Nicki Wolmarans, Department of Civil Engineering and Centre for Research in Engineering Education (CREE), University of Cape Town

I am currently an "Academic Development Lecturer" in the Civil Engineering Department at the University of Cape Town. As an ADL I am part of a programme in the Engineering and the Built Environment Faculty initiated to address issues of student experience and success.

Corrinne Shaw, Department of Mechanical Engineering and the Centre for Research in Engineering Education (CREE), University of Cape Town

After graduating from the University of Cape Town, I worked in both the public (as an educator) and private sectors before returning to postgraduate study and embarking on an academic career. As with many South Africans, growing up under Apartheid has had a profound impact on my worldview and life choices. This has included influencing the choice of a career in education, both as a practitioner and scholar. I currently convene a postgraduate programme in Engineering Management and teach undergraduate courses in Engineering Management. I draw on multiple theoretical constructs for the design of learning contexts, including complexity and systems theory. My research is primarily focussed on student experience of learning events and student learning more broadly both in formal settings and the workplace.
“Wearing that hard hat and those boots and being there with all the dust”: Students’ conceptions of becoming a Civil Engineer.

This paper reports on a phenomenographic study describing how students conceive of civil engineering through their engagement with six projects on a first year introductory engineering course. In the simplest of four phenomenographic categories students don’t engage with becoming an engineer at all. They tend to see the course activities as prescribed by the lecturer, unrelated to a more abstract understanding of identity formation. In the second category there is a relationship between course activities and engineering practice, but it represents a literal translation into engineering practice, as though they are doing exactly what engineers do. In the third category students begin to abstract the course activities as representations of engineering practice, but what distinguishes this category from the most complex category is the notion that science is compromised by the multi-disciplinarily nature of engineering practice. In the most complex category students extrapolate the course activities as representations of aspects of engineering practice; and they see conflicting requirements for problem solving as a challenging form of optimisation rather than merely compromise. These phenomenographic findings are supported by a qualitative analysis of the stories of becoming or not becoming an engineer which add an affective layer to the phenomenographic categories that emerged. In combination, these findings challenged assumptions regarding the student experience of the course and provide a rich evaluative element of the course for the purpose of informing the design and delivery thereof.

Introduction

It has become common practice in engineering programmes to include a professional or introductory course in engineering at the first year level. These courses tend to focus on academic and professional skills development, and/or the introduction to the engineering disciplines through project based learning. In our course in the civil engineering programme we intend to introduce students to engineering through six projects from various civil engineering specialisations. The objective of the course is to make explicit what it means to think like an engineer, and to recognise what it means to be an engineer. However, it can be assumed that not all students achieve our objectives. The purpose of the study is to better understand our students’ experience of the course with the view to enable more students to derive the full benefit of the course.

In an effort to better understand how our students experience the course we interviewed a range of students who had completed the course in the previous year and conducted a phenomenographic analysis of these interviews. Phenomenography allows us to categorise the qualitatively different ways of experiencing a shared phenomenon, in this case how the course frames a student’s conceptions of becoming an engineer.

However, because of the centrality of the notion of being or becoming an engineer in our course philosophy, some focus on identity is critical. The phenomenographic categories that emerged from our interviews, while very useful for understanding the course, seemed to suppress individual identity. We have therefore appended a very brief discussion based on the stories told as narratives during the interviews to acknowledge this aspect of the data.
**Becoming an engineer**

The background to being or becoming an engineer lies in studies of graduate attributes or competencies. This body of literature focuses on the need to develop core knowledge and skills for success as an engineer. In the mid to late 1990’s the focus was predominantly concerned with deficiencies in graduate engineers in terms of complementary skills such as teamwork, communications and business skills. More recently, there has been a shift towards acknowledgement of the primacy of the ability to apply theoretical knowledge to real industrial applications or as Ferguson warns, a danger of losing the basic analytical skills in the push for employment ready graduates.

The response to these concerns includes the introduction of project based courses. Bailie showed that the most common approach to addressing the changing needs of engineering education at first year level was to introduce a new subject, usually an ‘introduction to engineering’ or ‘professional engineering’, with “an attempt to link the various parts in the course in the context of how to think like an engineer” (p.456). Our course, Introduction to Civil Engineering, is very typical of such a project based course.

**The course**

The course is structured around six projects, each representing a different specialisation within the civil engineering profession, intended to introduce the profession. These span water supply and management, informal settlement upgrades, construction, water treatment, transportation engineering, and an engineering materials and structures project. Within each project there are a number of teaching and learning activities intended to build academic and professional skills. Figure 1 represents a part of the course structure diagrammatically, where the stars represent teaching and learning activities located within a project and the lines indicating how tasks link between each other even across different projects towards developing skills and building on content.

