# Engineering education, practice and engineering education research: critical realist insights

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***Abstract:*** *Given that 2011 has been declared, by Engineers Australia, the year of Humanitarian Engineering, it seems fitting that the conference theme is engineering for social justice, encompassing community involvement, ethics and sustainability. This opens the door for the introduction of new approaches for engaging with the world, which extend the current mandate of the engineering professional, as well as that of the engineering educator and engineering education researcher. The invited paper draws on critical realist insights to argue that the world of the engineering professional is stratified and complex. These insights are used to argue that the engineering education research mandate needs to be emancipatory and thus prioritise the uncovering of structures and mechanisms which cause the effects (social, environmental etc) and phenomena that we see in the world. Engineers, in all their activities, whether in practice, in pedagogy, in research, and in engineering education research, need to ask the question, 'what does the world have to be like for things to be as they are?' In order to do this, a multiplicity of approaches will be required underpinned by concerns with both being (ontology) and knowing (epistemology), and which do not privilege 'scientifically verifiable' evidence over other notions of evidence. Further, it is argued that such positivist epistemologies, which have sustained and continue to sustain scientific activity and research, cannot be assumed to be appropriate for emancipatory engineering work.*

## Introduction

The paper first presents the critical realist philosophy. Secondly, engineering practice is interrogated by taking up the subject of 'engineering disasters and the lessons learned' from a critical realist lens. The point here is to argue for the inclusion in engineering education, of modules which do not present a naïve view of the world to the student towards those that present a more complete picture of engineering practice. Thirdly, the paper looks at the status quo of the engineering discipline and the limits it places on engineering education and engineering education research. The mandate of research is defined, again through a critical realist angle. At this point, an example that uses critical realist insights in research is given. This is followed by a brief discussion of some of the critiques levelled at critical realism with respect to the research agenda. There are numerous and more complex aspects to critical realism. This paper has restricted itself to key tenets of the philosophy which serve as the building blocks for the subsequent discussions on engineering education and engineering education research. The paper concludes by discussing the mandate of the engineering educator in educating for change and the perils of neglecting this aspect of engineering education for the 21$^{st}$ century graduate.

## Critical realism: the philosophy of Roy Bhaskar

There are various versions of realism and what is presented here is Roy Bhaskar's particular version. His is peculiar in stressing the 'critical' angle, i.e. the focus on emancipation, that our descriptions of the world are fallible which means our categorisations cannot be verified in any absolute sense. According to Corson (1991), Roy Bhaskar is concerned with emancipatory social practice. In developing the philosophy, Bhaskar sought to bring to the social sciences the same rigour characteristic of the natural sciences and thus extends his ideas from the sciences to the social sciences. Bhaskar believes that in order to change the world rationally, it needs to be interpreted adequately. His philosophy of critical realism is therefore a particular way of seeing and interpreting the world. This interpretation rests on the idea of the independence of the natural and the social worlds; the idea that there is an objective reality that exists beyond humans.

According to Lopez & Potter (2001), this philosophical development was a reaction to positivist claims that all knowledge is empirically derived, that is, experience is the sole source of human knowledge (Forrester, 2010), and through the process of observing the constant conjunctions of events (that is, repeated experiments confirming associations between two or more events or variables) invariance is established from which in turn causality is inferred. Critical realism was also a reaction to post-modernism, according to which reality is socially derived, a product of discourse (McGettigan, 1998), and where knowledge is anything human beings certify as such (Younkins, 2004). It seems therefore that the philosophy developed as a reaction against both the exclusively positivist and exclusively situational techniques.

According to Corson (1991), Bhaskar argues for a world that is structured, differentiated and changing, a position he refers to as transcendental realism. It is transcendental in that scientific (both natural and social) practices are viewed from the perspective of what they presuppose about the world. A differentiated world allows a distinction to be made between the objects of science, the 'things' that we study or that science is about, from the theories used to gain knowledge about them. He maintains therefore that these objects reside in the intransitive domain and have an existence that is independent of the mind. The theories and any processes of generating knowledge about scientific objects are the social aspects of science. They are open to change and review and thus belong to the transitive domain. This distinction between the transitive and intransitive dimensions ensures two things. Firstly, it allows for the socially derived nature of knowledge. Secondly, it ensures that one does not reduce the world to one's knowledge of it. According to Bhaskar (1989), the latter would be committing the epistemic fallacy.

Further to being differentiated, critical realism rests on the notion of a stratified reality, consisting of the domains of the *real*, the *actual* and the *empirical.* The domain of the real contains structures, mechanisms and relations which possess powers and tendencies. These are not observable but their effects are felt nonetheless, i.e. they are independent of mind and society in the sense that they operate regardless of whether anyone is aware of their existence or not (Bhaskar, 2008). Bhaskar argues that structures and mechanisms generate events in the natural world while the relations generate behaviour in the social world. He notes that the structures, mechanisms and relations are distinct from the patterns of events that they generate. These events, effects or phenomena are in the domain of the actual and may be (or not) experienced by people. The domain of the empirical is concerned with the individual experience of the events and behaviour (Corson, 1991). Structures in the domain of the real possess powers which, while possessed, may not always be exercised; or exercised but are not always actualised and finally, even when actualised, are not necessarily always perceived (Collier, 1998).

