AIMS OF ENGINEERING EDUCATION RESEARCH – THE ROLE OF THE CDIO INITIATIVE

Kristina Edström

School of Education and Communication in Engineering Science,
KTH Royal Institute of Technology

ABSTRACT

The CDIO Initiative is first and foremost an endeavour for engineering education development, but in the 12th International CDIO Conference in 2016, a special track is opened for engineering education research (EER). This paper aims to clarify a tension within the emerging EER field regarding the aims of research: is it seeking new knowledge to improve educational practice, or for its own sake? While usefulness and scholarliness are not mutually exclusive characteristics, it is a matter of priorities when selecting and formulating problems, and defining the quality of research. Considering this tension is not merely an abstract exercise of ideas and ideals, because definitions of quality also come with assumptions of who can be a legitimate judge. There are implications for legitimacy and power, with real consequences for the people within engineering education and its stakeholder groups. The EER community needs to understand the tension and create a working and productive relationship between scholarliness and usefulness. There is a need for quality mechanisms to stake out borders and standards for EER, at least weeding out such work that is neither scholarly nor useful. Success means creating legitimacy for the research that is simultaneously credible and useful, so it actually can contribute to the improvement of engineering education and create conditions for sustainable careers in academia. In the light of this discussion, an argument is made for how CDIO can contribute to shaping the EER field, and how EER can strengthen CDIO.

KEYWORDS

The CDIO Initiative, the International CDIO Conference, engineering education research, engineering education development, research aims, discipline, usefulness.

INTRODUCTION

The work within the CDIO Initiative (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014) has continuously been documented and openly shared, in books, reports, conference proceedings, and not seldom as peer-reviewed papers in international journals. Despite this long list of publications, the development of engineering programs has always been the priority (Edström & Kolmos, 2014). When the CDIO Initiative opens a new conference track for engineering education research (EER), it is worth considering the purpose of EER, as well as the nature of research that can be relevant for the CDIO Initiative.

This paper starts with a background of the emerging field of engineering education research in the United States and Europe, highlighting somewhat different traditions. The next section explores more deeply the fundamental inherent tension regarding the aims of research, contrasting research with a *consideration for use* and research to further a *discipline*. In the light of this tension, a suggestion is made for the rationale for adding an EER track in CDIO.

ENGINEERING EDUCATION RESEARCH – AN EMERGING FIELD

The study of engineering education was historically scattered across different disciplines as individual scholars found it an interesting *object of study*. Now a more coherent international academic field is evolving; this time the initiative comes from within the engineering community itself. The growth of academic infrastructures for the EER field includes conferences, peer-reviewed journals, and research centres with professorships and PhD programs. Below, some of the development in the United States and in Europe is sketched.

EER in the United States

The development is most visible in the United States, where a well-organised movement is working to establish EER as a discipline. Their efforts are documented in the Journal of Engineering Education (JEE), published by the American Society for Engineering Education (ASEE). It signalled a transition in 2003 from a “scholarly professional journal” into “an archival record of scholarly research in engineering education” (Jack R Lohmann, 2003). In 2005, JEE added the bold subtitle “the research journal” (Jack R Lohmann, 2005). The goal was to be a “world-class journal globally advancing rigorous scholarship” and forming a global community for “advancing engineering education through education research”. Using “rigorous” eight times in two pages, a five-year strategic plan (JEE, 2005) called EER “an emerging discipline”. The National Science Foundation (NSF) was calling for fundamental research (Gabriele, 2005), enabling careers for specialised researchers, and large research centres, most notably departments with PhD programs. When Haghighi (2005) announced the PhD program at Purdue University, he called it the “birth of a new discipline… in the domain of serious science”. Since then, several other institutions have started PhD programs.

The role of NSF funding is crucial for the EER movement. Wankat, Williams, and Neto (2014) noted that in a 2003 issue of JEE the US-based authors of almost one third of the papers acknowledge NSF grants – but ten years later this is true for *all* papers. Editor Lohmann (2011) acknowledged that the development of the journal reflected the rapid growth of educational research in the engineering education community. More specifically, it reflects the volume of NSF funding for US-based researchers specialising in EER. It should be noted that JEE authorship does not reflect the espoused global ambitions. For instance, 88% of its authors in the first issues of 2013 were US-based (Wankat et al., 2014).

