AN ANALYSIS OF ENGINEERING EDUCATORS' UNDERSTANDING OF COMPLEMENTARY STUDIES COURSES USING THE REPERTORY GRID TECHNIQUE

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ABSTRACT

Accreditation bodies such as the Engineering Council of South Africa and the Canadian Engineering Accreditation Board have a group of courses that fall under the umbrella of Complementary Studies. This term is used to describe a set of engineering courses that include knowledge areas other than the more common mathematical sciences, natural sciences, engineering sciences, design and synthesis, and work-integrated learning. Studies have shown that engineering educators sometimes view these courses negatively. They are seen as distracting the focus of the students on the so-called technical courses, which the educators feel are more important. This paper reports on a research study that explored the way that engineering educators make sense of complementary studies courses within an industrial engineering curriculum. The repertory grid technique was used to explore complementary studies courses when compared to other engineering courses within the same curriculum. The relationships between elements and constructs in the grids were analysed using the repertory grid techniques of principal component analysis and cluster analysis. What became clear was that while most of the educators interviewed did recognise complementary studies courses as different to courses considered as core or technical, what made them different was very unclear. Each educator had a very different conception of what defines, differentiates or constitutes a complementary studies course. This range of variation may go some way to explaining why complementary courses seem out of place in engineering programs by educators and students alike.

1 INTRODUCTION

The undergraduate engineering curriculum includes courses which span a range of knowledge areas including mathematical sciences, natural sciences, engineering sciences, design and synthesis, and work-integrated learning. There are also courses which accreditation bodies such as the Engineering Council of South Africa (ECSA) refer to as complementary studies. This is a term used to describe courses that include knowledge areas other than the aforementioned, that complement the practice of engineering (ECSA, 2016). Complementary courses are intended to create, amongst other benefits, well-rounded, socially conscious engineers who are able to work in multi-disciplinary environments (Donald et al., 2017). As with many other universities around the world, universities in South Africa are required to incorporate these courses into their engineering curriculum.

As suggested in the literature (see for example (Donald et al., 2015) and (Dubreta, 2014)), many engineering students appear to face difficulties when engaging with complementary studies courses in the engineering curriculum. They are often perceived as unimportant and an unnecessary hurdle to overcome by both educators and students. Educators often view these courses as distracting from the focus of the students on the technical courses which they feel are more important (Arms, 1993). Navarro et al. (2016) do however argue that if educators are given enough guidance, it should be possible to successfully deliver engineering curricula which include complementary studies courses. This suggests a certain amount of uncertainty around complementary subjects.

The purpose of this study is therefore to explore the way that engineering educators perceive (construe) complementary subjects and their role in the curriculum. Engineering educators in an industrial engineering curriculum that includes complementary studies courses were interviewed to determine their perceptions of these courses. The interviews were conducted using the repertory grid technique, a structured interview protocol associated with Personal Construct Theory (PCT).

2 METHODOLOGY

2.1 The Repertory Grid Technique

The repertory grid technique is a widely applied tool which is associated with Personal Construct Theory (Fransella, 2003). According to this theory, people make sense of the social world around them by creating and recreating implicit theoretical frameworks which become their personal construct system (Fransella, Bell and Bannister, 2004). Any concept encountered is contrasted with concepts within their existing construct system. Each construct has two poles that represent the range that the person uses for ‘sensemaking’ of a particular concept. For example, one of the constructs evident from a participant in the current study was a range from ‘real-world’ oriented courses on one pole, to ‘classroom oriented’ courses on the other. Any course would then be located on the continuum between these poles.

The purpose of the repertory grid technique is to elicit constructs from participants through a structured interview process. The first stage of the interview is to derive a set of elements with which to elicit a participant's constructs. In this present study, the elements were different courses in the curriculum which the participant was familiar with. For example, a course such as Engineering Mathematics could be one element, while Operations Research and Labour Law would be other elements. From a set of elements, a participant would be asked to compare and contrast three elements (a triad) in order to elicit constructs. Participants are asked to group the triad into a set of two that are different in some way to the third. The interviewer then probes the reasons for the distinction the participant is making. A participant's bipolar constructs are elicited from this process.

