

2011-06-01

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Recommended Citation

Kelly, K., Bowe, B.: Qualitative Research in Engineering Education. 118th. ASEE Annual Conference and Exposition, Vancouver, Canada, June 26-29, 2011

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Qualitative Research in Engineering Education

Introduction

Engineering education programs provide students with the knowledge, understanding, skills and competences required to be professional engineers. These include scientific and mathematical theory, engineering applications, design and problem-solving skills, communication skills and so on. The development of research skills and an understanding of research methods is often assumed to be inherent in the scientific and technical modules and is often explicitly learned in research methods or research design courses. At graduate level, and to a lesser but growing extent at undergraduate level, programs include projects that require advanced research skills and a thorough understanding of the research methods, from data acquisition, data analysis, sample size, validity and so on. The research found within engineering programs tends to be grounded firmly in the positivist paradigm with a predominant dependence on the use of quantitative methodologies and methods. Even where qualitative research methods are used, the analysis tends to use coding to transform the data back into quantitative numbers and percentages (e.g., the frequency of the use of certain phrases or words). When professional engineers are required to design an artefact or solve a problem, it may be appropriate to employ qualitative research methods.

This paper argues that engineering students should learn a variety of research methodologies and methods covering the spectrum from the positivist quantitative approach to a more interpretative qualitative approach. This will ensure that as professional engineers, they will be equipped with the requisite knowledge, skills and understanding to choose the appropriate research method or mixture of methods in any particular context.

The nature of research methods and methodologies courses has come in for intense scrutiny across many disciplines over many years. Scientific based research is widely viewed by engineers, to be rigorous and objective driven, using empirical methods in experiment driven systemic methods that test hypotheses and justify conclusions. Such positivist traditions sometimes argue that such a truth can never be confirmed, only disconfirmed, i.e. the concept of falsifiability^[1]. This paper effectively raises a number of epistemological issues and questions the absence of qualitative research within engineering education.

Petroski^[2] refers to Snow's famous lecture in Cambridge in 1959 about the two distinct intellectual cultures of science and the humanities. Petroski^[2] argues that Snow's lecture, and the sometimes vitriolic debate that followed, epitomised the gulf between the sciences and the humanities and concludes that engineers have much to learn from the qualitative research methods used by our colleagues in the humanities. Indeed Berliner^[3] wonders if the use of qualitative methods, such as those used in educational research, is the hardest science of all. He argues that qualitative research is often considered soft,

unreliable and imprecise when compared with other sciences such as bridge design and electronic circuit design. Berliner^[3] concludes that qualitative research is *the hard to do science*.

Qualitative Research is often about the local rather than the general, and usually involves human actions and interactions. Such data is notoriously difficult to plan, collect, analyse, code and present (particularly to an audience who are more comfortable with quantitative data and studies with large sample sizes). In qualitative research the context is critical because of the myriad of interactions that occur in different applications and cultures. There is also a myriad of qualitative research methodologies that can be employed, including phenomenology, phenomenography, ethnography, case study research and narrative research. For example with good quality case study research, qualitative data may be presented in a rich format and set within a context that the reader is invited to judge and select appropriate data from, which may apply to their own situation. The findings must be presented with the underlying assumptions and limitations of the research made clear to the reader. Critical analysis of the methodology is particularly important in qualitative research. Studies should be presented in sufficient detail and clarity to allow replication or at least offer opportunity to build systemically on their findings. Qualitative studies may finish by identifying future research questions that were not addressed in the study. The very nature of qualitative research is such that it often ends in surprises that the researcher may not have expected nor had time or resources to address.

Apart from not being able to answer questions with multiple constructions, one of the weaknesses of quantitative research is that it may result in what is described by social scientists as a thin description of what happened; whereas qualitative studies are usually rich and thick in data. For example, quantitative studies can show trends and correlations but they are very often unable to provide explanations or reasons. However, qualitative studies allow theory to emerge from the data and hence the richness in explanation. This article sets out to explore the use of qualitative methods of research in engineering and argues that perhaps engineering programs should be equipping students with a greater knowledge of the range of research methodologies and methods.

Engineering examples?

The first author is a chartered engineer with a background in electrical engineering and energy management, and he holds an education doctorate. The second author has undertaken extensive education research studies that used both quantitative and qualitative methods and he also believes that qualitative research plays an important role in engineering and hence should also be included within engineering education programs, particularly at graduate level.