It is clear that both *rigorous* and *discipline* were important buzzwords in the EER movement ten years ago (see also Adams et al., 2006; Borrego, 2007b; Streveler & Smith, 2006). This signalled an ambition to achieve recognition equal to (any other) engineering science. EER is represented more as an offspring of engineering than of educational research. For instance, Felder, Sheppard, and Smith (2005) call for research “subjected to the same rigorous assessment and evaluation that characterize first-rate disciplinary research”. However, both rigorous and discipline turned out to be contentious concepts. Jesiek, Newswander, and Borrego (2009) identified stakeholder ambivalence toward a discipline, with better consensus for calling it a *field*. The next strategic plan (JEE, 2011) uses neither rigorous nor discipline –

but *scholarly research*. If the first plan emphasised “advancing rigorous scholarship” per se, the intention of impact was now brought to the foreground: “scholarly research that leads to timely and significant improvements in engineering education worldwide”.

EER in Europe

The development of European EER is far more diverse. In the absence of a strong funding agency, the researchers who can dedicate their careers to studying engineering education are few and far between. Hence, there is less capacity for a concerted EER movement. To support and strengthen the fledgling community, the European Society for Engineering Education (SEFI) started a working group for EER in 2008, aiming to “create a European community of engineering education researchers in order to contribute with research evidence to the advancement of engineering education” (Kolmos, 2008). At the annual SEFI conference, the EER track is the largest sub-theme since 2011 (de Graaff, 2014).

The European Journal of Engineering Education (EJEE) is published by SEFI. Like JEE, its character has gradually become more scholarly (Osorio & Osorio, 2004), but it is deliberately positioning itself as more inclusive. The editorial policy talks of a forum for “dialogue between researchers and specialists”, inviting a wide array of stakeholders to “share accounts of good practice”. Editor de Graaff (2014) notes that EJEE articles in 2012 were cited 0,139 times on average (while JEE had 2,7 citations per paper). de Graaff suggests that readers are engineering educators looking for inspiration, rather than researchers looking for references. In stark contrast to the academic ambitions of JEE, de Graaff declares that EJEE will stay on this course and consider usefulness to practitioners to be its real impact. Another difference is that EJEE authorship is highly international, far beyond what is expected due to the diversity of Europe itself, as a considerable share are non-European.

To some extent, the emerging EER community in Europe can be seen as response to the movement in the US, formed around the work and the people with the closest match to a more clearly defined identity offered from across the Atlantic. The exchange among the communities is intense, with several US-led efforts to establish bonds and shape the field (see for instance Finelli, Borrego, & Rasoulifar, 2015; Jesiek, Borrego, & Beddoes, 2010). In addition to cross-participation in each other’s conferences (SEFI and ASEE), the global Research in Engineering Education Network (REEN) organises a biannual symposium.

An Inherent Tension

Already this brief history demonstrated how the different ambitions for the EER field reflect various stakeholders’ interests and actions, and also significant diversity in how EER is conceptualised. Simply put, the battle cry on one side of the Atlantic was *scholarliness* and on the other it was *usefulness*. To investigate some of the possibilities and trade-offs in staking out the field we will now consider the *aims* of doing EER. It is not so much a geographic issue, but a far more fundamental one. As will be seen, it is a highly value-laden issue, everyone who sets out to study engineering education will experience the same inherent tension, and it will always be discussed. We must learn to understand and deal with it, positioning our work and positioning ourselves.

The fundamental defining question for EER regards: is the aim of research to improve educational practice, or is it to seek new knowledge for its own sake? These are not mutually exclusive categories, but different priorities will be set in the definitions of quality depending on what aim is in the foreground and what is in the background.