Figure 1 represents the relationships between the three domains (Elder-Vass, 2004: 3).

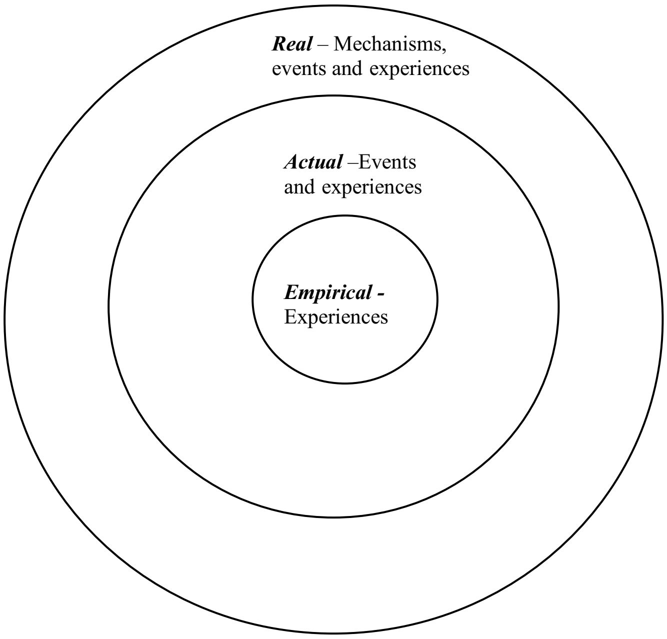


**Figure 1: The three domains of a stratified reality**

This represents a nested arrangement in which the domain of the actual contains both our experiences and the events in the world whether we experience them or not. In the same way the domain of the real contains our experiences of the world, events in the world, as well as mechanisms, whether or not they produce events.

Danermark et al. (2002) stress that mechanisms in one domain (e.g. the actual) are formed by the effects of the powers and mechanisms in the underlying domain (the real), but that these mechanisms represent something new and are qualitatively different from the mechanisms and structures which generated them. These newly formed mechanisms have their own distinct powers. This occurrence gives rise to the idea of *emergence* such that we can say the newly formed mechanisms have 'emergent powers' (2002: 60). Emergence is defined by Elder-Vass (2004) as that property which makes it possible for the whole to be greater than the sum of its parts. The newly created 'thing' is not simply a combination of the elements from an existing domain. Instead, the elements from the underlying domain must have a distinct relation to each other which gives rise to qualitative changes and new behaviour.

Bhaskar makes a further distinction between closed and open systems. His notion of a closed and open system is not to be confused with the use of the same terms in systems theory however. In fact, some critical realists have been criticised for promoting a flat ontology in restricting the definition of 'closed' to event regularities, which contradicts the idea of the stratification of reality (Mearman, 2006). Perhaps a more helpful definition is provided by Archer (1995) in the context of social research in which she notes that the 'peopled' nature of society makes a social system an open system. According to Shipway (2010), 'Generative mechanisms are responsible for the pattern of natural laws and it is the task of science to explain these laws. However in critical realism, natural law does not mean a constant conjunction between cause and effect, but refers rather to causal powers of things which have tendencies in the way they operate, such that they may or may not give rise to tangible phenomena, which in turn may or may not be detected my humans. Thus the different levels of stratified reality are 'out of phase' with each other, making it impossible for humans to predict with absolute certainty the connection between observable events and the underlying structures and mechanisms which cause them' (Shipway, 2010: 59).

What other aspects of reality can be seen to cause effects? Apart from structures, mechanisms and relations, Bhaskar (1989) contends that actor's reasons for action can be regarded as causes and can be viewed as a species of causal explanations. There are alternative views to this one (see for example Risjord, 2005; Solomon, 1974). The 'reasons as cause' debate is an age old philosophical debate with some disagreement on whether indeed reasons for action explanations can be legitimately classified as causal explanations. According to Bhaskar (1989), 'unless a reason could function as a cause there would be no sense in a person evaluating (or appraising) different beliefs in order to decide how to act. For either a reason will make a difference to his/her behaviour or it will not. In the former case it counts as a cause. In the latter case, it is logically redundant, and deliberation, ratiocination (or indeed thought generally) become otiose' (Bhaskar, 1989: 92). Bhaskar contends therefore that these reasons can be viewed as what lies 'behind the scenes' which manifest in certain observed effects. Carter & New (2004), in circumventing the controversy of the debate have substituted the formulation 'reasons can be causes' with 'psychological states (which can include states of mind, beliefs, obsession and so on) cause actions' (Carter & New, 2004: 12). They further note that mental states which bring about action can be complex, stratified, conflict-ridden and to some extent are available to reflection. The point being made here then is that the search for what is behind observable effects or events in the world has to include not only mechanisms and structures, but also peoples' experiences and therefore their accounts of meaning in their contexts. The next section gives an idea of why this might be important in the context of engineering practice.

## Engineering practice: disasters and lessons to be learnt

According to Bigneil (1999), 'cases illustrating failure in engineering now abound in the literature and must become part of the joint experience retained by the engineering profession' (Bigneil, 1999: 311).Three disasters will be discussed in this section but to go into detail of each is beyond the scope of this paper. However the analyses and conclusions drawn from these three disasters will be revisited and discussed from a critical realist lens. The point is not to rehash the themes but rather to paint a picture of the world of professional practice and to outline how engineering education can better prepare graduates to deal with this world.

