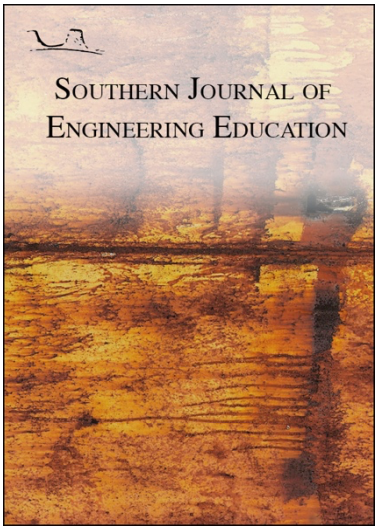

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Engineering Education Research for educational change: the possibilities of critical realism for conceptualising causal mechanisms in education

Jennifer M. Case[a]
Margaret A. L. Blackie[b]

[a] *Department of Engineering Education, Virginia Tech, Blacksburg, VA, USA*
[b] *Centre for Higher Education Research, Teaching and Learning, Rhodes University, South Africa*

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Engineering Education Research for educational change: the possibilities of critical realism for conceptualising causal mechanisms in education

Jennifer M. Case*[a]
Margaret A. L. Blackie[b]

[a]*Department of Engineering Education, Virginia Tech, Blacksburg, VA, USA*
[b]*Centre for Higher Education Research, Teaching and Learning, Rhodes University, South Africa*

Engineering Education Research (EER) grew in prominence from the late 1990s as purposes for this field were espoused in relation to the necessity of change for engineering education in the newly globalising world. Arguments centred on overall challenges with recruitment to engineering, specifically in relation to historically underrepresented populations, as well as with the forms of education (both in terms of quality of teaching and relevance of curricula) offered to students, and the needs of employers as reflected in newly-emerged global accreditation systems. In a field that is at least partly directed towards educational change, there is a need to understand how change typically happens in education systems. This article first draws on findings from the sociology of education to show that causality in relation to educational change is complex. It then turns to the philosophy of critical realism for a way of thinking about change that can inform EER, and concludes by outlining how this might change the research questions that drive the field, and how these might be approached.

Keywords: educational change, critical realism, causal mechanisms

Introduction

While the first published research on engineering education dates to the early 20th century (Strobel et al., 2008), it is around the start of the 21st century that those doing this research started to formulate explicit statements on its purposes and scope (Klassen & Case, 2022). Much of this kind of writing first emerged in the USA, where significant investment by the National Science Foundation led to growing prominence for a field now with an acronym: EER (Engineering Education Research). A key player was the Journal of Engineering Education which had pivoted towards a research focus (Lohmann, 2005). An oft-cited paper from this period scoped out 'The Research Agenda for the New Discipline of Engineering Education' (Adams et al., 2006). Writing very much from a US perspective, the authors state:

*Corresponding author email: jencase@vt.edu

> Research in engineering education must become the engine that drives change to improve the technical fluency of students and teachers, increase interest in engineering and awareness of the social impact of the engineering profession, increase diversity in the engineering student body, and increase the United States' contribution to the global engineering workforce (p. 259).

It is evident that the 'research agenda' put forward was framed mostly around change and offered an argument (especially to funders) that it carried the potential for increasing both the number and diversity of enrolments in engineering. This, it was argued, would then have a knock-on effect, impacting on the workforce and global competitiveness of engineering in the USA. Some later work has interrogated the methodological focus on 'rigour' in this article (Riley, 2017), but the proposed aims for the research remained unquestioned.

Five years later, the Journal of Engineering Education carried another influential paper which aimed to offer an international perspective on the emerging field of EER (Borrego & Bernhard, 2011). These authors outlined what they saw as five motivations for EER (based on a selection of published work from different national contexts):

1. Increasing diversity (of engineering professionals), including participation of those historically underrepresented in the profession;
2. Improving the public image and understanding of engineering, which is believed to be key to attracting a broader range of students;
3. Preparing students to solve complex problems, which involves change to the way in which engineering students are educated, in order to produce graduates with the skills and attributes needed for a changing workplace;
4. Meeting the challenges of globalisation, which relates not only to the skills referenced above, but also to advancing global systems of accreditation of engineering qualifications;
5. A deeper understanding of learning to improve learning: improving EER methodology and dissemination of findings to avoid 'reinventing the wheel' by trial and error.