Simply put, if the aim is to produce new knowledge, it is a task of *proving* something and the main criterion is *truth*. On the other hand, if the aim is to have implications for practice, the consideration for *usefulness* will be most important. This affects how quality is judged. Borrego and Bernhard (2011) cite Alan J. Bishop's distinction between two research traditions. In a *method-led* tradition, quality comes from proper use of methodology, making conclusions credible. In fact, the term 'rigorous' is used precisely because it is assumed that rigorous methods ensure truth. In a *problem-led* tradition, quality lies in selecting questions that are interesting and significant for real-world problems, and generating meaningful insights relevant for these problems.

Any definition of quality is always intricately intertwined with the question of who can be the legitimate judge of it. Considering the balance and relationship of the two aims is therefore not merely philosophical exercise. The priorities are followed by implications for legitimacy and power, with real consequences for the people within engineering education and its stakeholder groups. The tension is also relevant for the researcher's personal motivation to do EER. The identity as a researcher with a development agenda is quite different from that of a 'disinterested' researcher whose identity is often tied to a disciplinary belonging. This is, of course, a classic discussion for all research, and the debate has been lively within higher education and in society at large, not least with the expansion of research and higher education in recent decades. In the following, some useful ideas from these debates will be presented, first discussing discipline-led and then practice-led research.

DISCIPLINE-LED RESEARCH

Disciplinary autonomy and quality control

In academia, seeking knowledge for its own sake is, in practice, often the same as furthering a discipline. This is because the judgement of quality belongs with one's disciplinary peers, whose approval is the basis for dispensing all resources under academic control. The academic capital comes in hard currency such as publication, dissertation, funding, appointment, tenure, promotion, awards and prizes, etc. Borrego (2007b) defines a "rigorous engineering education researcher" as one who attracts funding and publishes in journals such as JEE, because, she explains, in both cases rigorous standards are enforced through peer review. The peer review instrument functions as a "powerful selection mechanism of problems, methods, people and results" (Gibbons et al., 1994), and the result is discipline in every sense of the word. The dictionary lists several meanings of discipline: a system of *rules of conduct* or *methods of practice*, the possession of *self-control*, and the act of *punishing* – all of which are also applicable to academic discipline. As Harvey Brooks (1967) points out: "Although scientists like to emphasize that fundamental research is 'free', it is actually, in another sense, a highly disciplined activity. The discipline is provided by the scientific community, to which the researcher is related. His choice of problem and direction is heavily conditioned by the social sanctions of this community, the requirements of originality, and scrupulous reference to related and contributing work of others." In the end, those individuals whose work is not judged to be up to the mark will inevitably be weakened and marginalized by a lack of resources and recognition – and this is exactly how the quality mechanism works. The weeding and pruning of its practitioners is the responsibility of the discipline; it is the quality control that legitimises academic freedom.

Thus the effort to establish EER as a discipline aims ultimately to achieve this autonomy, without which the researchers will struggle to achieve status and recognition in the academic landscape. As long as the researchers work in the academic environment the disciplinary logic will still fundamentally define their careers. In academia, disciplines are the "homes to which scientists must return for recognition or rewards" (Gibbons et al., 1994). Academic homelessness is a highly relevant issue for EER: "[Most] people in the community are living on the fringes. They are staff on soft money with no reward structure. The only way to give them a home to gain recognition is to have a home as a discipline." (Jesiek et al., 2009). In reality, stakeholder approval is also important for any discipline that depends on external funding. If legitimacy is lost, e.g. if it is perceived as an irrelevant ivory tower of "disinterested" researchers, there is a risk for discontinuation of resources (de Graaff, 2014). But as Gibbons et al. (1994, p. 23) point out: "Scientists have long appreciated that there is no intrinsic reason why the funding strategies of governments, firms, or foundations should conform to the current internal, cognitive structure of their discipline. Over the years, they have exercised great ingenuity in translating their own research interests into the language appropriate to other agendas."

What Defines a Discipline?

In a highly interesting account, Fensham describes the evolution of science education research (Fensham, 2004), which can be seen as a parallel to EER. He identified a number of maturity indicators for the disciplinary development of the research field (see Table 1).

Table 1. Fensham's disciplinary criteria for science education (Fensham, 2004).

