# A personal journey towards interdisciplinary engineering education research: Lessons learned for undergraduate education

**Nicki Sochacka**
The University of Queensland, Brisbane, Australia
n.sochacka@uq.edu.au

**Joachim Walter**
University of Georgia, Athens, United States
jwalther@engr.uga.edu

***Abstract**: The graduate attributes for engineering students emphasise the need for students to acquire an understanding of the socio-technical context in which engineering solutions are embedded. This paper describes early experiences of a professional engineer and how this led to an inter-disciplinary PhD in engineering education research. The transition from a technical engineering background into interpretive research in engineering education is characterised by three key lessons: i) an awareness of 'technological determinism' in engineering practice and research, ii) an appreciation of socially constructed realities, and, iii) an awareness of the inherent complexity of socio-technical systems. Each lesson is introduced with an abstract description, an example of how it 'surfaced' in the research, and a discussion of its implications for engineering education research. The journey points towards ways of achieving the aforementioned graduate attribute in engineering students.*

## Introduction

In addition to mandatory technical capabilities, undergraduate engineering programs are expected to instil in students an understanding of the socio-technical context in which engineering solutions are embedded. In the United States for example, the Accreditation Board for Engineering and Technology's (ABET) (2008) list of program outcomes requires that students attain:

- "The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context".

Similarly, graduate attributes developed by Engineers Australia (EA) (2008) state that engineering graduates should develop:

- "An understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development".

This paper examines this aspect of engineering education by drawing on personal experiences of the first author in transitioning from professional engineering work into research in engineering education. An analysis of this transition identifies three key lessons which are discussed in their applicability to engineering education research and undergraduate education.

## A personal account of the relevance of social context in engineering practice

The following account describes a key challenge that I (the primary author of this paper) faced in my early experiences as a professional engineer. It concerns the limitations of technical problem solving approaches in understanding non-technical, or 'social', factors which influence the design of engineering solutions.

I began my career as an environmental engineer working in an international engineering and environmental consultancy. In this role I participated in the environmental testing, modelling, and remediation of contaminated industrial sites both in Australia and in Scandinavia. In the course of my work, I quickly became aware of how much each stage of this process depended on a set of variables quite different to those which I had become familiar with in my undergraduate studies. For example, when tasked with designing a remediation system, the greater part of my work entailed the investigation of a diverse range of 'social' variables such as: the different environmental policies of our clients, ever-changing environmental regulations, different cultural attitudes, the expertise of available personnel, and time and money constraints. In contrast, the job of neatly enfolding the relevant maths and science into an engineering problem solving approach to *actually remediate* the contaminated area, struck me as surprisingly small.

The degree to which engineering solutions, such as the design of remediation systems, are influenced by social variables was one of the reasons that I decided to pursue a PhD in the social aspects of urban water management. The interdisciplinary nature of this topic necessitated that I make the transition from a technical engineering background into interpretive, or 'social', research in engineering education. The paragraphs below describe three key lessons which marked this transition and how these lessons impacted on my research approach.

## 1. Awareness of 'technological determinism' in engineering practice and research

The basic premise of my research is that the widespread installation of decentralised technologies, such as domestic rainwater tanks, has fundamentally changed the set of variables that water practitioners, over 50% of which are likely to have backgrounds in either engineering or science (Brown, et al., 2009), need to understand in order to maximise socially, economically and environmentally sustainable outcomes (Sochacka, et al., 2008, 2009a). This is because, in contrast to conventional centralised approaches to urban water management, the success of decentralised technological solutions depends not only on technical factors (e.g. rainwater tank size, roof area, fittings and connections) but also on a diverse range of social factors (e.g. extent and nature of policy support, and household acceptance and management).