This list of motivations offers more detail on the ways in which EER researchers argue that their research will contribute to change, particularly in relation to who are recruited to engineering, and how they are educated. Here the authors show that the overall motivations for the research have global similarities, even though some of the details might change – most

notably in relation to which populations are the focus for increasing diversity. Overall, it can be seen that these arguments for change are based on a sense of a rapidly-changing world, the period after the end of the Cold War having seen dramatic geopolitical and economic realignments which exacerbated concerns about national competitiveness in many parts of the world, and rapid advancements in technology which put engineering education prominently on national agendas (see Lucena, 2006).

Klassen and Case (2022) offer a fuller survey of this literature from the early 2000s that sought to legitimate EER, outlining aims, purposes and scope. Drawing on Basil Bernstein's notion of a 'region', they identify productive tension between a view on EER that looks inwards to other social science disciplines for research questions, and a view that looks outwards to the world of the classroom and the profession itself for relevant problems to solve.

A further useful framing for thinking about research fields and their orientations is represented in Pasteur's Quadrant (Stokes, 1997) (Figure 1). This classifies fields on twin axes: firstly, whether they aim towards furthering understanding, and secondly, whether they aim to produce findings of use i.e., whether they can be used to solve immediate problems in the world.

Research is inspired by:

		Considerations of use?	
		No	Yes
Quest for fundamental understanding	Yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
	No		Pure applied research (Edison)

Figure 1: *Pasteur's Quadrant (adapted from Stokes (1997, p. 73)*

The value of this quadrant is that it identifies not only fields that are purely in the domain of basic research (as exemplified by the physics research of Niels Bohr) or fields that are purely applied (as in the work of Thomas Edison). They also characterise fields that hold both of these aims with the term 'use-inspired basic research', as exemplified in the work of Louis Pasteur.

Likewise, Engineering Education Research, in its focus on building rigorous methodologies and a scholarly knowledge base, as well as its orientation towards what it sees as urgent needs for change, can be seen to fit this description.

Thus, we argue that EER aimed at building a fundamental *understanding* of what is happening in a given educational environment is important, but additionally, in a changing world, educational environments must adapt to be fit for purpose. The ideal is to effect change based on a solid understanding of the current situation in a trajectory that aligns well with our perception of the changing needs of our world. EER thus fits comfortably within the framing of 'use-inspired basic research' in Pasteur's Quadrant.

This article thus embraces these twin aims for the field but argues that if our research field is to be framed at least partly in pursuit of change, we need to make sure we have in hand an understanding of how we might think about change in (engineering) education. This is to say that having a robust and rigorous description of a system is necessary but insufficient of itself to effect change. If we are to have a view on how change happens in education, then we also need a perspective on causal mechanisms.

In this article we begin by exploring what can be achieved through educational change. We start by pointing to the limited efficacy of achieving social change through education alone, in order to illustrate the complexity of causality in social systems. We then turn to the work of Roy Bhaskar to illuminate ways of thinking about causal mechanisms. Critical realism seeks to afford transformational changes but refuses any reductionist notion of causality.

Education and change

Arguments for change in education form a central part of many contemporary social debates, whether in relation to compulsory or post-compulsory levels. In her history of the development of education research in the USA, Ellen Lagemann offers the view that Americans have 'evangelical expectations for education' (p. xi). She observes that for a society which is invested in a fundamental belief in the possibility of individual self-improvement, achieving social change through education might be considered more palatable than other means. But a focus on educational change as the key for social reform is not limited to societies which are stereotypically considered to value individualism, and here we might turn to South Africa to

note Nelson Mandela's famous and much-quoted aphorism from 1990: 'Education is the most powerful weapon which you can use to change the world' (Mandela, 1990).

For an empirical basis on which to base our thinking about education and change, in this section we turn to an overview of key findings from the field of the sociology of education that offer a high-level view of the history of educational reform movements and educational change, spanning both compulsory schooling and post-secondary education.

Setting out on an historical overview of education in the USA, Rury, in his book, Education and Social Change (2012), notes the problems of a tendency to over-expect on what education can deliver: 'Is relying on educational institutions to address larger social problems a strategy ultimately doomed to failure or disappointment? The answer to this question is a persistent puzzle in American history, for people in this country have placed uncommon faith in the power of education to improve society' (p. 1).