In the Flixborough explosion of 1974, the Health and Safety Executive (1975) reported that the disaster was due to technical failures which were listed. The list included the following items (not an exhaustive list):

1. A plant modification occurred without a full assessment of the potential consequences.
2. No pressure testing was carried out on the installed pipework modification.
3. Those concerned with the design, construction and layout of the plant did not consider the potential for a major disaster happening instantaneously.
4. The incident happened during start-up when critical decisions were made under operational stress.

It is interesting that these failures were termed technical failures. The question that comes to mind it, what constitutes a technical failure and why is it important that the failures are labelled correctly? What the above list shows in fact is failure by key actors or agents in the system to act appropriately and to make the right decisions at a critical time. If failure is understood to mean the state or condition of not meeting the intended outcome or objective, then it would be reasonable to assume that human agency (including action and inaction) was at least partially responsible for the Flixborough disaster. At the very least, correct labelling of the failure would give a better idea of the processes that were involved in the failure. The next question then is how this human failure is categorised, i.e. was it negligence (workers were lazy and took short cuts or forgot to follow procedure), intentional (workers for one or other reason made a calculated decision not to follow protocol) or unintended outcomes (designers were not able to design for every eventuality, could not imagine all possible scenarios and account for them). Is it even fair to call the last a human failure?

In a systems view of failure analysis, Bigneil (1999) argues for a better descriptor than 'technical failure'. He argues for one which does not downplay the human factor involved in failure, indeed in engineering practice in general. He notes that, 'the lesson emerges from such studies that, although it was a failure of a piece of metal that was the final disabling event, behind each factor contributing to the failure, there had been a human action, inaction, poor decision, or neglect. The materials and components themselves are innocent tools of human or system failure. The supporting network of system links, broken links, gaps and unsatisfactory arrangements behind an evident failure takes us away from laboratory engineering to the real world, where much more is involved than just metallurgy and mechanical principles. The complete system that designs, builds and runs a mine hoist, or erects a bridge, is called the socio-technical system' (Bigneil, 1999: 315). This means that failure events exist at the level of the actual but that implicated in these events are physical (mechanical, electrical etc.) and social processes at the level of the real and it is these that need to be uncovered in disaster investigations for lasting lessons to be learnt. The reader is directed to Law & Callon (1988) for their take on socio-technical processes.

In the Bhopal disaster, which happened a decade after the Flixborough disaster, post disaster inquiries revealed that a number of safety checks to minimise the risk of exposure to MIC (Methyl Isocyanate) had been violated. These included vessels which were over capacity, material inventories that were higher than the recommended values, incorrect storage temperatures, as well as failure of several safety devices (Varma & Varma, 2005). Further, it seems in this case that the location of the plant in a developing country led to various complications including general poor monitoring of safety measures. Again here it was humans involved in poor decision making regarding for example keeping large stocks of MIC on site in a bid to keep the plant on line. It reasonable to assume that somebody with the power to do so, decided that it was more important to keep the plant online by keeping large stocks of MIC even though prior safety audits on the plant had cautioned against this as the rick associated with MIC was high. Other actors were also involved here although not necessarily as part of the plant system. These were the officials who made the decision, despite warnings, to build a town close to the site (Varma & Varma, 2005). There were numerous political issues associated with this decision of course but again the point being made is that the system that failed was not simply a technical system. The plant did not operate in a vacuum but at every stage there were humans involved who had the power to influence events both at a local system level (i.e. on site) and a the global level (i.e. government bodies offsite).

The last case is not as famous as the first two but because it involves a young graduate who was thrust in what turned out to be an unenviable position, it deserves some attention. The young supervisor had been out of university for a year and was put in charge of a unit. In this case, material leaked from a distillation column, an event which was the last to occur after several other events had occurred. While there were no fatalities in this case as the vapour did not ignite, the incident was thoroughly investigated nonetheless. According to Kletz (2006), the conclusion reached after the investigations was that the accident was due to the 'failure of the young supervisor to stand up to the maintenance foremen' (Kletz, 2006: 72). The investigating team further noted that the supervisor's situation was a difficult one, that 'the maintenance foreman was a strong personality, widely respected as an experienced craftsman, old enough to be the supervisor's father, and he assured the supervisor that he had done similar jobs before' (Kletz, 2006: 73). Kletz argued however that while the supervisor couldn't be blamed, sooner or later every supervisor has to learn to stand up to his staff, be reluctant to overrule them if they are advocating caution but willing to do so if they want to take a chance as was the case in this accident. He concludes that there was no adequate training for young graduates at this particular company and that the organisation's attitude towards safety was poor.

In making judgments the young supervisor would have been influenced by his assessment of his manager's reactions and attitude to safety (Kletz, 2006). Was the concern to get the plant back on line as soon as possible while still adhering to safety procedures? Was this even possible? Or would the manager have maintained that despite the loss in production, he was happy that everyone had adhered to the safety standards?