2.2 The Interview Process

Six engineering educators (referred to as Participant 1, Participant 2 etc.), were identified from the same industrial engineering program as a pilot study for a larger PhD study. Considering that this was a qualitative study, this number of participants proved sufficient in generating rich data for analysis. The repertory grid technique was new to all the participants who expressed both fascination with the unique way of collecting data, and a general appreciation for the benefit of such a study of complementary studies. All six of the educators had knowledge of both complementary and non-complementary studies courses with three of them having recent experience of teaching complementary studies courses in the curriculum.

The interview began with agreeing on the set of seven elements, in this case seven industrial engineering courses, to be used in the discussion. The courses had to cover both complementary and non-complementary studies in order to ensure that a comparison is made between the two types of courses. The interviewer provided a list based on the courses currently offered by the institution in the Diploma in Industrial Engineering programme. From this list, each participant had to pick seven elements based on seven different eliciting questions asked by the interviewer. These questions were asked so that there were at least two complementary and two non-complementary courses in the chosen list which would allow for a comparison to be made.

Once the participants and the interviewer had agreed on the seven elements to be used, different constructs were elicited by using a triad of three elements at a time. For each of these triads, the participants had to state which two were the same in some way and different from the third. Through a laddering process, they then had to state what exactly the two had in common, as opposed to the third. The thing that the two elements had in common was written on the left side of a grid sheet and the reason the third element is different, on the right of the grid sheet. This created a bipolar expression in the form of words or phrases which express a contrast and thereby the person's construct. These three elements then had to be rated by the respondent based on a 5-point scale with each rating being recorded on the same grid. The remaining elements were then also rated based on the same construct. This process was repeated several times with different triads until a set of constructs and ratings were elicited and recorded on the repertory grid. The result was six repertory grids, consisting of elements and constructs with ratings from six interviews.

3 RESULTS

Three kinds of analyses were conducted and are discussed below. Firstly, by thinking back to the interview itself and the participants' responses to particular questions, a process analysis was done. This was then followed by conducting a cluster analysis, which involves highlighting the relationships amongst constructs and elements in a grid so that they become visible at a glance. Finally, a principal components analysis was conducted with the same purpose of highlighting relationships amongst elements and constructs. In the pilot study, the analyses were conducted on six participants. In this paper, the results of two of them, i.e. Participant 1 and Participant 6, are illustrated as examples that show the greatest variety of the responses received.

3.1 Process Analysis

The process of agreeing on the set of seven elements to work with provided some early indications of the perceptions that the participants had towards certain courses. Questions such as, *"Name one course which, if given the opportunity, you would like to teach."* were posed with the aim of eliciting the elements which the participant viewed in a positive light. In all six instances, no complementary studies courses were chosen by the participants as a course that they would like to teach. A question was also posed to each participant with the aim of including a course which the participants felt was the least relevant to the curriculum. The question in this regard was, *"Name one course that surprised you with its presence in the curriculum."* There was only one out of the six instances, where the course that was chosen was from the complementary studies group. The rest of the courses were from the non-complementary group with the second year Engineering Mathematics course surprisingly being chosen more than once.