Surveying the early 20th century, he notes how the dramatic expansion of secondary schooling certainly had a significant impact on the economy, by providing workers with higher levels of education. But at the same time, this was the era of progressives like Dewey, and their vision that education would foster a more democratic and humane sense of community was arguably not achieved, as the American high school developed as an institution that certainly fostered youth culture but incorporated different sub communities depending on social class. In the post-war period, issues of inequality and social justice rose to the fore, especially during the civil rights era, and many felt that education reform would help achieve resolve these issues. In fact, this was the period where significant federal funds started flowing to schooling, to attempt to alleviate social inequalities. Despite these unprecedented levels of funding, no significant progress was made in terms of relative school outcomes. Studies started to show the troubling finding that family background was a greater causal determinant of school outcomes than anything that happened in the school, at least at a macro level (see, for example, Coleman 1994).

This is education's 'inconvenient truth' and why social policy focused solely on education as a change agent is doomed to fail. For a whole range of reasons, individual students respond differently to education environments, and even when these environments are improved, it is hard to avoid differential outcomes. Advancing social equality is probably more effectively done through measures in the areas of labour and tax reform, child welfare, public housing etc.

The sociologist Basil Bernstein (1972) famously (and controversially) wrote that 'education cannot compensate for society' (p. 159).

Similar overall findings are seen in the context of the UK, surveyed in the book Education and Society, written by the sociologist Rob Moore (2004). Moore commences his investigation with the observation that in education, 'the kinds of things expected to make differences often do not' (p. 2). To understand those changes that we *have* seen in education and education outcomes in the post-war period, Moore argues we cannot find explanations only within education; we need to locate these in an understanding of broader dramatic changes in society over this period: in the nature of work, in family structures, in the role of women, and around multiculturalism.

Looking at social class, over this period, despite its being a major focus for reform and the impetus for significant interventions, especially in schooling, there has been no change in relative outcomes, although there has been an upward change in absolute outcomes. Conversely, this period has seen what is often termed a 'gender revolution' in terms of women's participation and outcomes in education – but here the reform efforts were at best fragmentary. Moore argues that these changes are certainly more due to changes in broader society than anything else. In terms of ethnicity, it is entirely dependent on which group one is talking about; some have seen huge relative changes in educational participation and outcomes, and others have not. Overall, Moore reflects that the degree of social mobility in modern societies is so great as to negate the Marxist reproduction thesis, but also not enough to support the liberal open meritocratic ideal.

In terms of national comparisons, Moore raises further questions about causality: 'It might be that richer societies have more developed education systems because they are richer, rather than their being richer because they have more developed education systems' (p. 36).

Contemplating this brief survey of key work in the sociology of education, it is clear that simplistic views on the causal relationship between education and society, and especially between educational change and social change cannot be sustained. What makes this challenging is that this goes against some deeply-ingrained views in contemporary society. As already mentioned, education tends to take a central place in our debates on social change. Moore notes that a reason why education is such a primary focus for reform is that 'it is amenable to change in a way, say, that structure of the labour market, family relations is not'

(p. 6). Education thus gets treated as 'the principle means of creating a more equal society' (p. 7).

Drawing further on Lagemann's (2000) work, cited in the introduction, she notes a surprising tension in society between, on the one hand, 'evangelical' expectations for what education can achieve, and on the other hand 'popular disdain for education and educationists' (p. xi). She argues that '[t]his tension has fuelled an impulse to extend education to more and more people and to rely on it for an ever-increasing range and variety of social purposes, while also encouraging a reluctance to bear the costs of supporting education at truly adequate levels' (p. 3). Importantly, she notes how education is located in 'larger constellations of social values and views that have often found their clearest manifestations in debates about education….' (p. xiii).

Returning to Moore, he argues that these commonplace justifications for why we embark on education research might help us to obtain external support and funding for our endeavours, but they might also seriously limit our thinking on the true capacity of education to stimulate individual change. Here he makes a subtle but important argument:

> … if the *instrumental* capacity of the education system to realize certain kinds of economic and social policy objectives is weaker than has often been thought, then there is less justification for restricting the flexibility of schools in realizing intrinsically *educational* objectives ....The final implications of these sociological accounts might well be that the best reasons for doing things in education are educational reasons, and that educators are best employed pursuing these intrinsic aims rather than being harnessed to external objectives (p. 118).

In concluding this section, we note that simplistic arguments about the causal relations between educational research, educational reform and societal change cannot be sustained. Education systems do change, often quite substantially (contrary to the argument that they don't) but they don't always change in the directions that the reformers might have intended. In general, educational change seems to be caused more by changes in the external social and economic environment than the prescriptions of those within the system, such as teachers and scholars with a reform mindset. Moore argues that instead of abandoning our work, we should be prompted to focus our efforts more directly on the educational purposes of education rather than its external impacts. In other words, we might narrow our focus from big arguments about reforming engineering education to effect social change, to focusing on educational reform to shape engineering graduates to take on the challenges of the world as we know it. Nonetheless,

the narrowing of our focus might still not be sufficient to ensure that we are able to reform education in the ways that we intend. We need to take causality into account, specifically how causal mechanisms might work in the social world.