Structural Criteria	**Research criteria**	**Outcome Criteria**
▪ Academic recognition ▪ Research journals ▪ Professional associations ▪ Research conferences ▪ Research centres ▪ Research training	▪ Scientific knowledge ▪ Asking questions ▪ Conceptual and theoretical development ▪ Research methodologies ▪ Progression ▪ Model publications ▪ Seminal publications	▪ Implications for practice

Applying these criteria to EER, Jesiek et al. (2009) noted that the structural criteria, i.e. the academic infrastructures of the field, are beginning to match. However, the research criteria, e.g. common research questions, conceptual and theoretical development, methodologies, and progression, imply a more coherent endeavour than is presently seen. Of Fensham's criteria, the *implications for practice* (outcome criteria) have hardly begun to be discussed and will need a deeper analysis.

So far, much debate on quality in EER has focused on methods, indicating a method-led approach (Borrego & Bernhard, 2011), and consistent with discipline formation. Borrego, Douglas, and Amelink (2009) state that to develop a scientific field, "appropriate methods, convincing evidence, and standards for evaluating the quality of research studies are just as important" as identifying important research areas. Clearly, claiming quality definitions is key to staking out disciplinary territory.

The focus on methods could also reflect certain assumptions about EER. An understanding of qualitative methods is seen as the missing element for engineering faculty who set out to do educational research (Borrego, 2007a; Case & Light, 2011; Koro-Ljungberg & Douglas, 2008). At one stage, EER was conceptualised as measurement, or 'assessment', of effectiveness of teaching methods (Olds, Moskal, & Miller, 2005). It was thought of as the first step for faculty who want to demonstrate that a (their) teaching intervention "works", making methodological soundness crucial. However, this was identified as a limited view already by Streveler and Smith (2006) who argued that EER has the wider purpose "to answer fundamental questions about how students learn engineering". And as de Graaff and Kolmos put it, "the aim of a scientific study is to understand the causes of the success or failure, not just to assess it" (Johri & Olds, 2014). They further note that the measurement paradigm conveys a false ideal of context-free knowledge, as "demonstrating that a specific method is successful in one classroom does not necessarily mean it will also be successful in another school with different conditions and with different teachers" (ibid). To deepen the discussion on methods, Baillie and Douglas (2014) argue that quality must start with the epistemology – the ways of knowing – and the ideal is a coherent alignment of theory, methodology, and methods.

So far, quality discussions focus little on the aims of research. In particular, the potential for improving education is seldom mentioned as a quality dimension. To take usefulness seriously, we need sophisticated understandings of what kind of research would be useful. Compared to well-established methodological aspects, it is more challenging to operationalize criteria related to usefulness. The problem-led research tradition emphasises values such as relevance to practitioners and meaningfulness of insights. Bernhard and Baillie (2013) propose criteria for the quality of the study *in general* (e.g. informed by theory, research question and literature, internal consistency), the quality of the *results* (e.g. richness in meaning, contribution) and the *validity* of the results (e.g. heuristic value, empirical anchorage, pragmatic criterion). As these dimensions can accommodate both scholarliness and usefulness, such criteria can lead the quality discussion, and the field, forward.

RESEARCH WITH A CONSIDERATION FOR USE

Mode 1 and Mode 2

Gibbons et al. (1994) provide useful concepts for understanding the interests on each side of the argument. 'Mode 1' is their term for the ideal model of traditional science, organised according to a discipline-led logic, where "problems are set and solved in a context governed by the, largely academic, interests of a specific community". Thus, success can be described as "excellence defined by disciplinary peers". Here, the relationship between research and practice is seen as linear: "discovery must precede application". The other (newer) ideal with a problem-led logic is labelled 'Mode 2'. Here, knowledge production and application are integrated: "When knowledge is actually produced in the context of application, it is not applied science, because discovery and applications cannot be separated, the relevant science being produced in the very course of providing solutions to the problems defined in the context of application" (p. 33). Such problem-led research challenges the disciplinary structure, because the cognitive logic follows the problems at hand: "…because the solution comprises both empirical and theoretical components it is undeniably a contribution to knowledge, though not necessarily disciplinary knowledge. Though it has emerged from a particular context of application, transdisciplinary knowledge develops its own distinct theoretical structures, research methods and modes of practice, though they may not be located on the prevailing disciplinary map" (p. 4).