<u>*Example*</u>

As a first step in my project, I used the inter-disciplinary search engine, SCOPUS, to search the literature for research on rainwater tanks over the past three years (2006-2009). I found that the overwhelming majority of papers published on this subject were of a technical nature. For example, many studies used computational modelling tools to predict savings to mains water supplies and stormwater retention levels (Coombes, et al., 2007; Fewkes, 2007; Johnen, 2006; P. S. Kim, et al., 2008a; Y. Kim, et al., 2008b; Lucas, et al., 2006; Male, et al., 2006; Mitchell, 2007; Niven, et al., 2007; Sharma, et al., 2008). Others employed environmental testing and experimentation to predict tank water quality (Heyworth, et al., 2006; Huston, et al., 2009; Magyar, et al., 2007; Simmons, et al., 2001). In contrast, relatively few papers addressed social questions such as how to encourage homeowners to install water tanks and provide advice on installation requirements (Clarke, et al., 2006; Collins-Roe, et al., 2004) or, following implementation, how water tanks are accepted and managed at a household level (Clarke, et al., 2006; Gardiner, et al., 2008).

In an attempt to understand this apparent imbalance in research attention, I turned to a growing body of literature which explores the social shaping of technology (SST) – "how the design and implementation of technology are patterned by a range of 'social' and 'economic' factors as well as narrowly 'technical' considerations" (Williams, et al., 1996, p. 865). SST research argues that engineers and scientists subscribe to a technological determinist model of the nature of technology and its relation to society (Russell, et al., 2002). In this model, technological solutions are conceived as essentially autonomous entities having "determinate impacts on society" (Russell, et al., 2002, p. 1). In research underpinned by technological determinism, the priority lies in attaining universal, technical 'truths', e.g. what storage capacity (tank volume) is required to achieve a given potable supply reduction level (Mitchell, 2007). While valid and reliable from a traditional scientific perspective, these 'truths' implicitly assume that technologies have determinate, that is, predictable and controllable impacts on society. Alternatively, SST research stresses that technology and social arrangements develop as part of the same process – they co-evolve, or are co-produced, leading to emergent and not necessarily predictable technological and social change (Russell, et al., 2002).

An awareness of the technological determinist model thus provided me with a theoretical construct for i) understanding some of my own preconceptions in approaching what appear to be 'engineering' problems, such as the design of remediation systems described above, as well as, ii) a possible explanation for why the greater part of rainwater tank research is conducted with little regard for the social complexities associated with their implementation and use. This awareness, in turn, led me to choose a research method, Realistic Evaluation (Pawson, et al., 1997), which allows for both social and technical factors be to taken into account.

Research approach

Realistic Evaluation (Pawson, et al., 1997) conceptualises technological solutions, such as rainwater tanks, as but one part of broader *social programs* which are designed to achieve some form of social change. More specifically, it is not only technical considerations which determine the nature and extent of social change but also the opportunities that technological solutions provide and the context of implementation. For example, rainwater tanks with essentially the same technical capabilities could be used by some residents to water the garden, by others for drinking, and by others to wash clothes and flush the toilet. The investigation of technological solutions thus needs to span not only technical capabilities but also the opportunities they afford to users. In the Realistic Evaluation approach, these technical capabilities and opportunities, in turn, are explored in social contexts. For example, the backdrop of a drought and accompanying outdoor water restrictions, on the one hand, may encourage some householders to install a tank so that they can continue to water their garden, while concern for increasing water rates, on the other, may influence others to install a tank and connect it to the washing machine and toilet.

The investigation of choices made in contexts is based on the notion of *generative causation*. In other words, programs are said to 'work' (generate successful "outcomes") only insofar as they introduce the appropriate technologies and opportunities ("mechanisms") to groups in the appropriate social and cultural conditions ("contexts") (Pawson, et al., 1997). In this way, Realistic Evaluation provides a means to investigate the socio-technical context in which technological solutions are embedded. The figures below contrast the Realistic Evaluation approach to technological determinism.