![Figure 1: Partial Course Structure](image)

By way of example of a project, the construction site project requires each team of students to negotiate access and visit a construction site periodically over a four month period. Each
student is then required to individually write a substantial technical report on any aspect of construction they select. However, prior to visiting the sites there is a team project in which the team is presented with a concept related to structures or construction. The team is required to research the topic in structured library visits, produce one page of referenced text and a small scale model to illustrate the concept. Each student in the team then has an opportunity to teach the topic to a small group of students in the class.

Through the structured activities students are introduced to sourcing information in the library; technical reading; referencing; writing in a technical genre; and communicating technical concepts to a small group of peers. In addition each student learns about a number of concepts related to structures and construction as an orientation to their site visits.

Skills are typically not isolated to a single project, but build together through multiple projects. For example, in preparation for writing the major technical report, structure and coherence in paragraphs is introduced in the informal settlement upgrade project. The basics of experimentation, with a focus on measurements and data presentation, alongside spreadsheet functionality and design are introduced through three activities within the service reservoir project. Students are expected to use these skills in subsequent projects.

**Fluency in an Engineering Discourse**

Through their engagement on the course our intention is that our students will recognise civil engineering as encompassing a broad range of specialisations, certainly beyond only designing and building structures. This recognition should include values such as the centrality of people in civil engineering and to value the notion of civil engineering as science in the service of communities.

Our second objective is to develop the generic skills needed for success as a student and a professional. These include: problem solving; computing; experimentation; teamwork; communication, both formal and interpersonal; and time and study management. To a large extent the generic skills identified as important are those articulated as Exit Level Outcomes (ELO) by ECSA (Engineering Council of South Africa) as a requirement for programme accreditation within the Washington Accord (ECSA is the equivalent of ABET in the USA).

Possibly more importantly we hope our students can contextualise the activities as ways of *doing* engineering and *being* an engineer. Not only do we want them to learn to solve problems, but to take on ways of approaching problems and ways of representing information (data and writing) such that they will be recognised by others as legitimate engineers or engineering students. The philosophy underpinning the course is founded very strongly on Gee’s ideas around Discourse, where Discourse (with a capital D) is seen as encompassing not only words, but also ways of being, doing and valuing. Central to this is being recognised by others as being in the Discourse, and therefore the course tries to make explicit what counts as legitimate ways of doing engineering and being an engineer.

It can however be assumed that students experience the course in a multiplicity of ways, some more aligned with the course intentions than others. The focus of this study was therefore to understand how students conceive of becoming an engineer through their experiences in the Engineering I course, and what meaning they attach to these experiences.
Theoretical framework

Phenomenography is the research approach which was adopted for this study. One of the aims of phenomenographic research is to “study how people experience a given phenomenon”8 (p. 133) i.e. a second order research approach. A defining feature of phenomenography is that the researcher is interested in the variety of experiences across a group rather than the richness of individual experiences. For example, in phenomenography learning is viewed as “a change in the ways in which one is capable of experiencing some aspect of the world”9 (p.135). When using it as a lens for educational settings the focus is on the understanding of the content in these settings as a consequence of engaging with various learning activities9.

Since the objective of phenomenography is to capture variation, purposive sampling is required. We selected 6 participants based on a comparison of their performance in the course and on other first year subjects. Two participants were high achievers on all courses, two were passing the Introduction to Civil Engineering course well, (although one had failed a different course) and two students had left the civil engineering programme, having struggled to meet minimum academic performance requirements. We also had representation across race and gender.

An additional variation of interest noted from the interviews related to their reasons for choosing to study civil engineering. One participant admitted to knowing nothing about civil engineering before entering the programme. Two others were more interested in a different course of study and career, but registered for the civil engineering program due to family pressure in the first case, and in the second case as a result of being rejected for their first choice academic program. Three had chosen civil engineering because of their strength in maths and science coupled with a desire to ‘make a contribution to society’ in some way. Of these three, two had a clear affinity for engineering and had made a conscious choice between alternatives, while the third seemed to be struggling with her motivation.

While we do not claim to have exhausted the variations possible, the variation in background knowledge, academic performance and affinity for the profession suggest good potential for variation in experiences. In addition, the very diverse range of projects within the course provides opportunities for variation in the experiences of individuals.

The six students were each interviewed individually following a semi-structured interview protocol. The interviews were transcribed and the transcripts were analysed by the two authors. The analysis process involved dealing with each whole transcript followed by categorising data across transcripts separating the data from individual transcripts.