The point is that both forms of knowledge production coexist and will continue to do so. Mode 2 challenges the hegemony of disciplines, with implications for what counts as interesting and valid problems to study, for the methods and participants of knowledge production, and for the evaluation of process and results. Quality is determined not only by the truth criterion but also by relevance and usefulness.

Usefulness is a Stakeholder Perspective

'Usefulness' implies someone beyond the researchers themselves who can benefit from the research, and this opens up for other interests and perspectives. Research agendas can be formulated in wider dialogues, and quality control may involve also other stakeholders. It is perhaps understandable if researchers hesitate to share the ownership of the research enterprise; it is a different order than the traditional academic one. It is perhaps telling when Jesiek et al. (2009) label the two aims "research" (in itself) and "practice and other 'external projects'". It remains to be seen if the EER community can sustain legitimacy if improving educational practice is seen as *external*. Research with a consideration for use may require a mind-set where research and development are more integrated, and rather than linear progression, we should create many kinds of interplay. If we are to understand how solutions and interventions could work, research problems cannot be reduced and context-free. Thus, the cognitive structure follows the logic of problems and the problems are set in a context. The boundary between research and development must be blurred and permeable, in a spiral of discovery, integration and application. Plenty of boundary work is needed and must be recognised, and so should boundary people.

COMBINING USEFULNESS AND SCHOLARLINESS

Pasteur's Quadrant

The balance and relationship between scholarliness and usefulness is both a philosophical and practical question, on the individual and collective level. For the field, there are implications for peer review, for upholding borders and forming relationships between research and development, or between researchers and developers. For individual researchers the tension is at the heart of every inquiry: do I consider 'what can be useful' or 'what can be known'? Or (how) can my work be *simultaneously useful and credible*?

Harvey Brooks (1967) helpfully pointed out that "the terms basic and applied are not opposites. Work directed toward applied goals can be highly fundamental in character in that it has an important impact on the conceptual structure or outlook of a field. Moreover, the fact that research is of such nature that it can be applied does not mean that it is not also basic." He mentions how Pasteur's work on practical problems was also conceptually ground-breaking, founding a whole new branch of science.

Elaborating Brooks' argument, Stokes (1997) put the label *Pasteur's Quadrant* on the intersection of consideration for use and quest for fundamental understanding (figure 1). In Edison's quadrant, focus is mainly on solving a specific problem, and Stokes points out "how strictly Edison kept his co-workers from pursuing the deeper scientific implications of what they were discovering in their rush toward commercially profitable electric lighting". Also Soderberg (1967) mentions how Edison, as well as Ford, were characterised by "a core of anti-intellectualism along with impatience toward scientific sophistication".
Bohr's quadrant is the basic science, seeking fundamental understanding. This is knowledge for its own sake, and the ideal is a disinterested researcher. Here, the premise is that *someone else* should figure out *later* if and how the new knowledge can be used. This is the

linear model of innovation starting with basic research, followed by applied research and development, and then with production and diffusion. The linear model has been largely refuted empirically but remains strong in arguments for funding basic science (Godin, 2006).

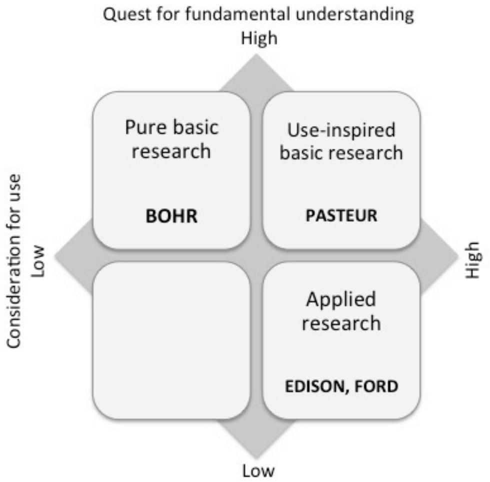

Figure 1. Pasteur's Quadrant (based on Brooks, 1967; Soderberg, 1967; Stokes, 1997).