The first author currently employs qualitative methods for post occupancy evaluation of buildings. That is, to find out if building users are satisfied with comfort levels and the degree of control they have of energy use within a building. If energy usage of a building is higher than it should be, then qualitative methods can be used to investigate user

behaviour, knowledge and attitude. A well designed building, services and controls will not function well from an energy perspective unless user behaviour in this regard is satisfactory and users are satisfied with the performance of the system. To achieve this fine balance between minimising energy and maintaining user satisfaction, it is acknowledged in many Chartered Institute of Building Services Engineers (CIBSE) publications that building occupants must be energy aware and have some level of control of services and comfort levels. To evaluate energy performance, utility bills and other quantitative data may be used. But if the energy performance of the building is higher than expected then human factors usually come into play and evidence of the knowledge, attitude and behaviour of building users may need to be examined thoroughly. This evidence will be qualitative. It is not just anecdotal, but instead it should be rigorously collected and analysed. There is a danger that due to a lack of knowledge (and hence respect) qualitative research can be perceived as simplistic. An engineer without adequate knowledge and skills in qualitative research, may attempt to carry out the research through questionnaires or interviews; but without the rigor, in both the acquisition and analysis, the findings will lack validity and credibility.

A qualitative research study will end with conclusions, findings or recommendations and/or a discussion section. In this final stage the limitations of the research are always stated and future research questions (which have not been adequately answered in the research undertaken) identified for the reader. A good piece of qualitative research may also be a fore runner to an other research study which will be either, or both, a qualitative or/and a quantitative study. For example, the qualitative study is exploratory where the researcher is trying to investigate a problem without knowing the exact parameters of the problem and theory emerges from the data which might later underpin a quantitative study. Alternatively quantitative data may indicate a problem that needs further investigation through qualitative methods. It is important to note that qualitative and quantitative methods are not mutually exclusive. They can be complementary to one another and the qualitative aspect can deepen explanation as well as provide answers to research questions.

Qualitative Research

As this is a *publish to present paper* it might be useful to present some material here in the form of questions which might arise from an audience of engineers. A hypothesis for this part of the paper could be that “Rigorous Qualitative Research can be Useful in Engineering”; from this, the following questions might be posed:

1. When is qualitative research appropriate?
2. How is qualitative research done well and how is qualitative data analysed?
3. How is adequacy assessed?
4. Can you provide an example of qualitative research in engineering?

1. When is Qualitative Research appropriate?

Qualitative research is often exploratory; it is useful when it is necessary to investigate human behaviour or why something has happened or not happened in a building or elsewhere, or to find out how well or otherwise something performed but for which quantitative data does not offer a complete picture. It is particularly suited to examining what people think, know, conceive or perceive. The use of phenomenology in architecture to examine peoples' perceptions and experiences of a building is a common example from a related discipline. Post occupancy evaluation of buildings is an example in engineering and an example from one such study is provided in answer to question 5 below. Engineering design is very often informed by user requirements or by user specifications, and qualitative research methods are employed to ascertain these prior to design and also to evaluate the product from the user's perspective post-production. Effectively, if the research questions are about what people think or know or do or how they experience something, then qualitative methods often offer the best solution. A wealth of information and data can be gathered from knowledgeable people about just about anything; but in particular about their own behaviour and perceptions. Sometimes people may not even be aware of their behaviour until they are asked about it. The data collected in such research is rich because the researcher and reader not only find out what they did or did not do - but the reasons and explanations. It is this aspect that allows a design engineer to re-think something from the perspective of the user and provide a more user friendly solution. In other words qualitative research can offer a means of implementing customer friendly solutions.

2. How is Qualitative Research done well and how is qualitative data analysed?

Carrying out qualitative research well is difficult and the analysis of qualitative data can be daunting. Data collected from interviews can be huge in volume and the methods of analysis must be carefully considered. Various software and methods are available to help the researcher but the researcher needs to have a thorough understanding of the analysis method before collecting the data (e.g., writing the interview questions). Otherwise they will end up asking themselves where to start or worse still, finish with data that is incomplete. For example, it is quite common with novice qualitative researchers, who seek to obtain experiential data (knowledge of the participants' experiences), to analyse the interview data only to realise they have only obtained opinions and descriptive data instead of reflective accounts. Interviews are difficult to do because people are not always honest or sometimes may not realise or be aware that they know something. In addition, the wording and the sequencing of the questions can alter the answers to the questions.