Apart from foregrounding the 'non-technical' in the failure events, it is also clear in the last case in particular that intentional action by some actors in the plant and their reasons for those actions or decisions 'caused' undesirable effects and contributed to the failure events. Moreover, it might be argued that the actors were operating under a cultural system (the company's for example) in which it was understood that production targets were to be met 'at all costs' and that this then constrained the range of options available to the production foreman for example. The young supervisor was in a contradictory situation in which he felt he couldn't reasonably satisfy both requirements, that is, to get the plant back on line and at the same time to follow safety procedures (Kletz, 2006). Students need to then hear about such conflicts of interest in the context of failure analysis.

In a critical realist sense therefore, the investigators in some of these disasters undertook event-level investigations of the disasters. They assumed a flat ontology. They tried to uncover the chain of events that led to the accident in each case and this process allowed some light to be shed on a number of issues. However, are event-level investigations enough for real lasting lessons to be learnt? It seems that not much was learnt from the Flixborough explosion as a decade later an even bigger disaster occurred in another part of the world. The difficulty with event –level investigations is that they do not allow one to address the deeper structural 'things' which might be the cause of the events. In other words, it is perhaps less contentious to deduce that if a tank bursts and liquid escapes and vapourises, the likelihood of an explosion is high if there is an ignition source in the vicinity. It is much harder but arguably more generative to also then ask about the cultural and social effects which formed the basis of decisions made at critical points in the process which led to failure. Therefore, there were on the one hand the physical mechanisms that combined in perhaps unpredictable ways to result in material failure, and on the other, there were the social effects. It is of course often the combination of these two that is not always obvious but should have the most gains. The fact that it is 'harder' to get behind peoples' experiences and their interpretations as objects of investigations does not mean the cause is abandoned. Allowing for a differentiated world in which 'peopled' or open systems feature just as strongly as closed systems do, has the potential to move practitioners towards lasting change in the way engineering 'is done'.

The lessons learned from such disasters are that both physical and social systems are unpredictable. It seems that designers are not always in a position to anticipate all the scenarios and account for them in their designs in a bid to minimise risks. By the same token one cannot predict what a fellow employee will decide to do or not do for whatever reason, which may ultimately place the process and other employees at risk. A stratified view of the world however might allow for the uncovering of organisational cultures which lead to (promote?) unsafe practices and therefore to failure. They may also lead to the uncovering of other agendas in the global system (i.e. beyond plant borders) which constrain the range of options that plant personnel have in which to act. These lessons are important for students to learn. The world is not 'given' nor is it predictable. Physical or technical systems are no more predictable than are social systems. Engineering professionals work in socio-technical systems in which both technical and social systems have causal efficacy and engineering graduates of the 21st century need to have a holistic sense of the world in which they will be operating. It is differentiated and stratified. They need to have more than just technical skills in order to deal with the range of challenges that present themselves in professional practice.

## The engineering discipline: challenges to engineering education

The argument for engineering graduates, whose skills go beyond the technical, is not new. But what are the challenges that stand in the way of progress in engineering education?

Radcliffe & Jolly (2003) point to positivist approaches that dominate activity in the engineering discipline. They note that 'our current understanding of engineering, engineering education and research in engineering education is shaped by the traditions and cultural characteristics of the profession and grounded, albeit implicitly, in a particular suite of epistemological assumptions' (2003: 1, session 1630). Johnston, Lee & McGregor (1996) have named the epistemology as a positivist one and lament the 'captivity' of engineering to the discourse of science. They attribute this to the popular view that engineering is based on scientific principles. According to them, while true, it has meant that 'while engineering teaching and scholarship have remained closely connected with the academic disciplines of science, to a large extent they have remained isolated from the pragmatics of engineering as a professional practice' (1996: 20). It is precisely this disjuncture that hard lessons from practice need to address.

They further note, 'where areas of engineering science, in particular mathematics and physics, draw heavily on the empirical approaches similar to Logical Positivism, issues of meaning and social impact are rejected or ignored... Scientific method, the structure of hypothesis, proof, validation, publication, and critique, is clearly embedded in the scientific culture and serves it well… The culture and discourse of science impose their own rigor on the academic discipline of engineering and when adopted by engineering, their authority becomes almost absolute. Practitioners commonly believe themselves immune from the influence of theory or philosophy, but the discipline of engineering remains to a great extent captive to the sorts of ideas developed within positivism, due to the overwhelming dominance exercised by positivism in the development of scientific thought during this century' (1996: 2).

Riley (2008) has also written about engineering mindsets. She notes that due to the almost exclusively technical focus of engineering programmes, which mostly serve a corporate audience, students have a narrow sense of the career path. She argues that engineering students learn to think analytically only in the context of a technical problem. She states, 'we typically do not come away with the ability to think critically, to question what is given, or to question the validity of our assumptions, because we are too busy learning the essentials of problem solving. For this reason we often cannot see the larger context of the problem we are working. … We do not learn, with any depth, the critical approaches from the humanities and social sciences, and we do not learn many communication skills beyond written technical reports and giving PowerPoint presentations' (Riley, 2008: 41).

Riley further argues that the positivist mindset in engineering fuels reductionism and technological determinism. Reductionism holds that the analysis of different parts of a problem can fully explain the system. In technological determinism emphasis is placed on the impact technology has on communities as opposed to the role communities play in co-constructing technology (Riley, 2008). This leads to the belief that science and engineering are objective.