Defending Both Sets of Values

Since success depends on internal recognition as well as external legitimacy, the demands of scholarliness and usefulness will always apply simultaneously. This does not mean that the tension can be glossed over. Values on *both* sides of the balance must be safeguarded and we must be able to see through hollow claims. For instance, disciplines have an interest in claiming usefulness to legitimate their resources. Likewise, there is an interest in labelling as research also what is really development, to improve status and opportunities for career and funding.

EER is facing the dilemma of any new community. To grow the field, thresholds to enter must be reasonable – but to enable progression and create recognition, standards must be raised and specialisation encouraged. The diversity has been seen to cause friction. Established researchers have rolled their eyes at newcomers' descriptive papers stating that "we tried it and liked it and so did the students" (Felder et al., 2005). Practice-oriented scholars have critiqued rigid definitions of rigour (Felder & Hadgraft, 2013) and worried that "high publication standards exclude practitioners" (Borrego et al., 2009). The field needs both specialists devoting their career to EER, often crossing over from other backgrounds, as well as part-timers, e.g. engineering faculty taking key roles in dissemination and implementation.

The conclusion is that the field needs a culture that can handle the diversity, and structures for productive dialogue. Nevertheless, EER needs quality mechanisms to stake out some borders and standards, at least to weed out such work that is neither scholarly nor useful. The EER community must understand the tension between the two aims and take on the important task to create a working and productive relationship between them. This is not going to be a simple task, but it must be done. Otherwise we risk landing in different camps, weakening the community in an eternal trench war. Success means creating legitimacy for the research that is simultaneously credible and useful, so it actually can contribute to the improvement of engineering education *and* create conditions for sustainable careers in academia.

THE ROLE OF CDIO IN EER

Criteria for review

When the CDIO Initiative opens a track for EER papers, the ambition is to make a contribution in the handling of this tension, by combining usefulness and relevance for improving engineering education with demands for scholarliness, while supporting the goals of the CDIO initiative.

Inspired by Bernhard and Baillie (2013), the first draft of review criteria for the 2016 International CDIO Conference were formulated with the aim to balance the aspects related to scholarliness and usefulness. See Table 2. The guiding questions avoid superficial compliance with technicalities. For instance, instead of asking about a methodology section, they ask for an adequate explanation how the problem is approached and the argument built. Instead of asking for research questions, they ask for a clear aim or problem statement.

Table 2. Review criteria for the EER track in the 12th International CDIO Conference, in Turku, Finland, June 12-16, 2016 (Edström, 2015).

Overall relevance	▪ Is the topic relevant, significant, interesting and timely for the engineering education community, and in particular for the CDIO Initiative?
Literature	▪ Is the paper informed by relevant theory and other literature? ▪ Is it put into good use here?
Aim or problem	▪ Is it clear what the paper is trying to achieve, what problem it addresses? ▪ Does this have significant implications for the audience?
Research approach	▪ Does the paper adequately explain how the problem is approached and how the argument is built? ▪ Are limitations critically discussed?
Conclusions	▪ Do conclusions address the stated problem or aim? ▪ Are the claims credibly supported? ▪ Does the paper deliver a take-away message for the community?
Coherence and clarity	▪ Is the paper clearly and logically structured? ▪ Do the parts contribute to the whole? ▪ Can the reasoning be followed through the paper? ▪ Is the paper readable and language appropriate for the audience?

How CDIO can Strengthen EER, and Vice Versa

Creating a connection between the CDIO Initiative and the EER community has potential advantages for both sides. CDIO brings to the table a dynamic international community with many experienced people, a diversity of institutions, and the CDIO approach as a joint frame of reference. The International CDIO Conference attracts a wide international audience of experienced and critical practitioners; it is an arena for developing a bold agenda for useful research.