Effecting desirable change in education – a turn to critical realism?

To propose a way forward in thinking about causal mechanisms in engineering education, we draw on the critical realist philosophy of Roy Bhaskar (1978; 2008; 2009). In his early work, Bhaskar was driven by curiosity about the nature of the physical world. For Bhaskar, there is an ontological reality which we attempt to explain through epistemology. But our epistemology is always subject to improvement through judgemental rationality in the light of new empirical information. In A Realist Theory of Science, he proposes that there is a three- tiered nested structure of the physical world. The largest sphere is the 'real', which encompasses all that exists and all that possibly could exist. This includes the causal mechanisms that bring things into being. The middle sphere is the 'actual', and is the world that is in existence. The smallest sphere is the 'empirical', which is that which is observable. This means that which can be empirically observed is always a subset of that which actually happens which itself is a subset of that which can possibly happen. This is because not all possible causal mechanisms are always enacted.

There are three important phases in the scientific endeavour. Firstly, to describe accurately that which is empirically observed. Secondly, to postulate the possible causal mechanisms which give rise to those observations. Thirdly, to evaluate the reliability of that proposed explanation (Blackie, 2022b). The last of these is greatly enhanced through conversation and interaction with others who are trying to investigate the same causal mechanisms (Blackie, 2022a).

In a later development of his thinking, now called dialectical critical realism, Bhaskar turned his attention to social systems. A recently published interview with Bhaskar (2017) offers a compelling starting point for why this is a productive orientation for engineering education researchers to draw on. Here, Bhaskar offers three key characteristics of critical realism. Firstly, it is a *serious* endeavour; it cares about the world and seeks for societal betterment. Secondly, it is committed to *immanent critique* i.e., the criticism comes from the inside, from the community of researchers. Thirdly, it is directed towards *enhanced reflexivity and transformative practice*. These principles resonate well with the field of engineering

education research, and there is the promise that this interrogation might allow for an enhanced characterization of research priorities and what this means for the use of theory and method towards framing research designs.

Some policymakers from the 1990s onwards have been in thrall to the notion of 'evidence-based research' which has been so influential in fields like medicine (Parkhurst, 2017). However, education scholars have raised a number of difficulties with this approach. There is a significant field of education research that works quantitatively to measure the impact of educational interventions. Here the overall finding by John Hattie and colleagues after doing 800 meta-analyses of some 50 000 research studies on teaching and learning is noteworthy:

> The most important discovery from the research was that almost any intervention can claim to 'work'. Almost every intervention had an effect size above zero which simply means that the intervention had some positive effect on achievement. However, if every intervention has some effect on achievement, then all we need to do is implement more of what we already do – so all we need is more money, more resources, more teachers, and all of our problems will be solved. However, this will not solve the problems in education. Instead, we need to be more discriminating (Inside Visible Learning, n.d.).

In a key overview article considering the potential for evidence-based practice in education, Biesta (2007) points to two specific issues. Firstly, much of the thinking around evidence-based practice tends to focus on questions of efficiency or so-called effectiveness, not taking into account that what is a desirable outcome is not necessarily a simple matter, easily agreed on. But a second key issue that we take up further here relates to how causal mechanisms might work in education. Teachers teach and learners learn but the causal link is not straightforwardly linear (Case, 2015). In Bhaskar's terms a rigorous empirical observation of a particular situation does not constitute knowledge of the causal mechanism, but it is a necessary first step upon which to build understanding of these mechanisms.

For Bhaskar a simplistic causal connection is untenable. The world is more complex. There are multiple strata of reality operating in any educational setting. And each stratum has its own set of causal mechanisms. According to Bhaskar (2008), if we are to effect change in any system, we must consider four different planes: the physical environment; social interaction between people; the social structure in operation; and the particularity of people. The causal mechanisms in all four planes are not likely to be equally influential in a particular research context but we cannot presume the absence of a complex operational mechanism which may

significantly influence the effect of any change. Indeed, Bhaskar puts it slightly more negatively, stating that transformation is unlikely unless we consider all four planes.