Other challenges apart from the positivist approaches include the meanings and values that sustain the discipline of engineering (Jolly & Radcliffe, 2001). They argue that the engineering discipline is sustained by a high degree of individual competitiveness. They further argue that engineers tend to be concerned with order and certainty, are averse to ambiguity, have a rather narrow range of interests, and are not given to introspection. The previous discussion on engineering disasters illustrates that these tendencies need to change. Jolly & Radcliffe conclude that reflexivity is an aspect that needs to be introduced to the life-long learning aspect of the education of engineers. They use the term to refer to the ability to reflect upon one's experiences in order to enable connections among different elements of an experience. This would be to reflect on one's personal experience of the engineering practice, as opposed to reflecting on the engineering problem as a phenomenon.

## Critical realism and research

According to Glatthorn (1998), the purposes of conducting any research project are to generate and disseminate knowledge. More specifically however, Richey & Klein (2007) assert that most research can be viewed as being exploratory, descriptive or explanatory. In critical realist fashion, Danermark, Ekstrom, Jakobsen & Karlsson (2002) contend that the fundamental task of research is the 'explanation of social phenomena by revealing the causal mechanisms which produce them … in this explanatory endeavour abduction and retroduction are two very important tools' (2002: 1). The foregoing discussion on critical realism suggests that the above explanation holds for natural phenomena as well, with the difference being the manner in which the underlying causal mechanisms are accessed. According to Bhaskar, it is only in identifying the structures at work in the domain of the real that the world can be understood and transformed.

Moreover, Lopez & Potter (2001) argue that questions concerning what we know depend on what there is there to be known; 'epistemological questions are dependent upon ontological answers to questions about the nature of existence' (2001: 10). As Burgoyne (2008) aptly put it in his title, 'the nature of what there is to know affects the way we learn it'. The question then is, in the realist philosophy, what sorts of 'things' are considered worthy of being understood and therefore interpreted adequately? And what tools are available for the study of these things?

In order to address this issue, it's necessary to again look at the stratification of reality model and to revisit the *positivist* and *situational* approaches to research. Typically in the natural sciences, the objects of study are non-human entities, or real physical things (e.g. atoms). In this field experiments are set up in order to isolate a mechanism or mechanisms which it is hypothesised give rise to the phenomenon under investigation. These systems which are then set up are termed closed, which means they are isolated and are not subject to external interference. This, according to Shipway (2010), amounts to collapsing the three domains into one. Further, in this research tradition, there is strong support for visually observed evidence. What this means therefore is that if it cannot be seen and therefore verified, it is not worthy of investigation. This research tradition concerns itself with regularity; i.e. constant conjunctions of events and therefore the research agenda becomes about prediction. Once a system is closed, a particular stimulus will always give a particular effect, i.e. constant conjunctions. Events are prioritised and the mechanisms which give rise to these, are not. Bhaskar defines this as a flat ontology.

The critical realist objection to the positivist approach in 'social research' is that the objects of knowledge in the social sciences are mostly experienced in open systems. The intransitive domain in the social sciences consists of social structures and relations. Thus, in the social world what counts as evidence has to include people's reasons which account for social effects, their beliefs and attitudes, and that these are then available as 'prime sociological data which not only guide our research but also morally compel us to act on the findings of that research by inserting in to the social world the emancipatory solutions that the research uncovers' (Corson, 1991: 233). Corson notes that these reasons etc. constitute social mechanisms and would therefore be located in the domain of the real. He goes on to then list a variety of methods which can be deployed to access these reasons and adds that, 'when used as multiple approaches in the study of the same phenomenon, they provide the evidence for uncovering that reality' (Corson, 1991: 237). It is precisely this kind of agenda that might be usefully deployed in the analysis of socio-technical systems.

On closed and open systems in the natural and social sciences, Scott (2005: 639) notes that closed systems operate in two ways:

1. They operate in a consistent manner, that is there must be no change in the object that is the repository of those causal powers between different cases, and this refers to all the possible cases, now and in the future,
2. The external conditions of the causal mechanism must remain constant to allow the closed system to operate.

Under both these conditions regularities are produced and causality can be inferred. He argues however that social reality takes place in open systems and as such, these conditions cannot be met. While natural scientists can then create closed systems where they seek to isolate conditions that may contaminate a system, in social sciences, researchers are not able to do that (Scott, 2005). The objects of research in the social sciences, such as individual behaviour, relations between individuals and properties of structures, may change over time and in different contexts.

Scott concludes by noting that when quantitative models are used in social sciences, there is the potential that *intensional* dimensions of social life are transformed to extensional properties' (Scott, 2005: 640). Intensionality refers to the property of non-substitutibility. An intensional definition specifies necessary and sufficient conditions for things to be what they are. Extensional definitions are less specific (more general) (Rapaport, 2009). The latter cannot be substituted for the former as the essence of the former gets 'swallowed' up in the general description. The transformation of intensional properties to extensional ones would imply that the intensional dimension, that which is true and specific about a person, may be repackaged and expressed extensionally to adhere to a quantitative principle. In this way it loses its 'truth' and essence, such that 'social actors and the relations between them are reduced to shadows of their social selves, and the resulting descriptions that are made rarely reflect the richness and depth of the human interaction' (Scott, 2005: 641).

