmental systems analysis contribute to training these cognitive skills	Qualitative study using students written reflections	Undergraduate students from a broad range of disciplines from Natural Sciences, Social Sciences, Humanities, Technology, and Economics 2007 ($n = 16$) 2008 ($n = 21$) 2010 ($n = 24$)	Students gained a more holistic understanding of environmental issues Students explored systematic vs. systemic approaches to environmental issues Students gained skills in identifying, understanding, and appraising disciplinary knowledge Students reflected on the role of science in solving environmental problems and learned by doing and through interaction
Gama (2018) [36]	To identify what effects the combination of challenge-based learning and design thinking can have on hackathon projects	Mixed methods including survey (quantitative data) and group interviews (qualitative data)	22 undergraduate Computer Science students who were enrolled in the <i>Web of Things</i> course	Quantitative analysis shows an agreement about the effectiveness of using design thinking The strict time for intermediate deliveries in each step of the process helped to narrow down ideas and quickly find solutions to be developed Challenge-based learning helped guide students and give purpose to their projects, and guided them to learn more about the target domain and potential users
Gillet (2019) [38]	To learn what was working and what could be improved with the <i>Michigan Initiative for Global Action Through Entrepreneurship</i>	Qualitative study: class focus groups	Multidisciplinary undergraduate students	For some teams, the biggest challenge was that members dropped out part-way through, often due to scheduling conflicts or personal issues The most effective ingredients for building strong teams were students' own efforts to step up and become leaders

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Gosselin (2016) [39]	To assess student learning related to course goals and student preferences related to course design and pedagogy	Mixed-methods case study: assignments, class discussions, team project, and student surveys	Interdisciplinary undergraduate students from Science, Technology, Engineering, Math, and some from non-STEM disciplines	Student assessments that helped bridge the disciplines were outside events, multidiscipline instructors, problem-based learning, and project-based learning The multidisciplinary course created challenges to achieving the learning goals There was a need to incorporate greater systems thinking and fundamental knowledge into the next offering of the course
Griffin (2011) [40]	To gauge student learning outcomes at the conclusion of the project	Qualitative study using written reflections	Upper-level undergraduate Political Science students	The course offered students a unique learning experience by developing their ability to actively apply their understanding of course concepts to formulate creative solutions to real political and social problems
Holzer (2016) [43]	To examine if an interdisciplinary program for engineering undergraduates including soft skills can increase students' perspective on societal issues	Pre-post tests	1800 first-year undergraduate Engineering students from 12 courses	An interdisciplinary program for engineering undergraduates including soft skills can increase students' perspective on societal issues as measured by the ESIT, especially when they show a positive attitude towards group work as measured by RIPLS and especially if they have a low ESIT at the start A majority of students appreciated the course and almost 80% found the topic of their group work interesting. Where students have a positive attitude towards group work at the beginning of the course, there are greater gains in postconventional reasoning during the course. This is especially true for students with the lowest levels of postconventional reasoning at the outset

