1 Background and Purposes

The *International Handbook of Engineering Education Research (IHEER)* is a reference volume intended for those new to the field of engineering education research (EER) and current experts in the field. This short introduction to the handbook provides a background on its development and briefly describes its content.

Although interest in documenting and improving the education of engineers has existed for over a century, the institutionalization of EER as a discipline-based education research (DBER) field is a more recent phenomenon (Froyd & Lohmann, 2014; Loui & Borrego, 2019; National Research Council, 2012). Especially over the past couple of decades, the field has coalesced around the idea that a more research-focused approach to creating and implementing educational changes can lead to improved engineering education for all. Consequently, research-focused departments, doctoral programs, centers, journals, and conferences have proliferated not only in the United States, where significant funding is available for EER, but also across the world (Bernhard, 2018; Borrego & Bernhard, 2011).

This increasing and evolving footprint of EER has meant that many newcomers to the field, both students and faculty, are now looking for resources that can guide them as they conduct research or develop new educational resources. *IHEER* will serve this goal by providing readers with an overview of some of the major developments in the field over the past decade. In addition, emerging scholars and experts in the field will find the review of existing literature as well as the discussions of directions for future research useful. One highlight of this volume is the critical perspective authors take towards different topics, especially in Part 2, but also in other chapters interspersed throughout, to bring into focus new concerns and alternate viewpoints and methodologies.

Within the realm of publications in the field, *IHEER* appears almost a decade after the previous handbook, *The Cambridge Handbook of Engineering Education Research (CHEER)* (Johri & Olds, 2014), was published. *IHEER* was conceptualized as a volume that builds on *CHEER* by introducing new ideas, topics, and contributors rather than revising or revisiting content already covered. *IHEER* is also more international in scope, with authors and topics from many more non-US countries than *CHEER*. Education is a contextually applied science, and therefore, it is inconceivable that all research findings will be equally applicable across places and people. Yet a comparative approach can benefit all, and certain ideas and innovations should propagate universally. For this,
it is important that scholars from across the globe engage in a dialogue. This is already taking place through conferences and journals, and *IHEER* further cements some of those exchanges.

Given the large volume of publications in the field, *IHEER* only captures a slice of the research developments within EER. To determine the topics and contributors, a survey was distributed to community members and resulted in 150 responses. These responses were analyzed to create broad categories, and then, further subareas were identified. Finally, author teams were invited to submit chapters that underwent two rounds of reviews. The result is a handbook with 30 chapters authored by 100 scholars from 20 countries spread across five continents.

In addition to *IHEER* and *CHEER*, there are numerous sources that readers can consult to learn more about EER, including John Heywood’s comprehensive book on the topic (Heywood, 2005) and special issues published in the *Journal of Engineering Education* and *European Journal of Engineering Education*, among other journals. Recently, several reviews of the fields have also been published (see Chapter 7). A more comprehensive overview and list of different publications, programs, scholars, and opportunities is available in sources listed under *Resources* at the end of this chapter, and additional readings and texts have been cited throughout this handbook.

2 Organization of the Handbook

In addition to the introduction and conclusion chapters, *IHEER* contains 30 chapters distributed equally across six sections. Any act of classification is a social exercise, and the organization of this handbook is no exception. The chapters have been organized according to some underlying logical similarities between them; in some instances, the alignment is stronger, but readers are cautioned against reading too much into the organization. Chapters across sections are meant to be in dialogue with each other and frequently refer to each other.

**Part 1: Comparative Perspectives for Engineering Education Research**

The first part of the handbook directly addresses the issue of taking an international perspective on engineering education and contains five chapters authored by teams of authors from across the globe. The first chapter is a compendium of viewpoints from authors from five countries. It provides a historical and global analysis of topics spanning engineering education during the colonial period, the entry of women into engineering education institutions, the teaching of ethics and technical education, and the consistent and persistent discussion of why and how we are training future engineers. In the second chapter, Tang et al. introduce and discuss comparative education that examines education across countries and uses the country as the unit for comparison. They provide a brief overview of the evolution of comparative education and outline its three main approaches for comparing education systems across countries: scientific, ameliorative, and interpretive. They then utilize a comparative approach to present exemplar EER studies that illustrate each one of the three main approaches of comparative education. Seniuk Cicek et al. tackle the contested notion of decolonization and its absence within engineering and related literature. They explore how decolonization is conceptualized within engineering education and identify four categories of decolonization. They further discuss drivers for and barriers to engaging in decolonial work within engineering education and make recommendations. In their chapter on engineering ethics education and research, Martin et al. make a plea for academics to engage explicitly with the value-laden nature of engineering and its contextual elements, especially global aspects. The chapter provides an overview of major actors within engineering ethics education research and surveys recent pedagogical and institutional practices to broaden engineering ethics education towards a global and culturally inclusive vision. In the final chapter of this part, Lindsay et al. address the disruption in engineering and engineering education that is taking place globally due to innovation in engineering processes, whereby engineering
practice is ever evolving and requires new ways of tackling complex sociotechnical problems. They argue for and give exemplars from four different programs using the continuous improvement mindset to commence, continue, and sustain disruptive innovation in engineering education. They discuss potential barriers to innovation and how they can be overcome.