Qualitative studies begin with research questions and the research methodology and methods are chosen to best answer these questions. The methodology could be phenomenology, case studies, participatory research and/or action research to name but a few. For example, action research is an iterative research process intended to change the researcher's own behaviour and hence is often employed in practitioner-based education research studies. As Qualitative Research has been widely used in the social sciences for

many years, rigorous research methods are well established. Qualitative methods useful in post evaluation case studies include in-depth interviews, small surveys, participant observation and document examination. Interviews result in thick descriptions that allow a deep examination of what has happened and why.

Good quality qualitative research will gather and analyse such data to answer research questions in a transparent way that convinces the reader of its authenticity and rigour^[5]. Various ways are used in qualitative research to do this^[6]. Firstly the researcher provides details of their own background, why they undertook this research and who else is involved or is funding it.

Interviews are carefully prepared, recorded and transcribed. The interviewer should write a reflective log of what happened in the interview and how they think the interview went^[7]. Because such data collection is not easy, using a reflective log allows inexperienced interviewers to benefit by evaluating their own performance. Researchers should always 'pilot' the interviews to ensure the appropriateness and suitability of the questions and sequencing. As it is often only after the transcript is analysed that the effectiveness of the interview can be evaluated, the pilot study should also include the analysis. For example, in one particular case, one of the authors asked double barrelled questions which confused interviewees and yielded poor data. The interviewees were allowed to speak for too long on topics that were not relevant to the research. Sometimes the questions were not precise enough or the interviewees elected to answer a different question than the one asked. Sometimes interviewees were interrupted so as to clarify a point but this disturbed their train of thought. Therefore reflection on and critical evaluation of interviewer performance is important so as to ensure good quality data.

Interviews should be recorded and summaries of interviews should be submitted to the interviewees so that they get a chance to clarify matters, add afterthoughts or correct misrepresentations. In this way the data is carefully considered and does not just rely on a quick response at the interview. Interviewing is time consuming for the interviewee and the interviewer. A one hour interview will typically take four hours to transcribe and summarise for an experienced interviewer and much longer for an inexperienced one.

Ethical approval is also necessary with anonymity for interviewees normally required. This means colourful or individual quotes, which might accidentally identify a source, must often be omitted. The basic ethical requirement is that no harm can be allowed to come to sources because of their contribution to your research^[8]. The standards of propriety have been raised in this area in recent years and the idea that you can let the data speak for itself whilst allowing harm to somebody's reputation or cause embarrassment to them are gone. Sometimes issues such as criticism of a product or a designer can be overcome by allowing this person respond to any criticism and allow them have their say; but this has to be carefully thought through. Consideration must also be given to where the data will be stored, who will have access and when will it be destroyed.

3. How is adequacy assessed?

The term reliability used in quantitative studies is replaced with the term adequacy in qualitative studies. Although this term is often seen as adding to the perception that qualitative research is not rigorous or complex (i.e., it is just adequate), it relates to the credibility of the research. It simply reflects the context-specific nature of qualitative research and the realisation that different research methodologies can be used to answer the research questions. Reliability does not apply in qualitative studies because the findings of the research will depend on the context^[9]. However, adequacy includes both the validity and the transferability of findings. The research methods design (methodology, methods, participants) must ensure that the research is valid, i.e., the most appropriate design to answer the research questions. Transferability depends on context but the findings are presented in a way which allows the reader to judge and select which aspects are appropriate in their own context and to what extent.

Qualitative studies are intended to inform readers about things they did not know or things they wanted to hear more evidence about or maybe had not even thought about. The description is rich enough and detailed enough for the knowledgeable reader to extract that which applies to their case and they can then explore this more fully for themselves. So the qualitative study might act as a stimulus to further research by the reader in some cases or as a catalyst to a change of view or behaviour.

As mentioned earlier, in qualitative research a researcher provides their own background to the reader and highlights any baggage they bring to the research. For example if a study into lighting controls was funded or carried out by the company supplying controls then this needs to be stated. In this way the researcher is on guard to be extra vigilant in being objective and transparently fair, and the reader is facilitated to act as arbitrator or judge of this by knowing the researcher's background. In this way the reader more easily assesses validity and transferability.

5. Do you have an interesting example of Qualitative Research in Engineering?

In January 2010, one of the authors began supervising a mature student who was carrying out a final year thesis for an honours degree in Electrical Services & Energy Management. He initially intended to do a post evaluation case study into the performances of lighting control systems in three buildings^[10]. He had access to each building having worked on them before beginning his thesis in September 2009. The thesis seemed straightforward and he submitted his proposal in December 2009. He intended to gather data about installation costs, lighting energy data for each building before installation of the controls and so on. He then intended to gather data for a period after installation of the controls, compare the two sets of data, calculate the annual savings, calculate the payback and estimate value in monetary terms, visual comfort and

savings in carbon emissions. This seemed to suggest that a straightforward quantitative study would be most appropriate.