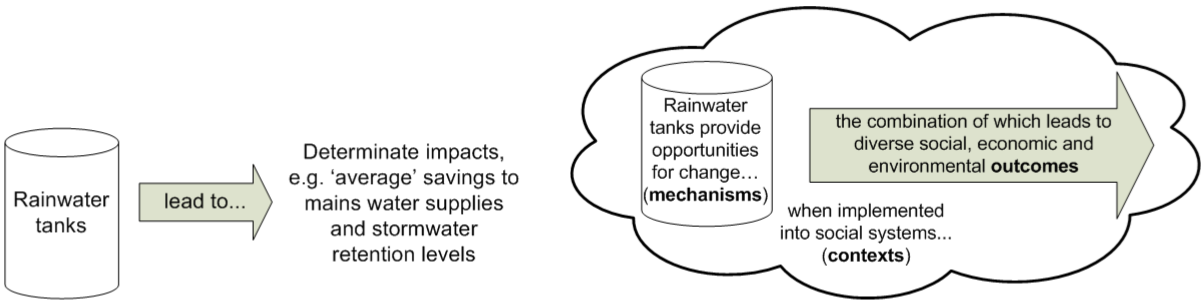


**Figure 1: Technological determinism and the Realistic Evaluation approach**

## 2. An appreciation of socially constructed realities

Looking in more detail at the social factors considered in Pawson and Tilley's (1997) notions of mechanisms, contexts and outcomes necessitated the recognition of socially constructed realities. That is, non-materialistic realities that are 'constructed' (Berger, et al., 1966; Hammersley, 1992), or 'created' through multiple perspectives, or "individuals' shared lived experiences" (Cohen, et al., 2000). These realities are thus dependent on context. Socially constructed realities are unlike universal truths within the traditional scientific paradigm in that they are not 'out there' (Lincoln, et al., 1985) in a materialistic sense. Rather they emerge from social interactions (Sawyer, 2005) and yet, at the same time, have tangible and often crucial impacts on the success of engineering solutions in social contexts.

Example

Early in my PhD, I conducted preliminary interviews with water and planning professionals to gain an understanding of the rationale behind the State and local Governments' push to encourage homeowners to install rainwater tanks. In the course of these interviews, I soon became aware of the diverse, and often conflicting, views that constitute what planners might refer to as the 'public response to', or 'public sentiment' concerning the purpose and efficacy of domestic rainwater tanks. For example, one study participant held the view that rainwater tanks enhance people's awareness of their water consumption:

> *It's the ultimate tragedy of the commons thing. You think you're getting it for free, even though you get a rate's bill, you're not aware of how much water you're using so you waste it. If your whole psychology changes* [as a result of installing a tank] *[...] people suddenly become aware, oh, my tank's empty, I've got to click over back to the potable system. The potable system costs me money* ('Alex', Local Council Town Planner).

When this view was put to another study participant, they disagreed stating that:

> *There's anecdotal evidence to say that if you have a tank you actually use more because, well, we're saving water over here so we can have a little bit, we can use a little bit more here because we're doing the right thing* ('Gerald', Water Company Customers Services Officer).

Contrasting views such as these highlighted the need to for me to choose a research approach which takes multiple perspectives into account in order to gain a deeper understanding of that particular socially constructed reality.

<u>Research approach</u>

To illustrate this interpretive process, the following shows how these contrasting perspectives are expressed in realist terms. In the previous discussion of Realistic Evaluation, we proposed that technologies constitute but one part of broader social programs which are designed to bring about some form of social change. We further attributed program outcomes (O), to mechanisms (M), acting in contexts (C) (i.e. C + M = O). The above example illustrates two different perspectives relating to the same 'program'- the incentivised installation of domestic rainwater tanks. These two perspectives are expressed in realist terms in **Table 1**.

**Table 1: Two different program perspectives expressed in realist terms**

| Context (C) | + | Mechanism (M) | = | Outcome (O) |
|---|---|---|---|---|
| <u>**'Alex'**</u><br>Perception of 'free' water from potable system **(C1)** with limited awareness of consumption levels **(C2)**. | | Installation of domestic rainwater tanks **(M1)** fitted with 'click over back to potable system' function when tank is emptied **(M2)** increases awareness of true 'free' water (i.e. tank water) vs. billed water **(M3)**. | | When mechanisms **M1-M3** are introduced into contexts **C1 & C2**, residents become more aware of their water usage and are thus better equipped to try, as far as possible, to avoid clicking back over to the billed potable system. **(O1)**.<br>This leads to reductions in water consumed from the potable system **(O2).** |
| <u>**'Gerald'**</u><br>Culture of 'saving water' **(C3)**. | | **M1** and use of captured rainwater gives residents the feeling that they 'are doing the right thing' **(M4)** and that they can therefore use a 'little bit more' from the potable system **(M5)**. | | When mechanisms **M1, M4 & M5** are introduced into context **C3,** water consumption from the potable system may increase **(O3)**. |