Part 2: Theoretical Orientations and Critical Approaches in Engineering Education Research

The second part of the handbook focuses on theoretical and critical orientations newly or further developed or deployed within the field. The part begins with a chapter outlining the role and uses of theory and theoretical frameworks. In the chapter, Goncher et al. discuss the role of theory in engineering education research (EER) and elaborate upon the utility of using theory and related underpinnings, such as paradigms and concepts. They outline and discuss three theories – social cognitive career theory, situated learning, and intersectionality – each corresponding with either the postpositivist, interpretivist, or critical paradigm, which are commonly used within EER to illustrate the use of theories. Lönngren et al. argue that affective constructs, especially emotions, need to find a more central place within EER. Through their chapter, they introduce the reader to the multidisciplinary field of emotion research and describe different disciplinary and theoretical perspectives on emotions, as well as methods and methodologies. They outline important and promising areas for future research and provide advice for researchers and doctoral students who plan to pursue engineering education emotions research. Huff and Ross advance an integrated conceptionalization of engineering identity that considers the complexity of this theoretical construct, and locate engineering identity research within three foundational frameworks: (1) personal, (2) social, or (3) sociocultural. They further advocate strategies for EER to advance theory development on identity. Secules et al. review research from learning sciences and engineering education research to highlight considerations of power and culture as they intersect with knowledge, identity, agency, language practices, discourse, and sociomateriality. They elaborate on critical cultural analysis and demonstrate its utilities for examining, elucidating, and informing learning practices. Mejia and Martin take a critical view and argue that most US-based research related to diversity, equity, and inclusion (DEI) in engineering education is reductionist in its approach, and discuss recent scholarship that advocates for methodological activism and pluralistic approaches in engineering education research in order to truly address issues of DEI.

Part 3: Engineering Education Across Contexts and Participants

In Part 3, we take a look at engineering education beyond the traditional focus on undergraduate programs and curriculum. In recent years, there has been an increase in interest and research on the PK–12 level, and one of the actors here are teachers. The first chapter, by Carberry et al., examines teacher preparation, an important but often-overlooked aspect of preparing future engineers. In their chapter, the authors discuss the importance of and need for pre-college engineering teacher professional learning (PCE TPL). They present a case within a US context supporting the need and place for engineering teacher professional learning. The chapter also provides a foundation for future directions in pre-college engineering teacher professional learning. Fleming et al. review graduate engineering education, primarily within the US context. They present an overview of available data about graduate education and its contexts, and they discuss gaps in data. They discuss topics including students’ graduate school experience, motivation to pursue graduate studies, skills development, and identity development, as well as career preparation. They also examine institutional practices that affect graduate enrollment and experience. Cutler and Strong review research on how faculty influence engineering education, who engineering faculty are, and how they can be better
supported within their roles. They argue that a focus on faculty and incorporating faculty voices and narratives are essential if the EER community wants to further its efforts towards creating an educational system that is inclusive, student-centered, and equitable. In their chapter, Polmear et al. provide an overview of informal learning, discussing its definition, history, settings, and activities as relevant to engineering education. They further discuss the benefits and outcomes of informal learning, related to competency development and engagement of diverse learners. They end with implications and recommendations for engineering researchers and practitioners. In the chapter that follows, Chen et al. discuss innovations in engineering education and new approaches that acknowledge and recognize learning and competencies including non-degree credentials. The authors argue that non-degree credentials have the potential to broaden access to engineering and that engineering educators should care about the potential of non-degree credentials in their courses, degree programs, and institutions.

**Part 4: Advancing Pedagogy and Curriculum in Engineering Education**

The five chapters in Part 4 directly address pedagogical and curriculum issues within engineering with both practical and research-related discussions. In the first chapter, Chen et al. examine both the implementation of social justice into engineering curricula and the barriers preventing wider adoption. The chapter discusses three initiatives to infuse social justice into engineering at three different institutions to highlight entry points and barriers as well as the role institutional support has played in accelerating, enabling, and legitimizing the success of this integration. Alarcón et al. present a research-to-practice chapter for prospective and current engineering educators, scholars, and leaders interested in learning about how hidden curriculum (HC) transforms engineering education via social capital. They provide an overview of HC research, discuss its connection to social capital, and introduce an HC pathways model in engineering. Mercier et al. review the last decade of research on collaborative and cooperative learning along four key dimensions of these forms of pedagogy in classrooms: tasks, teams, tools, and teachers. And they end with propositions for future work in collaborative learning in engineering education practice and research. Zappe et al. review the research on integration for creativity, entrepreneurship, and leadership in engineering education. They identify gaps and advance recommendations for practitioners who teach in these areas. They end with a set of reflections on the major concerns and future directions relating to creativity, entrepreneurship, and leadership in engineering education. Hitt et al. review efforts that have been made to promote and develop the inclusion of the liberal arts within engineering education and vice versa. They discuss the historical background of these efforts, review relevant scholarship, and highlight innovative and creative approaches to integrating liberal arts and engineering.