Findings and Discussion

The data revealed four distinct categories of variation in the way that the students experienced the course activities building in both complexity and abstraction. These categories are named in the horizontal axis in the table below. The distinctive features between the categories are most clearly seen in the four structural themes shown vertically in table 1.
Table 1: Categories of description and structural themes

<table>
<thead>
<tr>
<th>Category Theme</th>
<th>A collection of activities</th>
<th>A range of specialisations</th>
<th>Multidisciplinary Problem Solving</th>
<th>Independent Problem Solving</th>
</tr>
</thead>
<tbody>
<tr>
<td>What counts as civil engineering knowledge</td>
<td>No engagement with what constitutes engineering knowledge</td>
<td>Literal interpretation. Activities constitute engineering knowledge.</td>
<td>Use of scientific understanding (disciplinary knowledge) to model physical things.</td>
<td>Engineering disciplinary knowledge is multidisciplinary.</td>
</tr>
<tr>
<td>Approaches to civil engineering problems</td>
<td>Dependence: Problem, solution and process defined by the lecturer, no role for decisions.</td>
<td>Dependent on specialisation, decisions are made external to engineers.</td>
<td>Compromise: No clear process for comparison and evaluation of choice.</td>
<td>Independence: Adapt generic approaches, and evaluate choices to justify decisions.</td>
</tr>
<tr>
<td>Role of People</td>
<td>Limited to engagement with people on the course, rather than external stakeholders.</td>
<td>Some specialisations are seen as more people intensive than others.</td>
<td>Scientific considerations are seen in conflict with people.</td>
<td>Civil engineers work in the service of societal needs.</td>
</tr>
<tr>
<td>Drawing on course activities to make sense of engineering practice</td>
<td>Disconnection between project activities and engineering practice.</td>
<td>A literal understanding of what engineers do. The activity fully represents practice.</td>
<td>Recognition of the scientific complexity behind apparently simple technologies.</td>
<td>Projects seen as simplifications of complex systems.</td>
</tr>
</tbody>
</table>

Collection of activities

A response typical of the first category is:

S1: I learned about how to treat water - checking and all that –

Interviewer: And what was it about that one that helped you understand what it is to be an engineer?

Um - I don’t know - I just enjoyed them.

However, there were also indications that certain projects lent themselves more to this category of experience:

S4: I thought it was a really pointless module, cos we didn’t understand, we had to use some formulas. I’m sure 90% of the people didn’t even understand what those formulas are for, or why we’re using them. Normally you have to understand before the process that goes into deriving the formulas but I didn’t understand what are those, cos when it came to my report, I just started chucking in numbers and submitted. Luckily I passed it.

Range of specialisations

By comparison, in the second category students begin to link the activities into a broader view of the engineering profession. They see multiple opportunities for specialisation in the future:

S2: ... it showed like where we can go with Civil Engineering, like I had no idea that there was so much water flow dynamics and so on, in Civil Engineering, I thought it was mostly structures, as a lot of people do assume, it’s mostly structures, and I had no idea water treatment was part of Civil
Engineering, it never occurred to me, and I think it was a really nice way of like showing all the different ways, things you can go into, and what you’ll be able to do when you’ve got your degree. It was enough to give you a very good idea of what each section of Civil Engineering is like.

There is a strong link with the application of scientific knowledge within these specialisations:

S6: it added quite a bit but what it added was on more on a specialist field - it gave me an appreciation of what goes into the little things in life that we take for granted and how much work and thinking engineers actually put into those.

There is a tendency to make a very literal translation between the course activities and the engineering profession, a sense that they are mimicking exactly what engineers do.

S5: like this water treatment thing it really was what civil engineers do. The transport thing also - it was just like giving us a glimpse of what we are to expect in future.... - to say OK I know how to do water treatment.

**Multidisciplinary problem solving**

The third category starts to pull the specialisations together, with recognition of the multidisciplinarity of many problems.

S2: it obviously needs to stand, and the, the structure needs to hold, that is the key, but it needs to, the impact it has is how people are going to see it and how people are going to interact with your structure, and that is going to be what reflects the success of your structure.

But a sense of how to balance conflicting requirements is missing. In fact satisfying the needs of people is often seen to compromise “good science”:

S6: that water is clean but - it is clean but it smells - they have to add some chemical to help it smell nice but as engineers they know that it is clean, it doesn't have to smell nice, it can look green but it is clean but because people have perceptions and expectations you have to now suddenly alter and undo your potential good work to satisfy people.

There is a danger here that students compromise their own science when they view the profession from this perspective, or it gives them a sense that they can avoid rigorous scientific reasoning in their solutions because it will be compromised anyway.