Bhaskar has outlined some steps for carrying out a realist project. These have been simplified below (from Corson, 1991: 237).

1. An effect (regularity or result) is identified and described;

2. A creative model of the mechanism involved is postulated, as a solution or explanation or response to the problem, which if it were to exist would explain the effect;
3. Research is undertaken to demonstrate the existence and operation of the mechanism: either by isolating or in some cases observing the mechanism in action, or by eliminating alternate plausible hypotheses;
4. The mechanism, once shown to be real, becomes available as evidence for interpreting the world

The crucial difference then between the natural and social sciences according to Shipway, 'is that the social sciences are part of their own field of enquiry and as such they are subject to explanation in terms of the same theories they employ' (Shipway, 2010: 68). The point being made is that the nature of the objects of study should determine the methods appropriate for their investigation. Moreover, the above does not mean that there are no event regularities in the social world. Indeed, these are often the starting point for an investigation.

The foregoing discussion opens up a number of questions for engineering education researchers and engineering educators. For the former group the question is about the objects of study appropriate for engineering education research and the methods appropriate for the study of these objects. For the latter group, who in most cases form part of the former group, the question is about how to prepare and develop students to deal with systems in which the social and the natural are both implicated without unduly privileging one over the other.

## Critical realism and engineering education research

In what way therefore do critical realist insights advance the engineering education research discussion? For a start, a critical realist agenda allows a researcher to be exploratory and descriptive, but to also offer causal explanations. To do this requires that one uncovers the deep structures, mechanisms and relations, which produce the phenomena around us. Borrego, Douglas & Amelink (2009) suggest that qualitative research usually asks the following types of questions:

1. What is occurring?
2. Why does something occur? or
3. How does one phenomenon affect another?

Some of these questions have been asked by engineering education researchers before, in particular the last one, albeit worded slightly differently. This is usually in the context of evaluating a particular intervention, whether an assessment tool or a mode of delivery. Jolly, Crosthwaite, Brodie, Kavanagh & Buys (2011) have done work in the area of engineering education. Their project sought 'to evaluate an innovation in engineering education which promises to meet the needs of many future generations of students and employers through its emphasis on communication, teamwork, multicultural and multidisciplinary contexts and the ethics of professional practice' (Jolly et al., 2011: 1). Their investigation sought to ask not only whether the innovation worked but what it was about the innovation that produced the observable outcomes. They used the notion of 'mechanism' to mean 'propositions about what it is within the program that triggers a reaction from the subjects' (Pawson & Tilley, 1997: 66). Pawson & Tilley further note that mechanisms are the choices and capacities that people derive from group membership. The aim of the project therefore was to arrive at an explanation of why the innovation prompted the students to make the choices they did to produce the observed results. Realism holds that the outcomes observed from a particular mechanism depend on the context. Therefore the relationship between the causal mechanism and the effect is contingent (Pawson & Tilley, 1997).

In their project Jolly et al. (2011) note that the context includes 'all of the activities that make up an intervention, provide the subjects of the intervention with a range of possible ways of responding to it. These responses are **mechanisms** that bring about the outcomes or changes (or learning). Mechanisms are not the activities that the intervention puts in place but the choices the subjects make about how they will respond, along with the capacities they bring with them to the task' (Jolly et al., 2011: 2 - 3). These mechanisms work in the same way that reasons would in the case of the actors in the engineering failures discussed earlier. They also had a range of choices and it was their context that determined in many ways what they eventually decided to do. As already mentioned, the critical realist agenda is about emancipatory social practice. In other words, one's purpose for conducting the research must be for change for the better for those involved. That is the angle that evaluation research needs to take. It is therefore more than pragmatism, a popular approach in evaluation research, which holds that research questions need to drive methodological choices.

Why then do engineering education researchers need to concern themselves with emancipatory research practices, or embracing other ways of knowing? One answer is that these types of questions, combined with appropriate research purposes and methods, will allow exposure to other ways of knowing and being which may allow the engineering education researcher, in their capacity as educator, to model more to the student. It may also allow for better integration of humanities aspects to the engineering curriculum, instead of an 'add-on' that they appear to be at present. There is potential here then to contribute significantly towards the development of graduates who transcend the technologist or applied scientist labels that are sometimes put on engineers. Engineering education researchers could then be instrumental in developing engineers with the ability to respond to humanitarian ideals.

That argument, however, rests on the assumption that engineering practice is more than applied science. Williams et al. (1988) describe engineering as an activity that has both a human and a technical element to it. While his report was written some years ago, there is numerous current evidence that engineers work in very complex 'peopled' environments. According to Baillie and Catalano (2009), 'Engineers work in an increasingly complex entanglement of ideas, people, cultures, technology, systems and environments. … Engineers must develop the 'ability to respond' to emerging needs of all people, across all cultures. To do this requires insights and knowledge which are at present largely within the domain of the social and political sciences but which needs to be shared with our students in ways which are meaningful and relevant to engineering' (2009: Abstract).