In the CDIO community, the educational reform was always first and foremost a practical endeavour. However, although it was never a purely intellectual pursuit we always approached the educational development work with considerable curiosity and willingness to learn from the experiences. Our ideal for research on engineering education should be

Pasteur's quadrant (Figure 1), where practical usefulness intersects with new understandings. Even when our approach to educational development is highly result-oriented, i.e. when we are in Edison's quadrant, we recognise the potential for experiential learning. Not least, we have tried and failed, and tried again, enough times to result in interesting lessons learned.

The CDIO community has always been an arena for jointly analysing these experiences and validating empirical knowledge. The annual conference proceedings have became our most formal mechanism for archival and dissemination. The ultimate aim of adding a conference track for EER is to further sharpen our tools for educational development, and to increase our available toolbox by adding new perspectives. It will encourage us to practice even more of the good intellectual habits from research, e.g. building on previous work, making room for more systematic reflection, and raising the ambition in documenting our work and communicating it. This may support us in producing more, and more credible, evidence to increase legitimacy and support dissemination. The move to include EER can stimulate individuals to keep developing within the community over a longer term, when the work they produce is better aligned with incentive systems in academia. We can hope to attract some new friends who might bring new interesting perspectives and ways of knowing and working.

However, taking the step to add EER to our repertoire does not mean that we value engineering education development any less. The hierarchical and linear thinking, which places research before and above development, should always be rejected. We are not co-opted into research; we do it to strengthen our important mission.

REFERENCES

Adams, R., Aldridge, D., Atman, C., Barker, L., Besterfield-Sacre, M., Bjorklund, S., & Young, M. (2006). The research agenda for the new discipline of engineering education. *Journal of Engineering Education, 95*, 259-261.

Baillie, C., & Douglas, E. P. (2014). Confusions and Conventions: Qualitative Research in Engineering Education. *Journal of Engineering Education, 103*(1), 1-7.

Bernhard, J., & Baillie, C. (2013). Standards for quality of research in engineering education.

Borrego, M. (2007a). Conceptual difficulties experienced by trained engineers learning educational research methods. *Journal of Engineering Education, 96*(2), 91-102.

Borrego, M. (2007b). Development of engineering education as a rigorous discipline: A study of the publication patterns of four coalitions. *Journal of Engineering Education, 96*(1), 5-18.

Borrego, M., & Bernhard, J. (2011). The emergence of engineering education research as an internationally connected field of inquiry. *Journal of Engineering Education, 100*(1), 14-47.

Borrego, M., Douglas, E. P., & Amelink, C. T. (2009). Quantitative, qualitative, and mixed research methods in engineering education. *Journal of Engineering Education, 98*(1), 53-66.

Brooks, H. (1967). Applied Research, Definitions, Concepts, Themes *Applied science and technological progress: A report to the Committee on Science and Astronautics, U.S. House of Representatives* (pp. 21-55). Washington: National Academy of Sciences.

Case, J. M., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education, 100*(1), 186-210.

Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D. R., & Edström, K. (2014). *Rethinking Engineering Education: The CDIO Approach*. Cham: Springer International Publishing: Cham.

de Graaff, E. (2014). Research versus educational practice: positioning the European Journal of Engineering Education. *European Journal of Engineering Education, 39*(1), 1-6. doi:10.1080/03043797.2014.882146

Edström, K. (2015). Criteria for review of Engineering Education Research (EER) contributions in CDIO. Retrieved from www.cdio.fi/docs/CDIO2016_EERcriteria.pdf

Edström, K., & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development. *European Journal of Engineering Education, 39*(5), 539-555. doi:10.1080/03043797.2014.895703

Felder, R. M., & Hadgraft, R. G. (2013). Educational Practice and Educational Research in Engineering: Partners, Antagonists, or Ships Passing in the Night? *Journal of Engineering Education, 102*(3), 339-345. doi:10.1002/jee.20015

Felder, R. M., Sheppard, S. D., & Smith, K. A. (2005). A New Journal for a Field in Transition. *Journal of Engineering Education, 94*(1), 7-10. doi:10.1002/j.2168-9830.2005.tb00824.x

Fensham, P. J. (2004). *Defining an identity: The evolution of science education as a field of research* (Vol. 20): Springer Science & Business Media.