**Part 5: Engineering Education at the Intersection of Technology and Computing**

Part 5 consists of five chapters at the intersection of engineering education, technology, and computing. Gregg and Dabagh review prior work on online learning and advance frameworks to help create productive learning environments. They also argue for a more strategic and directed effort by engineering educators to become leaders in online learning. Bairaktarova et al. discuss the state-of-the-art and applications of virtual and augmented realities (VR and AR), as well as wearable and haptic devices, in engineering education. They review the empirical research behind their use to examine how the integration of VR, AR, wearable, and haptic devices into the learning environments can enhance learning. May et al. take a closer look at engineering education research on online laboratories, with a focus on remote and virtual laboratories. Their chapter reviews prior work on the topic and discusses the future potential of online laboratories in advancing engineering
learning. The final two chapters in this part focus on the intersection of engineering and computing education. The use of computing has become integral within engineering, as has the need to learn about computing. Yadav and Lachney discuss the historical development of computer science education and recent trends at primary and secondary levels, formally and informally. They show how recent developments in computer science education are moving away from perspectives that are overly celebratory or overly drab and towards techno-social realism. The chapter by Malmi and Johri discusses the history of computing education research (CER), a DBER field similar to EER, and focuses on two reviews of two specific subareas of research and practice at the undergraduate level – programming and tool development.

**Part 6: Engineering Education Research Methods and Assessment**

The final part of the handbook focuses on research methods and assessment. Holly Jr. et al. critique engineering education research methodology by articulating the ways in which anti-Black ideas are deeply embedded in the dominant approaches to knowledge production in the field. The chapter is grounded in the authors’ experiences and perspectives as Black scholars who earned their doctorates in engineering education at the two oldest US engineering education programs. It builds on prior critiques of US EER and draws on Black intellectuals from various traditions. The second chapter, by Svihla et al., introduces and discusses the use of design cases in EER as a form of scholarship. Design cases report on an instructional problem, the process of designing a solution, and the learning design created to address the instructional problem. They illustrate the value of design cases by examining exemplars and also provide a template and practical advice for readers. The following two chapters concentrate on quantitative methods, where the first chapter provides an introductory background and the next chapter looks at advanced methods. The chapter by Hjalmarson et al. describes the basic considerations for conducting engineering education research studies using quantitative methodological approaches, with a focus on data quality and data appropriateness. The chapter by Katz et al. discusses opportunities to apply advanced statistical theory and computational techniques within EER. Intended for readers with some familiarity in quantitative research, the chapter discusses emerging quantitative methods and their considerations for quantitative research in four areas: (1) study design, (2) data collection and preparation, (3) data analysis, and (4) data equity. The part ends with a chapter on assessment by Douglas et al. The chapter advances a socioculturally informed, evidence-centered design (SCI-ECD) model for designing and validating assessment instruments of engineering competencies and provides practical exemplars to guide assessment developers and researchers.

### 3 Future Directions

*IHEER* has certain limitations, both in the range of topics that are covered and also in the treatment any given topic has received. Some of this is due to limitations of length, and other variations are due to different approaches taken by the authors. The concluding chapter, by Buckley et al., presents the collective reflection of its authors centered on a view towards the future of EER. They discuss the complexity that exists within and around EER and argue that EER can “always be more,” and the community is faced with the question of what it wants EER to be and become.

The concluding chapter also discusses the limitations of the handbook in more detail. Here, based on my personal experience, I highlight some concerns. There is a need for a volume that focuses on implications, as the research is becoming increasingly insular, with little impact on students or other stakeholders. The criticism that EER is becoming increasingly devoid of any relevance is not entirely untrue. There is also the problem, as with many disciplinary fields, that there is limited experience of engineering as such within the field.
Finally, I hope this volume fits in with the overall EER oeuvre. Each publication venue in EER and each context of research has its unique flavor (Brozina et al., 2021; Valentine & Williams, 2021), and hopefully, this will continue to be the case, as this allows for a much broader range of work to be published. There is also a role for special issues and other review articles to bring specific topics into focus.

References


Resources

*Engineering education wiki* created in 2011 by the American Society for Engineering Education’s Student Division (ASEE SD), in collaboration with the Center for Engineering Learning & Teaching (CELT). The resource consists of links to programs, centers, researchers, societies, publication venues, etc. Primarily a resource for students and other interested individuals new to engineering education about the research happening in this field at institutions and centers all over the world.

http://engineeringeducationlist.pbworks.com/w/page/27578912/Engineering%20Education%20Community%20Resource

*Research in Engineering Education Network (REEN).* https://teen.co/