Therefore, the critical realist argument suggests that the objects of engineering knowledge which exist in the intransitive realm are a complex mixture of so called non-human things such as technological systems and artefacts, but that this intransitive realm for engineers also contains people and cultures, which encompass structures and social relations. Arguably therefore the scientific discipline is well served by its model given the nature of its objects of knowledge. Engineering, however, cannot sustain that position. This implies that one cannot legitimately take 'what works' in science and apply it 'as is' in engineering, without considering contexts of practice and service. It is this non-technical side that should also be taken into account in the education of engineers (Williams et al., 1988).

Finally, the popular (albeit reductionist) engineering idea that analysis of different parts of a problem can define the system fully, as reported by Riley (2008), is challenged by the critical realist notion of emergence. Emergence holds that the relations among aspects of a problem are such that the system is more than the sum of its parts. Emergence is not an exclusively critical realist concept of course as it has existed in systems theory for a long time. It is highlighted here to foreground its applicability in social systems or 'peopled' systems and to point out that engineering problem solving methods are not necessarily suitable when engineers deal with 'peopled' systems. While the reductionist approach might work in problem sets, it does not do justice to the full nature of problems that practising engineers may encounter in service to humanity or the inherent complexities that are part of 'peopled' systems. The interactions that might exist between parts of the system give rise to a new elaborated entity and these interactions need be identified and analysed as part of the problem solving agenda.

## Some critiques of the philosophy

Some aspects of the philosophy have been criticized for presenting oversimplifications of otherwise quite complex issues. There is not enough space in this paper to fully attend to these issues. However, there are two areas that I wish to address briefly. The first is the idea that objects of study determine how they are to be studied, and the second is the definition of structures and mechanisms. I've chosen both these since they are quite central themes in the paper. Alvesson & Skoldberg (2010) take issue with the confidence with which critical realists assert that the nature of the object determines what methods are appropriate for its study. Their issue here is the idea that objects of research disclose themselves and then tell the researcher how they are to be most appropriately studied and that the researcher has privileged access to the object. It would be difficult to argue against this critique because of course objects of study do not announce themselves in that way. The emphasis here is rather on validity. In other words, we are being cautioned against deploying methods that purport to tell us one thing but actually tell us something else altogether. If we use a pre-test/post-test method to test the success of an intervention, can we be sure that the difference we observe in performance is indeed due to the intervention or are we in fact uncovering something quite different?

It is worth noting that any realist researcher, who thought they had privileged access to the object of study or to knowledge, misses the realist agenda. Realism holds that our knowledge is fallible, that 'the world can only be known under particular descriptions, in terms of available discourses, though it does not follow from this that no description or explanation is better than any other' (Sayer, 2000: 2).

Secondly, the other objection is to the use of the words structure and mechanism. Their objection to the former is that the category 'structure' shows a tendency towards arranging the world in objective and sturdy categories. Wider reading around not only critical realism but social realism and emergence will show this to not be the case. Internally related objects at surface level would seem to invoke superficial descriptions. However, the critical realist agenda advocates going beyond the surface so that internal relations which might appear obvious and fixed are shown to perhaps not be so. This is part of the emancipatory agenda. The objection to the latter, i.e. mechanism, seems to be that it makes social processes appear mechanical and therefore oversimplified. This might be a case of 'lost in translation'. In other words, it may be that in an attempt (Bhaskar's attempt) to infuse the same rigour in the social sciences that exists in the natural sciences, the language stayed the same, which was problematic for some. Again, the idea to understand deep relations and transcend event-level analysis is not lost.

## Concluding remarks

The point of the paper was threefold. Firstly it was to introduce key insights from the philosophy of critical realism to help clarify the purposes of the research agenda in the natural and social sciences. Secondly, the insights introduced were used to advance the understanding of the challenges that face engineering educators in producing graduates who can respond to humanitarian needs. This discussion positioned the engineering discipline as a discourse emerging from science as the key limiting factor in this agenda. Finally critical realist insights were used to interrogate engineering education research activities, a discussion which was also linked to the discourse and practices of the engineering discipline.

Engineering is derived from but different to science. This implies that methodologies that work in the sciences may not be an exact fit for engineering 'work', particularly if the humanitarian engineering challenge is to be realised. All research endeavours, even those of engineering education research, need to be concerned with uncovering mechanisms in the domain of the real that have causal efficacy in the domain of the actual. Moreover, the accounts of the people who experience these events or phenomena, some of which can be engineering events and others pedagogic events, need to have their ways of meaning-making valued in the research processes. In achieving this, it is not helpful to assert that moral, aesthetic and religious values are scientifically unverifiable and therefore meaningless. Critical realism introduces rigour to the research process for both the natural and social sciences. The philosophy has the potential to challenge engineering educators to think differently about their objects of enquiry and to consider carefully what methodological choices they model to students.

The emancipatory mandate of critical realist research has the potential to liberate engineering educators in their pedagogic and education research practices. It might liberate them from being potential agents of social reproduction, responsible for an unelaborated engineering cultural system which is held captive by the same ideas and norms generation after generation, a situation which would not be to the best interest of the engineers or of society.

## References

Alvesson, M. & Sköldberg, K. (2010). Post-positivism, social constructionism, critical realism: Three reference points for the philosophy of science *Reflexive methodology: New vistas for qualitative research second Ed*. Sweden: SAGE Publications Ltd.