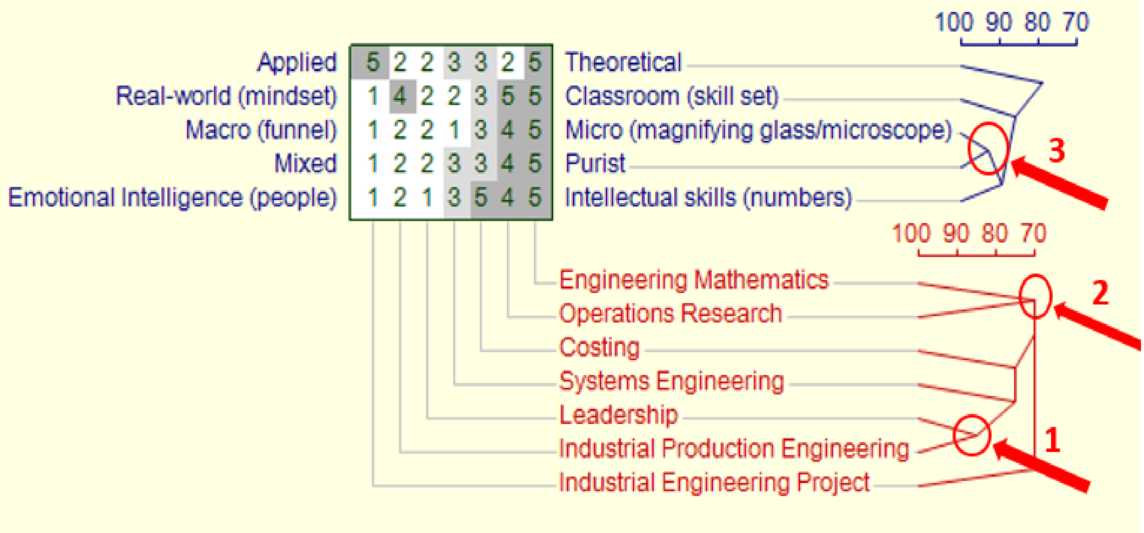
The process of eliciting constructs from the participants revealed just how varied their initial perceptions were of complementary studies courses when comparing them to the other engineering courses. In most instances, it was necessary for the interviewer to employ the technique of laddering down in order to get to the actual construct and not the initial answer that was provided by the participant. Despite the diversity of constructs, there seemed to be an understanding by the educators that complementary studies courses are necessary in the curriculum even if they might look different and not be the ideal course they would like to teach.

3.2 Cluster Analysis

Cluster analysis is a technique for highlighting the relationships in a grid so that they become visible at a glance. The elements and constructs within the grid are organised so that those with the most similar ratings lie side by side. The extent to which the ratings are similar is indicated by percentage similarity scores with the higher percentages indicating more similarities between the elements or constructs. This is useful for the present study as it can help us to determine the extent to which complementary studies courses are similar to the other courses based on the construals of the participants. Figure 1 and Figure 2 show the cluster analysis output for Participant 1 and Participant 6 respectively with the percentage similarity scores for adjacent elements and adjacent constructs provided. The RepPlus grid analysis software (Gaines and Shaw, 2021) was used to generate this output.

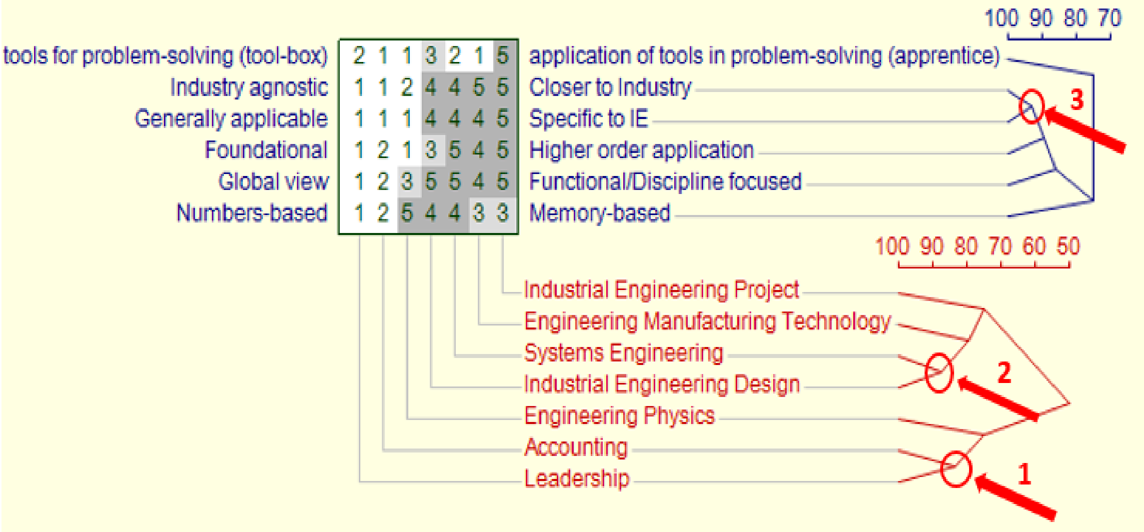
Participant 1 construes the Leadership (complementary) and Industrial Production Engineering (non-complementary) courses as the same with a similarity score of approximately 85% (arrow 1 in Figure 1). Engineering Mathematics and Operations Research, which are both not complementary, have a weaker relationship of approximately 70% (arrow 2). There is one distinct branch which stands out with regards to Participant 1's constructs. This branch comprises the constructs of 'Macro (funnel) vs Micro' and 'Mixed vs Purist' which have a similarity score of over 92% (arrow 3) according to the educator's construal.