The articulation of such CMO configurations constitutes an important *theory building step* in the Realistic Evaluation approach. CMO configurations identified in the theory building step are thus propositions, or hypotheses, about how a program might 'work'. The goal of further research therefore is to *test and refine* these theories. This process involves iterative investigations of program understandings across a *hierarchy of expertise* (Pawson, et al., 1997) designed to cover the multiple perspectives of stakeholders involved in the program, e.g. policy-makers, practitioners and citizens/ program targets.

Finally, it is the researcher's task to interpret these theories into *transferable lessons* (Pawson, et al., 1997) which may be of use to programs in other contexts, e.g. a drought response in a different country. In a similar way Geertz (1974) describes this process of theory formation and abstraction as "grasp[ing] concepts which, for another people, are experience-near, and do so well enough to place them in illuminating connection with those experience distant concepts that theorists have fashioned to capture the general features of social life" (p. 29).

## 3. Awareness of the inherent complexity of socio-technical systems

The third key lesson learned by the first author in her transition from a technical engineering background into interpretive research in engineering education concerns the process of establishing knowledge claims. As discussed above in the Realistic Evaluation approach, this entails the articulation of tested and refined theories as transferable lessons for future program initiatives. This part of the research process necessitated an appreciation of the inherent complexity of socio-technical systems.

Example

Coming from a technical engineering background, my early conceptions of valid and reliable research results were closely tied to the notions of accuracy and repeatability. Moreover, I understood the purpose of scientific results as having the ability to predict and control future scenarios. Before embarking on my current research project, I accepted these concepts implicitly and with limited awareness of other ways of establishing knowledge claims. Difficulties emerged when, implicitly, I tried to measure my Realistic Evaluation research findings by these standards. It was with some discomfort that I struggled with questions such as: how could I claim that my CMO configurations were accurate enough to lead to the same outcomes in future programs? This feeling of unease hindered my ability (and confidence) in generating theory on the basis of my findings, and, after some time, led me to fundamentally examine the nature and purpose of research findings arising from the study of complex socio-technical systems.

Research approach

In contrast to 'generalisable' results emerging from technical research approaches, the notion of 'transferable' results shifts the focus from results to "predict and control the behaviour of [the] system" (Cilliers, 1988, p. 12) to results that are "concerned with understanding" (Flick, 2006, p. 30). In this way, results arising from the Realistic Evaluation approach provide an informative, theoretical basis for the maintenance of current and design of future initiatives. For example, if further research confirms that 'Alex's' above theory of water conservation is reflected in the experiences of residents, policy-makers in other settings may seek to further support this mechanism by designing domestic rainwater tank systems which include an easily accessible display of tank volume, and rainwater vs. mains supply water consumption.

# Discussion

In this paper we discussed three key lessons which characterised the first author's transition from a technical engineering background into interpretive research in engineering education, namely: i) an awareness of 'technological determinism' in engineering practice and research, ii) an appreciation of socially constructed realities, and, iii) an awareness of the inherent complexity of socio-technical systems. The following paragraphs discuss (i) the contribution of this paper to engineering education research, and, (ii) how this journey points towards ways of assisting engineering students to acquire an understanding of the socio-technical context in which engineering solutions are embedded.

(i) The discipline of engineering education is currently in the process of developing its own research paradigm (Borrego, 2008). An integral part of this process concerns the need for engineering educators to cross disciplinary boundaries to educational, or, more broadly, interpretive research (Godfrey, 2009; Koro-Ljungberg, et al., 2008). These transitions may be accompanied by a range of "conceptual difficulties" (Borrego, 2007), such as the three lessons described in this paper which highlight some of the fundamental epistemological differences between the positivist norms of engineering research and the constructivist norms of work undertaken within an overarching interpretivist research paradigm.