Archer, M. S. (1995). *Realist social theory: The morphogenetic approach*. Cambridge: Cambridge University Press.

Baillie, C. & Catalano , G. (2009). Engineering and Society: Working Towards Social Justice, Part III: Windows on Society. *Synthesis Lectures on Engineers, Technology and Society, 4*(1), 1-124.

Bhaskar, R. (1989). *Reclaiming reality: A critical introduction to contemporary philosophy*. London: Verso.

Bhaskar, R. (2008). *A realist theory of science*. New York and Abingdon: Routledge.

Bigneil, V. (1999). Methods and case studies for teaching and learning

about Failure and Safety. *European Journal of Engineering Education, 24*(3).

Borrego, M., Douglas, E. P. & Amelink, C. T. (2009). Quantitative, Qualitative, and Mixed Research Methods in Engineering Education. *Journal of Engineering Education, 98*(1).

Burgoyne, J. (2008). The implications of critical realism for learning theory and practice: the nature of what there is to know about affects the way we learn it Unpublished Preliminary paper. University of Reading.

Carter, B. & New, C. (2004). *Making realism work: Realist social theory and empirical research*. London: Routledge.

Collier, A. (1998). Stratified explanation and Marx's concept of history. In M. S. Archer, R. Bhaskar, A. Collier, T. lawson & A. Norrie (Eds.), *Critical realism: Essential readings*. London: Routledge: Taylor and Frances Group.

Corson, D. (1991). Bhaskar's critical realism and educational knowledge. *British Journal of Sociology of Education, 12*(2), 223 - 241.

Danermark, B., Ekstrom, M., Jakobsen, L. & Karlsson, J. C. (2002). *Explaining society: Critical realism in the social sciences*. London: Routledge.

Elder-Vass, D. (2004, August ). *Re-examining Bhaskar's three ontological domains: The lessons from emergence* Paper presented at the International Association for Critical Realism, Cambridge.

Forrester, M. A. (2010). *Doing Qualitative Research in Psychology: A Practical Guide*: SAGE Publications.

Glatthorn, A. A. (1998). *Writing the winning dissertation*. Thousand Oaks, California: Corwin Press Inc., Sage Publications

Health and Safety Executive. (1975). *The Flixborough disaster: Report of the court of inquiry*.

Johnston, S., Alison, L. & McGregor, H. (1996). Engineering as captive discourse. *Society for philosophy and technology, 1*(3 - 4).

Jolly, L., Crosthwaite, C., Brodie, L., Kavanagh, L. & Buys, L. (2011). *The impact of curriculum content in fostering inclusive engineering: data from a national evaluation of the use of EWB projects in first year engineering.* Paper presented at the Australasian Association for Engineering Education.

Jolly, L. & Radcliffe, D. (2001, 2-5 July 2000). *Reflexivity and hegemony: Changing engineers. In (Eds), , . Proceedings of 2000 Conference,.* Paper presented at the ASET-HERDSA Toowoomba, QLD.

Kletz, T. A. (2006). Accident investigation: Keep asking “why?”. *Journal of Hazardous Materials, 130*, 69 - 75.

Law, J. & Callon, M. (1988). Engineering and Sociology in a Military Aircraft Project: A Network Analysis of Technological Change. *Social Problems, 35*(3), 284-297.

Lopez, J. & Potter, G. (Eds.). (2001). *After postmodernism: The millenium*. London and New York: Athlone.

McGettigan, T. (1998). Redefining reality: Epiphany as a standard of postmodern truth. *Electronic Journal of Sociology, 3*(4).

Mearman, A. (2006). Critical realism in economics and open-systems ontology: A critique *Review of social economy, 6*(1), 47 - 75.

Pawson, R. & Tilley, N. (1997). *Realistic evaluation*. London: Sage Publications.

Radcliffe, D. F. & Jolly, L. (2003, June). *Dilemmas in framing research studies in engineering education* Paper presented at the American Society for Engineering Education, Nashville, Tennessee.

Richey, R. & Klein, J. D. (2007). *Design and development research: Methods, strategies, and issues*. New Jersey: Lawrence Erlbaum Associates.

Riley, D. (2008). *Engineering and social justice*. Queens University: Morgan and Claypool.

Risjord, M. (2005). Reasons, Causes, and Action Explanation. *Philosophy of the Social Sciences, 35*(3), 1 - 13.

Sayer, A. (2000). *Realism and social science*. London: Sage.

Scott, D. (2005). Critical realism and mepirical research methods in education. *Journal of philosophy of education, 39*(4), 633 - 646.

Shipway, B. (2010). Bhaskar's critical realism, *Critical realist perspective of education*. Florence, KY: Routledge.

Solomon, R. C. (1974). Reasons as causal explanations. *Philosophy and Phenomenological Research, 34*(3), 415 - 428.

Varma, R. & Varma, D. R. (2005). The Bhopal disaster of 1984. *Bulletin of Science Technology & Society, 25*(37).

Williams, B., (Australia), R. o. t. D. o. E. & (Australia), C. T. E. C. (1988). *Review of the discipline of engineering*

Younkins, E. W. (2004, 15 December 2004). The plague of postmodernism. *Le Quebecois Libre* 149. Retrieved 1 November 2010, from http://www.quebecoislibre.org/04/041215-9.htm