S6: I would say there is a focus on maths on that side but from what I saw the maths that we need is really too much in the sense that there maybe you will maybe have to integrate - you won't have things such as triple integrals - you'll just have to integrate maybe the volume of a certain room so that you get - you can install the correct air-conditioning or whatever it maybe not triple integrals.

**Independent problem solving**

In the final category the focus is also on problem solving, but the main distinction with the previous category lies in a more rational basis for dealing with conflicting requirements, possibly to look beyond the immediately apparent and find out more.

S3: I always thought engineering or maths or science - it is either right or it is wrong - this project - it was all about making compromises. What could possibly be best - there are always pros and cons to every decision you make with regards to upgrading informal settlements which method, which approach you take - some people are always going to lose out ... I guess that was good to know that it is not all black and white and sometimes you have to do research to find out what the best compromise
There is also a more abstract view of the link between the course activities and the engineering profession, an acknowledgement that this is not what engineers do, but rather a representation:

S3 I was also frustrated there were two experiments that we had to do. The one was with the tin can and the other one was with the water drum and that felt very simplified and crude but I learned from that and you go back to something simple to understand and you develop a model from that - you don't have to go and develop a model on a dam because you won't know where to start - it is just too big.

Implications for the course

In terms of meeting the first course objective, that of exposing students to a range of specialisations within civil engineering, the introduction of coherent projects certainly allowed for most students to recognise multiple fields in the profession. Even in the first category there was a sense of the different activities that they engaged in. For many this provided a sense that they have options for specialisation in the future. It was clear that some projects lent themselves more obviously to higher order conceptions of civil engineering than others, and illustrates the importance of the explicit location and background of the project context.

By articulating qualitatively different ways in which students conceive of engineering, we saw a clear distinction based on how students deal with conflicting requirements in problem solving. For some students the need to meet ‘soft’ or social requirements resulted in the potential to compromise science. We are left with a concern that in certain contexts, some students may avoid rigorous scientific reasoning in their solutions because they conceive of it as being compromised anyway.

Generic skills form an integral part of the course and students referred to activities they recognised encouraged development of skills such as teamwork, forms of communication, experimentation, thinking critically and time management. It was encouraging to see that students referred not only to teamwork, but also to interpersonal skills and mutual respect. In some cases skills were conceived as separate and concrete entities, whereas the intention of the course is that these skills become a part of a person as we develop. In a course where skills development is so central to the course objectives, and where they play a foreground role in the teaching and learning activities, more attention needs to be given to how they become embodied.

Phenomenography as a tool for evaluating a course

We found the strength of the phenomenographic analysis to lie in the rigour required to identify qualitatively different descriptions between categories of variation. In addition, the methodology forces recognition of the contextual and temporal nature of individual experiences, allowing for variation in each individual’s experience. This provided useful insight into strengths and weaknesses in different projects, often in terms of how explicitly the projects relate to students’ conceptions of engineering. On the other hand, separating the data from the rich narrative of individual students led to a loss of the affective layer of data. It was interesting to see how their affinity for their conceptions of engineering practice and their own success in the other science courses frame their experience of this course. We found it difficult to capture this layer using phenomenography.
Alienation and Affinity to an Engineering Identity

Polkinghorne\textsuperscript{10} suggests that analysis of interview data can take two fundamentally different forms: paradigmatic and narrative analysis. Our phenomenographic analysis is of the first form. The stories told by the participants are developed into qualitatively different categories. Therefore in order to capture the strong affective layer we took a narrative analytic approach. A narrative analysis results in the construction of a story that links the data into a coherent whole.

In two of the participants’ interviews there was a strong sense of alienation from engineering and yet this did not align clearly with the phenomenographic categories that otherwise emerged. If we look into the data provided by these two students we can construct individual narratives for them.

In the case of the first student, she came into engineering with little or no idea of the profession:

\begin{quote}
Some people have done research from high school or some people know other people who are engineers and they talk to them - ja I think before you come to university maybe students should do research in what they want to do. Try to ask around, what it is about and I think that is where the passion comes from. Getting to know what you are going to, having an expectation of some kind ... I didn't expect anything at all.
\end{quote}

Her sense of alienation began early in the course, when she visited a construction site:

\begin{quote}
The women - I didn’t feel like I could be respected in that environment.
\end{quote}

Much of the data for the first phenomenographic category came from this student. She was often out of her depth and simply trying to do what was instructed:

\begin{quote}
I didn't know what we were doing - we were counting cars and we had to do a report and pause - ja I didn't know what was happening. I had to count cars that were passing - that's it
\end{quote}