One way to confront these difficulties is to engage in "disciplinary reflexivity" (Wilkinson, 1988), that is, to adopt a critical stance towards implicit assumptions associated with one's own paradigm (Sochacka, et al., 2009b). Such reflexive examinations are becoming increasingly common in engineering education literature (for examples see: Godfrey, 2009; Sochacka, et al., 2009b). In this sense, this paper provides a 'nuts and bolts' account of the transition of an early career researcher from a technical engineering education background into interpretive research in engineering education. Our intention being, that the issues encountered may support other engineering education researchers in engaging in reflexive research practices with the view to conducting more effective interpretive work.

(ii) In the context of engineering education practice, methods of socio-technical analysis, such as Realistic Evaluation, could be introduced into the classroom in order to provide students with a way to get a handle on the more contextual and open-ended problems that engineering educators are introducing in the context of problem or challenge-based learning (Costantino, et al., 2009; Kellam, et al., 2009). Rather than just confronting students with socio-technical complexity in projects, frameworks similar to the method of investigation developed in this research project provide a systematic and yet flexible way to explicitly utilise the richness of open-ended problems in students' learning process. From such explorations students can, for example, begin to work towards an awareness of the underlying assumptions and limitations of traditional engineering approaches similar to the key lessons articulated in this paper. On the basis of this recognition they can then develop a true appreciation of other perspectives in an interdisciplinary and social sense. In combination, such learning processes would serve as a first step in achieving the "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" (ABET, 2008).

## References

Accreditation Board for Engineering and Technology (2008). *Criteria for Accrediting Engineering Programs*. Baltimore.

Berger, P. L., & Luckmann, T. (1966). *The social construction of reality: a treatise in the sociology of knowledge*. New York: Doubleday and Co.

Borrego, M. (2007). Conceptual Difficulties Experienced by Trained Engineers Learning Education Research Methods. *Journal of Engineering Education, 96*(2), 91-102.

Borrego, M. (2008). A New Paradigm for a New Field: Communicating Representations of Engineering Education Research. *Journal of Engineering Education, 97*(2), 147-162.

Brown, R. R., Farrelly, M., & Keath, N. (2009). Practitioner perceptions of social and institutional barriers to advancing a diverse water source approach in Australia. *International Journal of Water Resources Development, 25*(1), 15-28.

Cilliers, P. (1988). *Complexity and postmodernism: Understanding complex systems*. London, New York: Routledge.

Clarke, J. M., & Brown, R. R. (2006). Understanding the factors that influence domestic water consumption within Melbourne. *Australian Journal of Water Resources, 10*(3), 261-268.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research methods in education* (5th ed.). London; New York: Routledge Falmer.

Collins-Roe, M., & Davies, D. (2004). Urban rainwater tanks: Common sense under threat. *Water, 31*(4), 66-70.

Coombes, P. J., & Barry, M. E. (2007). The effect of selection of time steps and average assumptions on the continuous simulation of rainwater harvesting strategies, *Water Science and Technology* (Vol. 55, pp. 125-133).

Costantino, T. E., Kellam, N. N., & Cramond, B. L. (2009). *What can engineers and artists learn from each other about creativity: a preliminary study*. Paper presented at the American Educational Research Association.

Engineers Australia (2008). *Engineers Australia Policy on Accreditation of Professional Engineering Programs*.

Fewkes, A. (2007). *The field testing of a rainwater harvesting system.* Paper presented at the Proceedings of the Combined International Conference of Computing and Control for the Water Industry, CCWI2007 and Sustainable Urban Water Management, SUWM2007.

Flick, U. (2006). *An introduction to qualitative research* (3rd ed.). London: Sage Publications.

Gardiner, A., Skoien, P., & Gardner, T. (2008). Decentralised water supplies: South-east queensland householder's experience and attitudes. *Water, 35*(1), 53-58.

Geertz, C. (1974). From the Native's Point of View: On the Nature of Anthropological Understanding. *Bulletin of the American Academy of Arts and Sciences, 28*(1), 26-45.

Godfrey, E. (2009). Exploring the culture of engineering education: The journey. *Australasian Journal of Engineering Education, 15*(1).

Hammersley, M. (1992). *What's wrong with ethnography? - Methodological explorations*. London; New York: Routledge.