Bhaskar gives us two insights which indicate why many interventions can be shown to 'work' as per the research of John Hattie referred to above, but in fact might fail to be transferable to other contexts:

1. We conduct education research in a manner that focuses on effect without interrogating causal mechanisms in play. On a trial-and-error basis, elements are added or removed, and the outcome improves or doesn't to some desirable measure. We are seeking an effect, not an explanatory concept. As such, the methodology is more akin to alchemy than science: if we just get the mix right, we can attain the desirable outcome. But here we would be working in the absence of understanding that the 'mix' includes the social context, the preparedness of students, resilience to change, personal power of the reformer etc. Transferring the 'recipe' to another context comes neither with a guarantee of the same effect, nor any clear sense of what might need to be adapted to be effective. Essentially, the error here is taking the change in empirical data to be evidence for enacting a different causal mechanism when we have no foundation for making such a claim.

2. Our paradigm for exploring and improving phenomena might be influenced by our training and experience in engineering. Thus, the context is described in many studies, but little consideration is given to the causal mechanisms which may be operational in that particular context. Most papers focus simply on one of the four planes of social being that Bhaskar has identified. The fact is that any educational endeavour is necessarily an open system. This system is further confounded by the double hermeneutic (Price, 2019). Not only are we as researchers interpreting the system through a particular theoretical lens, but the students in our study are responding based on their own independent interpretation of the intervention. This is true whether the study is of the 'do this, then student marks get better' kind or leverages the more nuanced ideas of social structure such as structure and agency (Archer, 2000) or power (Bourdieu, 2004).

This is not to suggest that there is no value in careful descriptive research. The curious educator who is willing to try new interventions and attempts to measure impact is absolutely necessary to the improvement of education. All great discoveries begin with that beautiful question 'I wonder…?'. However, Bhaskar's perspective shows us why our desire to transform education is simply not possible if this is all that we are doing. If we are to effect serious change, we must seek to develop conceptions of the causal mechanisms that might be in play.

As an analogy, lost in history is quite how the combination of charcoal with molten iron came about, which resulted in a far stronger material we now call steel. Metallurgy has long been an important part of human development. But far outstripping the trial-and-error approaches of alchemy were the advances in materials science that were possible, once a molecular understanding of matter came about with the advent of modern chemistry. We are thus arguing for a similar approach to engineering education research. It will surely take the efforts of many to construct a causal 'map' for educational reform. And it is not likely that we will be able to create a complete map, but the recognition that there is a multiplicity of causal forces in play will serve to moderate naïve claims of 'success' in EER.

Concluding comments

This article commenced by considering the arguments that tend to be made around the purposes of EER. It was shown that reference is often made to much needed changes in engineering education, whether in relation to recruitment, the forms of education, or global accreditation. Characterizing EER as "use-inspired basic research", we argued that such fields do need to think about how they conceptualize change in relation to the phenomena they study. We then moved to consider the evidence from the sociology of education about causal relationships in the domain of education. Here it is clear that while educational systems do change, such change is often not a direct result of educational reform efforts. In short it is society that often causes education systems to change, rather than the primary cause being in the stated direction. We then considered some of the critiques of evidence-based education research before moving to the critical realist philosophy of Roy Bhaskar for a more nuanced ontology that might inform education research directed towards characterising causal relationships.

Drawing now on a critical realist perspective on causal mechanisms, we move to consider what it might it look like to undertake engineering education research that works with these less simplistic notions of change. We note that this might involve more complex and ultimately

somewhat more modest arguments in relation to the purposes of EER. This involves rejecting any simple notions of development, as well as a clear rejection of a positivist orientation to research. For those trained in STEM this can involve a critique of our own socialization to engineering and its commitment to economic and social development through technological advancement.

Critical realism offers us the possibility to take cognisance of an interpretivist stance, a focus on *verstehen* – 'understanding people and ourselves' – but also to move beyond this to identify causal mechanisms. What is really going on in the education systems we research? What forms do they take and why? What is changing and what is not changing? What are the forces that promote change and what forces limit it?

Perhaps the call here is to take the time to consider what we are actually trying to achieve with any single EER project. There is merit in research which is essentially a rich description of particular situation. If this is sufficiently careful and well-communicated it will provide essential information for those who are more focused on investigating causal relationships. It is clear though, that without a broad understanding of the pressures and influences on a particular situation, even the most well-considered, evidence-based approach may completely fail to have the desired effect. Social systems are not constrainable in the way physical systems may be. Those of us who come from training in interrogating physical systems can underestimate the complexity at hand in the microcosm of an engineering course that looks to be in one person's control. Taking on board a critical realist orientation holds great potential for EER that can both advance in its ability to understand what is at play in a given context, and also to use this understanding of causal mechanisms to plan effectively for change.

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