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Jahan (2019) [44]	To examine if students' adaptive learning engagement and perceived confidence for learning changes as a result of their participation in collaboratively taught design thinking project course	Mixed methods: pre-post tests ($n = 54$) and focus groups ($n = 9$)	54 first-year undergraduate Engineering students	<p>Students benefited from working in a "real-world" environment that required them to figure out what resources they needed to solve a problem</p> <p>Students expressed confidence in their ability to learn in the course</p> <p>Self-Efficacy test "I can figure out how to do difficult work" ($p = 0.011$)</p> <p>Self-Regulation test "I continue working even if there are better things to do" ($p = 0.025$), "I concentrate so that I will not miss important points" ($p = 0.008$), "I do not give up even when the work is difficult" ($p = 0.009$), and "I keep working until I finish what I am supposed to do" ($p = 0.004$)</p>
Johannes (1996) [45]	To explore students perceptions of an interdisciplinary sustainable development course	Authors did not indicate how they collected data	Interdisciplinary Engineering students	<p>Students experienced the course as a useful addition to their engineering education</p> <p>The strong points of the course were freedom to define the problem, learning aspects of project-oriented work, teamwork, the multidisciplinary character (learning from other disciplines), and the contact with an external principal Project work was less effective for pure knowledge transfer</p> <p>Contact with students from other departments and the different disciplinary aspects were noted as a positive learning experience, while stimulating interdisciplinary thinking and study</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Kienzler (2017) [24]	To evaluate the overall <i>Introduction to Global Health</i> course	Qualitative study using written and oral feedback	22 third-year Social Science study abroad students	<p>Midterm evaluations, completed by 21 students, indicated satisfaction with direct instructional guidance. Students also indicated that they did not feel prepared for the hackathon and course assignments.</p> <p>Final evaluation, completed by 15 students, demonstrated ongoing satisfaction with the course content and had increased confidence in their ability to complete the course assignments.</p> <p>Students reported positive reactions to how the course content was delivered.</p>
Lim (2016) [51]	To explore students' perceptions of how problem-based learning contributes to their understanding of sustainability competencies	Qualitative case study	Masters students in Law, Natural, and Social Science	<p>Students found problem-based learning challenging but appreciated the opportunity to “do something different”; to “engage with law in a way that makes a difference”; to “consider a wide range of issues at once” and to have a tool they could use in their future careers which would enable them to consider a wide range of options.</p> <p>Students' consideration of cross-sectoral issues and legislative enforcement and effectiveness broadened their thinking about how different parts should interact and how this often fails to happen.</p>
Petillion (2019) [72]	To examine student feedback regarding the learning activities used in a course focused on addressing the United Nations Sustainability goals	Mixed methods: surveys and course assignments	357 first-year chemistry undergraduate students	<p>47% of respondents perceived the course activities to support their learning, with 30% believing otherwise and 22% responding neutrally to that statement suggesting that the course assignment had a positive impact on cognitive learning for a large number of students.</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Radberg (2018) [57]	<p>To assess if students' in the <i>Challenge Lab</i> self-perceived learning fulfills the required academic learning outcomes for their education</p> <p>To identify additional learning outcomes students perceive they have achieved, which are not developed to the same extent in traditional MSc thesis</p>	Mixed methods: surveys and interviews	37 masters students in Engineering, multidisciplinary: Environmental Studies, Physics, Technology Management, Civil Engineering, Energy, and Maritime Engineering	<p>The perceived academic learning of the students who conducted their MSc thesis at the Challenge Lab was similar to students in general</p> <p>Intended learning outcomes (ILO's) measured on a 1–5 scale showed an average of 3.3 over all 3 years at the Challenge Lab, in line with all MSc thesis students studying at Chalmers in 2016 at 3.6 ($n = 1765$)</p> <p>The perceived learning about sustainable development was significantly higher for the Challenge Lab students compared with the Chalmers students in general</p> <p>Some students did not perceive that that had gained specialized knowledge within their main field of study</p>
Richards-Kortum (2012) [59]	To compare skills developed through the <i>Beyond Traditional Borders</i> course with other design courses at Rice	Survey	Undergraduate Engineering students	Students reported enhanced skills in creativity, leadership, ability to effect social change, and the ability to solve real-world problems
Sienko (2013) [61]	<p>To evaluate the educational impact of the <i>Design for Global Health: Sustainable Technologies for the Developing World</i> course on students' perceived abilities in specific engineering design-related areas of interest</p> <p>To measure self-reported professional progress in an interdisciplinary environment with a nontraditional teaching agenda</p> <p>To explore students' perceptions about teaching methodology, general direction of the course, and the impacts on students' academic and professional growth</p>	Mixed methods: surveys and focus groups	Fifteen Engineering students (one doctoral, 12 Masters and two Bachelor's degrees) from Mechanical Engineering ($n = 9$), Biomedical Engineering ($n = 5$), and the School of Information ($n = 1$)	<p>Paired <i>t</i>-tests were completed at the start and completion of the course, with statistically significant increases in confidence for 10/15 statements on the survey related to design task confidence</p> <p>Focus group findings report that the style of learning used in the course was a factor involved with increasing self-confidence</p> <p>Students also noted the importance of learning opportunities off-campus, increasing ability to contextualise needs</p> <p>All students agreed that being purpose-driven provided motivation for active engagement in the course</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Tandon (2017) [25]	To examine changes in student interest and knowledge about science and engineering when engaged in solving the problem of disease with technology	Cross-sectional survey	60 Science and Engineering	<p>Students had an overall increased interest in science and engineering after participating in the grand challenge</p> <p>Questionnaire asked students to report self-interest in knowledge in Interest in Drones (Air) and (Land), Interest in Biotech Industry, Knowledge of Drones (Air) and (Land), and Knowledge of Biotech Industry.</p> <p>Knowledge of drones (Air) ($p < 0.001$), Knowledge of Drones (land) ($p = 0.001$), Knowledge of Biotech Industry ($p < 0.001$) were significant</p> <p>Students felt their knowledge increased significantly by participating in a grand challenge</p> <p>All but one student stated that they would participate again in a grand challenge event if offered again</p>
Telenko (2016) [62]	To examine if the course and assignments encourage students' self-concepts in design, improve students' understanding of single subject material, and improve students' self-concept in integrating concepts from multiple disciplines of study through multidisciplinary problems	Surveys: postsurveys, paired pre- and postsurveys, and paired pre- and postconcept quizzes	136 junior college Engineering students	<p>The mean responses of all 136 respondents identified significant increase in students' ability to engage successfully in design, foster cooperative team problem-solving skills, and increase interest in learning more about design with an average response of 4.3/5 (95% CI [0.13])</p> <p>The students exhibited a modest understanding of concepts before the course and a stronger grasp after completing the design project</p> <p>There were no statistically significant shifts in students' perceived ability to solve thermodynamics problems</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Trowbridge (2018) [63]	To understand how participation in the <i>Grand Challenge Scholars Program</i> may influence first-year engineering students' development of a systems perspective of engineering To analyze how students understand and describe the relationship between society and technology in their reflections on their experiences in an interdisciplinary course	Qualitative study analyzing students written reflections	59 first-year Engineering students	Students recognized ways in which society influences technology and that technology has significant impacts on society Students recognized the need for multiple disciplines, including but not limited to engineering, to be involved in developing successful solutions to grand challenges Several students recognized connections between areas of application, such as health, sustainability, and security, and described several examples of challenges and solutions overlapping between themes
Udugama (2018) [64]	To evaluate the success of a real-world challenge for biotechnology students	Surveys	25 biotechnology graduate students	The student surveys indicated successful imparting technical and industrial knowledge to participants, while also providing a good balance between social and academic activities 96% of respondents would highly recommend the course, data for the balance are only displayed in a bar graph and can only be estimated ~ 80 % strongly agree, 20% agree, and the ~1% are neutral or disagree
White (2017) [66]	To examine students' understanding of sustainability by measuring geoscience literacy, their understanding of the process of geoscience, and their systems thinking To determine students motivation to contribute to solving grand challenges of environmental sustainability, depletion of natural resources, and natural hazards	Pretest-posttest surveys	27 undergraduate Geoscience students	Student's scores increased from 7.8 to 8.1 out of 10, on the overall the Geoscience Literacy Exam (GSE) score One-half showed an improvement from the pretest to the posttest on individual GSE questions A higher percentage of students envisioned using what they learned in the course to help society overcome problems of environmental degradation, natural resources limitations, or other environmental issues