Heyworth, J. S., Glonek, G., Maynard, E. J., Baghurst, P. A., & Finlay-Jones, J. (2006). Consumption of untreated tank rainwater and gastroenteritis among young children in South Australia. *International Journal of Epidemiology, 35*(4), 1051-1058.

Huston, R., Chan, Y. C., Gardner, T., Shaw, G., & Chapman, H. (2009). Characterisation of atmospheric deposition as a source of contaminants in urban rainwater tanks. *Water Research, 43*(6), 1630-1640.

Johnen, L. (2006). Britain's best kept secret... except in Germany. *Water and Wastewater International, 21*(5), 41.

Kellam, N. N., Costantino, T., & Cramond, B. (2009). *The Impacts of an Interdisciplinary Design Studio on Creativity.* Paper presented at the Creativity and Innovation Symposium, Winston-Salem, NC.

Kim, P. S., Yoo, K. H., Nyakatawa, E., Lee, N. H., Srivastava, P., & Byung, R. A. (2008a). *Rainwater harvesting system as an alternative water source for domestic and outdoor uses.* Paper presented at the American Society of Agricultural and Biological Engineers Annual International Meeting 2008.

Kim, Y., & Han, M. (2008b). Rainwater storage tank as a remedy for a local urban flood control, *Water Science and Technology: Water Supply* (Vol. 8, pp. 31-36).

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), 163-174.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, Calif. ; London: Sage Publications.

Lucas, S. A., Coombes, P. J., Hardy, M. J., & Geary, P. M. (2006). Rainwater harvesting: Revealing the detail. *Water, 33*(7), 89-94.

Magyar, M. I., Mitchell, V. G., Ladson, A. R., & Diaper, C. (2007). An investigation of rainwater tanks quality and sediment dynamics, *Water Science and Technology* (Vol. 56, pp. 21-28).

Male, J. W., & Kennedy, M. S. (2006). *Reliability of rainwater harvesting.* Paper presented at the WIT Transactions on the Built Environment.

Mitchell, V. G. (2007). How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling? *Hydrological Processes, 21*(21), 2850-2861.

Niven, D., Drummond, K., Wuthenow, K., & Anda, M. (2007). *Future Proofing Perth Housing for Climate Change: An Integrated Model on Retrofitting Housing for Sustainability*. Paper presented at the The 2007 International Conference on Engineering Sustainability.

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

Russell, S., & Willians, R. (2002). *Social Shaping Research and Technology Policy: Themes and Insights from Recent Work.* Paper presented at the Sino-European Symposium on Science, Technology and Society, Chinese Academy of Social Sciences, Beijing.

Sawyer, R. K. (2005). *Social emergence: Societies as complex systems*. Cambridge; New York: Cambridge University Press.

Sharma, A. K., Gray, S., Diaper, C., Liston, P., & Howe, C. (2008). Assessing integrated water management options for urban developments - Canberra case study. *Urban Water Journal, 5*(2), 147-159.

Simmons, G., Heyworth, J., & Rimajova, M. (2001). Assessing the Microbial Health Risks of Tank Rainwater Used for Drinking Water. *Environmental Health, 1*(3).

Sochacka, N., Jolly, L., & Kavanagh, L. (2008). *"Realistic Evaluation": A useful approach for investigating interdisciplinary issues associated with urban water management?* . Paper presented at the Universitas 21 Postgraduate Student Conference.

Sochacka, N., Jolly, L., & Kavanagh, L. (2009a). *A Realistic Evaluation of Universal Water Metering in the United Kingdom's South East*. Paper presented at the Environmental Research Event.

Sochacka, N., Walther, J., Jolly, L., & Kavanagh, L. (2009b). *Confronting the Methodological Challenges of Engineering Practice Research: A Three-Tiered Model of Reflexivity*. Paper presented at the Research in Engineering Education Symposium.

Wilkinson, S. (1988). The Role of Reflexivity in Feminist Psychology. *Women's Studies International Forum, 11*(5), 493-502.

Williams, R., & Edge, D. (1996). The social shaping of technology. *Research Policy, 25*.

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