However when he returned to the buildings in January 2010 disaster struck. The lighting controls on two of the buildings had been disconnected. The research took a different direction to investigate the reasons behind the disconnection. Starting again, new research questions were written that could only be answered by questioning the people involved in the decision^[11]. So began a qualitative study that was judged the best thesis submitted in May 2010. It was published by Lambert Academic Publishing in July 2010^[10] and the researcher won the CIBSE Ireland, Irish Lighter award 2010 for a paper presented from this work.

The researcher carried out semi-structured interviews, described by Robson^[12] as allowing flexibility for the researcher to probe and for the interviewee to explain. Facilities managers, general managers, lighting/controls designers, caretakers, and lighting control technical specialists were interviewed. Interviews were recorded for later analysis by him. Qualitative research must be rigorous if it is to be convincing and qualitative data must be organised well. It often involves inductive reasoning in that the data is often analysed without pre conditions or set theory. This can result in huge amounts of data without categories, and software might be necessary to help organise the analysis. With an undergraduate or Masters thesis where time and resources are limited, data may be gathered under general headings or under a conceptual framework or the researcher may use template analysis. In the case of Doyle^[10] some theory was applied before data collection began. Data was then presented to the reader and analysed through a conceptual framework using established methods of template analysis that were identified in his literature review of other research in this area. These were then fully explained and justified in the context of his research. This conceptual framework ensured questions on problems identified elsewhere in the literature were fully examined. These included:

- Lack of coordination
- Inadequate user directions
(including training, documentation & labelling)
- Wrong specification (controller type)
- User behaviour
- Wrong location of controller
- Poor commissioning

There were other findings outside of the conceptual framework which were very insightful. One included the high cost of ongoing maintenance and the support required for one system.

Template analysis^[13] allows data to be collected in categories within a conceptual framework. But it must be emphasised that data analysis is not selective except in so far as gathering data under the headings established. Data yielded that is outside the conceptual framework can be also be categorised using template analysis after the data is

collected. More theory then emerges from the data and has to be considered outside the original framework envisaged. For example in this case, the reasons why the controls were disconnected that were not known or envisaged when this research began. Nonetheless the bulk of his data was collected within the original conceptual framework identified from the literature review and the extra data was then small in volume and more easily dealt with. In his study Doyle^[10] found that there was a major mismatch between what the designer thought was happening and what actually happened afterwards. A designer was interviewed in the research and explained that the fee structure was such that his job ended long before the building was occupied.

Discussion

It is argued in this paper that qualitative research may be an appropriate way to address engineering problems and issues. Hence engineering research should be expanded beyond its current positivist paradigm. Engineers can learn a lot about qualitative research methodologies and methods from our colleagues in the social sciences who have been using such methods for many years. Engineering programs should educate students about the variety of approaches and research methods as well as the implications of using particular methods so that they are better able to make informed decisions when undertaking research.

So what can we learn from qualitative case studies? The answer is simple - everything we possibly can. Qualitative studies are open, exploratory and rich in data and description. They are often a stimulus for further investigation highlighting research questions for quantitative analysis, or as a follow on to quantitative studies which do not reveal the why of human behaviour. But qualitative research can be extremely informative in itself and act as a catalyst for change to the reader who can see the outcomes in a context that applies to them.

Qualitative research is contextual and often involves complex human action and interactions. Data is often very difficult to make sense of and analyse. Analytical tools are necessary to grind through voluminous data. Analytical software may be necessary for larger studies, but for smaller studies a conceptual framework may be used when collecting data and then as an analytical tool at the later stages. This makes data analysis simpler. Template analysis^[13] is also a useful tool for analysis of large amounts of qualitative data. But with qualitative research there is often surprises and unexpected data and methods of analysis must be flexible enough to deal with these.

The concept of adequacy is thought of differently in qualitative research than in quantitative research. Validity is about credibility and is judged by the readers. The findings either seem transferable for them or not. Usually with good quality studies they are partly transferable to a lot of other cases allowing the reader modify what they do in their own situation.

Rigorous qualitative research is time consuming and difficult to do but it offers a thorough and credible way of finding out about human behaviour in engineering applications.

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