Finelli, C. J., Borrego, M., & Rasoulifar, G. (2015). Development of a Taxonomy of Keywords for Engineering Education Research. *Journal of Engineering Education, 104*(4), 365-387. doi:10.1002/jee.20101

Gabriele, G. A. (2005). Advancing engineering education in a flattened world. *Journal of Engineering Education, 94*(3), 285-286.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*: Sage.

Godin, B. (2006). The Linear model of innovation the historical construction of an analytical framework. *Science, Technology & Human Values, 31*(6), 639-667.

Haghighi, K. (2005). Quiet no longer: Birth of a new discipline. *Journal of Engineering Education, 94*(4), 351-353.

JEE. (2005). JEE Strategic Plan 2005–2010: Advancing engineering education research worldwide. *Journal of Engineering Education, 94*(3), 283-284.

JEE. (2011). JEE Strategic Plan, 2011–2016: Sustaining and Expanding Engineering Education Research Worldwide. *Journal of Engineering Education, 100*(2), 217-219.

Jesiek, B. K., Borrego, M., & Beddoes, K. (2010). Advancing global capacity for engineering education research: relating research to practice, policy and industry. *European Journal of Engineering Education, 35*(2), 117-134.

Jesiek, B. K., Newswander, L. K., & Borrego, M. (2009). Engineering education research: Discipline, community, or field? *Journal of Engineering Education, 98*(1), 39-52.

Johri, A., & Olds, B. M. (2014). *Cambridge Handbook of Engineering Education Research*: Cambridge University Press.

Kolmos, A. (2008). Proposal for Working group on Engineering Education Research. Retrieved from www.sefi.be/

Koro-Ljungberg, M., & Douglas, E. P. (2008). State of Qualitative Research in Engineering Education: Meta-Analysis of JEE Articles, 2005–2006. *Journal of Engineering Education, 97*(2), 163-175.

Lohmann, J. R. (2003). Mission, Measures, and Manuscript Central™. *Journal of Engineering Education, 92*(1), 1.

Lohmann, J. R. (2005). Building a community of scholars: The role of the Journal of Engineering Education as a research journal. *Journal of Engineering Education, 94*(1), 1-6.

Lohmann, J. R. (2011). JEE and its Second Century. *Journal of Engineering Education, 100*(1), 1-5.

Olds, B. M., Moskal, B. M., & Miller, R. L. (2005). Assessment in engineering education: Evolution, approaches and future collaborations. *Journal of Engineering Education, 94*(1), 13-25.
Osorio, N. L., & Osorio, M. A. (2004). Engineering education in Europe and the USA: An analysis of two journals. *Science & Technology Libraries, 23*(1), 49-70.
Soderberg, C. R. (1967). A Note on Engineering Education. In *Applied science and technological progress: A report to the Committee on Science and Astronautics, U.S. House of Representatives* (pp. 399-413). Washington: National Academy of Sciences (U.S.).
Stokes, D. E. (1997). *Pasteur's quadrant: Basic science and technological innovation*: Brookings Institution Press.
Streveler, R. A., & Smith, K. A. (2006). Conducting rigorous research in engineering education. *Journal of Engineering Education, 95*(2), 103-105.
Wankat, P. C., Williams, B., & Neto, P. (2014). Engineering education research in European Journal of Engineering Education and Journal of Engineering Education: citation and reference discipline analysis. *European Journal of Engineering Education, 39*(1), 7-17.

BIOGRAPHICAL INFORMATION

Kristina Edström is an Associate Professor in *Engineering Education Development* at the School of Education and Communication in Engineering Science at KTH Royal Institute of Technology, one of the founding members of the CDIO Initiative. Her research takes a critical approach to the "why", "what" and "how" of engineering education reform. Kristina Edström is a co-chair for the 12th International CDIO Conference, responsible for the EER track.

Corresponding author

Kristina Edström
School of Education and Communication in Engineering Science
SE-100 44 Stockholm, Sweden
+4670-699 1420
kristina@kth.se