When asked about calling herself an engineer she said:

\begin{quote}
Never. I would tell myself, try to convince myself that I am an engineer but I was never confident enough to tell someone I am an engineer. Even when people asked me what I was doing I would say something different.
\end{quote}

This is a story of someone coming into engineering with little idea of what she is getting into, struggling with the academic requirements of the course, and becoming more and more alienated from it. She has since registered in a journalism program and the following quote expresses the strong contrast with her engineering experience:

\begin{quote}
I think if that is your profession from the start - cause I now am telling my friends I'm a journalist, I’m relating to what I am doing. I never thought of myself, I never called myself an engineer last year. So I think from this side if that is your profession if that's what you really want to do. If you know enough of what engineers do, and what you are doing then you can start from the beginning to call yourself an engineer.
\end{quote}

The second student had anticipated studying medicine but had not been accepted and had chosen engineering under pressure from her family. Her alienation came from her fear of Mathematics and Physics and commitment to an alternative career:
At first it was really difficult because I had to change my whole mind set from seeing myself from becoming a doctor to possibly becoming an engineer. And then I've always been intimidated by maths and physics and now had to start a degree that based so much on it so it was really scary.

Despite this personal alienation, the experience of the course had the consequence of a clear idea of what becoming a civil engineer constituted. These notions corresponded with a broader range of categories including higher order categories developed from the phenomenographic analysis:

...becoming more comfortable with what civil engineers do ... These projects and the other stuff we did exposed us to that - you have to analyse situations... All of it was important stuff ...all of those little things that we did every time would eventually build a proper civil engineer...

However, she is quite sure that she does not want to be an engineer, even when she does well in modules

it is just that you have to have a passion for it - you have to enjoy wearing that hard hat and those boots and being there with all the dust.

When we focus on throughput in a course we make the assumption that everyone who starts a course must necessarily finish it. We do not make allowance for those for whom the course serves as a filter to determine if this is an appropriate career choice for them or not.

By contrast, those students who were clear on what engineering was and why they were doing it; were strong in Mathematics and Physics; and expressed excitement about engineering, showed a clear affinity for the profession. These students did not however always align with higher order experiences of what it means to be an engineer.

It has become clear when considering the narratives of students, that affective experiences of alienation and affinity did not preclude experiences in any of the categories developed in the phenomenographic analysis. And conversely, an affinity for the profession did not necessarily illicit higher order conceptions and experiences of becoming an engineer. When considering notions of “becoming”, there are both cognate and emotional aspects which did not necessarily align with each other.

Conclusions

Our phenomenographic analysis described four hierarchically related, qualitatively different categories describing how students conceive of civil engineering through their engagement with the projects on the course. In the simplest category students don’t engage with becoming an engineer at all. They tend to see the course activities as prescribed by the lecturer, unrelated to a more abstract understanding of identity formation. In the second category there is a relationship between activities and engineering practice, but it represents a literal translation into engineering practice, as though they are doing exactly what engineers do. In the third category students begin to abstract the activities as representations of engineering practice, but what distinguishes this category from the most complex category is the notion that engineering science is compromised by the multi-disciplinarily nature of engineering practice. In the most complex category students extrapolate the activities as representations of aspects of engineering practice; and they see conflicting requirements for problem solving as a challenging form of optimisation rather than merely compromise.

These findings raise two concerns, the first relates to students experiencing the course (or aspects of the course) as activities prescribed by the lecturer with no link to the profession.
Two of the course projects were more susceptible to this experience and need refinement in terms of making links to the profession more explicit. The other relates to the third category, in which students tend to compromise science in an unreasoned way to accommodate conflicting requirement, especially the ‘soft’ requirements. We believe that this is a problem inherent in any integrative, ill-defined problem based learning and that it needs more scholarly consideration. This research project has merely highlighted the problem explicitly. On the other hand, it was encouraging to hear the extent to which the students were engaging meaningfully with many of the specific academic and professional skills developed through the course. There was clearly a developing understanding of what it means to be an engineer.

These phenomenographic findings are supported by a qualitative analysis of the stories of becoming or not becoming an engineer which add an affective layer to the phenomenographic categories that emerged. These reveal that alienation from the professional identity does not necessarily exclude meaningful learning; students alienated from engineering were able to express what it was about being an engineer that they disliked. In addition, success or affirmation in other subjects tends to reinforce students’ sense of access to the profession, even when they experience fairly unsophisticated conceptions of engineering.

In combination, these findings challenged assumptions we were making regarding the student experience of the course and provide a rich evaluative element of the course for the purpose of informing the design and delivery thereof.

References