First author (year)	Study aims	Study design	Participants	Results
White (2014) [67]	<p>To assess motivation for applying to the program; evaluation of the course structure, logistics, and content</p> <p>To explore perspectives on and commitment to social justice</p> <p>To self-assess professional skills, active engagement, confidence, and growth in seeking leadership and academic opportunities</p>	Mixed methods: surveys and focus groups, pre-post tests	35 interdisciplinary undergraduate students	<p>Survey results show that students felt highly engaged in the learning process</p> <p>Individual survey items indicated most or all students agreed or strongly agreed to items indicating a deep sense of engagement in self-directed learning, and satisfaction with the structures supporting self-directed learning</p> <p>8 questions on engagement showed 100% of respondents agreed or strongly agreed, with the exception of “I received the support I needed to be successful in designing an actionable solution) in which 96.6% agreed/strongly agreed</p> <p>All the students reported that they were active participants, they increased their knowledge and understanding of topics that interested them, and they enjoyed the intensity of immersing themselves in learning and project development</p> <p>100% of students agreed or strongly agreed that they see the world differently than they did before Students reflected that they see strengths in themselves that they did not previously see, and that they increased strengths they already had, becoming better versions of themselves. 100% of students agreed or strongly agreed with these statements</p> <p>Nearly 40% of students changed their study habits and two-thirds reflected a shift in how they participate in class as a result of this experience</p> <p>More than 60% of respondents changed their behavior in regard to seeking leadership opportunities and engaging in community service</p> <p>Nearly all current participants, and more than 85% of past participants, felt more integrated in their community</p>

TABLE 5: Continued.

First author (year)	Study aims	Study design	Participants	Results
Wilson (2019) [68]	To explore student perceptions of an interdisciplinary course about homelessness	Mixed-methods case study including survey data, pre- and postevent surveys, field observations, and artifacts in the form of team pitch presentations	32 multidisciplinary undergraduate and graduate students	Participants reported very high levels of satisfaction on their postcourse surveys A strong majority of participants (91%) agreed or strongly agreed that the course met their expectations, they gained something useful from the course, they enjoyed solving problems creatively, and they enjoyed working as an interdisciplinary team A majority (89%) agreed or strongly agreed that they enjoyed learning about homelessness Paired <i>t</i> -test showed that self-perceived knowledge increased ($p < 0.01$), change in attitude towards: society working collectively to address homelessness ($p < 0.01$), a contributing factor to people experiencing homelessness is failure of social systems ($p < 0.01$), participants should be involved in social system solutions ($p < 0.01$), and increased students reported participation in civic engagement ($p < 0.001$)

may similarly be important considerations for those seeking to create multidisciplinary grand challenge courses.

The promotion of critical thinking to develop a better understanding of societal problems was identified as a common learning objective in the grand challenge literature. As noted in our findings, critical thinking can facilitate thoughtful evaluation and strategic planning to develop innovative solutions to grand challenges. Walker [78] suggests questioning, classroom discussions, debates, and written assignments to be some of the best methods to promote critical thinking. Further, Hofreiter et al. [79] have suggested the use of real-world examples, such as societal grand challenges, as preeminent in promoting critical thinking skills.

The most common course assessments were design thinking projects. Design thinking is a process that is analytic and creative which “engages individuals in opportunities to experiment, create and prototype models, gather feedback, and redesign” [80]; p. 330). Foshay and Kirkley [81] suggest the use of authentic problems, such as grand challenges, in conjunction with practice and assessments, as seen in design thinking assignments, to promote the development of problem-solving skills. Glen et al. [82] suggest that design thinking facilitates rapid learning, builds confidence in working with complex problems, and provides tools to develop diverse perspectives. In addition to helping build confidence, design thinking promotes

the development of transferable professional skills including communication, integrative thinking, innovation, and collaboration [83].

Professional and personal skills development was identified as another common course objective and research finding. Singh and Gera [84] discussed the importance of skills development in higher education curricula and suggested the incorporation of collaborative pedagogy techniques and activities such as project work, practical learning, and group presentations to increase broader skill development. Nordstrom and Korpelainen [85] suggested creating videos, posters, and models, all of which are common to grand challenge courses, to help further enhance important professional and personal skills. Similar to design thinking projects, presentations, essays, and active discussions also promote the growth of transferable professional skills. Student presentations and active discussions help build the skills of verbal communication, active listening, networking, and time management, while written essays and reports promote the development of written communication, analytical skills, and professional language [84].

5.1. Gaps in Evidence and Suggestions for Future Research. Research regarding the incorporation of grand challenges in higher education is still in its early stages. The impact of the design and delivery of grand challenge courses in higher

education remains an underexplored area of research. To date, there are few comparative research designs and no experimental, quasiexperimental, or longitudinal research. Additional comparative studies are needed to identify effective approaches to design, embed, and promote the use of grand challenges as a pedagogical approach. Future research should also explore the involvement of females compared to males in grand challenges and how to promote equitable involvement of students in the minority.

5.2. Strengths and Limitations. Although a robust and systematic method was used to identify all published literature on grand challenges in higher education, we cannot rule out the possibility that our search missed some relevant sources. Contacting grand challenge experts may have helped identify more grey literature to include in our review. A majority of the included studies were from the US. While this reflects the current state of evidence on grand challenge use in higher education, the disproportionate geographical representation may not accurately reflect grand challenge use in other higher education institutions from other countries.

The limited depth to which grand challenges have been empirically explored reduced our ability to make strong conclusive statements about grand challenge outcomes. Due to the heterogeneity of current grand challenge literature, no systematic review of grand challenge studies is possible at this time. In general, studies examining grand challenge use in higher education are weak in their methodological rigor and did not adequately explain their data analysis procedures, making it difficult to conclude that, based on these studies, grand challenge initiatives were successful in meeting their intended outcomes. Despite these limitations, the findings from this scoping review reflect the current state of evidence for the use of grand challenges in higher education while underscoring the need for additional research with robust study designs to better understand the impact and outcomes of grand challenge work.

6. Conclusion

This scoping review helped further our understanding of the use of grand challenges in higher education. While there are clear benefits to incorporating grand challenges into higher education curricula, future research is needed to determine how instructors and institutions can best incorporate grand challenge teaching and learning opportunities. In identifying what is known as well as gaps in the existing literature, this review helps further the development of, and ongoing improvements to, grand challenges in the context of higher education.

Data Availability

The data used to support the findings of this scoping review study are included within the article.

Disclosure

The corresponding author completed JBI Comprehensive Systematic Review Training at the Queens Collaboration for Healthcare Quality: a JBI Center of Excellence.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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