On the other hand, Participant 6's highest similarity score is on two non-complementary courses, with Systems Engineering and Industrial Engineering Design being construed to be the same with a similarity score of approximately 87% (red arrow 1 in Figure 2). The complementary courses of Accounting and Leadership are also construed the same with a score of approximately 83% (red arrow 2). With regards to Participant 6's constructs, there is one distinct branch which stands out (red arrow 3 in the diagram). This branch comprises the constructs of 'Industry agnostic vs Closer to industry' and 'Generally applicable vs Specific to IE (Industrial Engineering)' which have a similarity score of over 92% according to the educator.



Applied	5	2	2	3	3	2	5	Theoretical
Real-world (mindset)	1	4	2	2	3	5	5	Classroom (skill set)
Macro (funnel)	1	2	2	1	3	4	5	Micro (magnifying glass/microscope)
Mixed	1	2	2	3	3	4	5	Purist
Emotional Intelligence (people)	1	2	1	3	5	4	5	Intellectual skills (numbers)

Figure 1: Cluster Analysis Output for Participant 1



tools for problem-solving (tool-box)	2	1	1	3	2	1	5	application of tools in problem-solving (apprentice)
Industry agnostic	1	1	2	4	4	5	5	Closer to Industry
Generally applicable	1	1	1	4	4	4	5	Specific to IE
Foundational	1	2	1	3	5	4	5	Higher order application
Global view	1	2	3	5	5	4	5	Functional/Discipline focused
Numbers-based	1	2	5	4	4	3	3	Memory-based

Figure 2: Cluster Analysis Output for Participant 6

3.3 Principal Components Analysis

Principal components analysis identifies distinct patterns of variability from the ratings supplied by the participant. Through an iterative process which is best performed using grid analysis software, the patterns of variability are grouped into components. The two components with the largest amount of variability, that is the principal components, are selected and plotted on the horizontal and vertical axis of a graph with the percentage amount of variability shown (see Figures 3 and 4 where the percentage variability is shown in green). The constructs are plotted as straight lines and the elements are positioned along each principal component. The angle between any two construct lines reflects the extent to which the ratings of elements on those constructs are viewed as the same by the participant, with a smaller angle showing greater similarity compared to a larger angle (Jankowicz, 2005). Similarly, the elements are positioned along each principal component and the distance between any two elements reflects the ratings each element received on all the constructs.

Figure 3 shows the results for Participant 1. Four of the five constructs lie close to the horizontal principal component axis. This means that, according to the educator, these constructs have strong similarities which are distinctly different from the single construct which lies closer to the vertical principal component axis. For example, the ‘Mixed vs Purist’ construct is seen in the same light as the ‘Emotional Intelligence (people) vs Intellectual skills (numbers)’ construct. With regards to the elements on the graph, courses such as Leadership (complementary) and Industrial Production Engineering (non-complementary) are construed the same and are distinctly different from a course such as Engineering Mathematics which is not complementary.

The constructs in Participant 6’s principal components analysis graph are not as clearly differentiated as they spread evenly all round the plot as shown in Figure 4. There are, however, two groupings of constructs that seem to emerge. The first grouping, which lies closer to the vertical principal component axis, consists of the ‘Memory-based vs Numbers-based’ and ‘tools for problem- solving vs application of tools in problem-solving’ constructs. The rest of the constructs fall into the second grouping which is closer to the horizontal principal component axis. With regards to the elements on the graph, the complementary courses of Leadership and Accounting are construed the same and are distinctly different from a non-complementary course such as Systems Engineering.

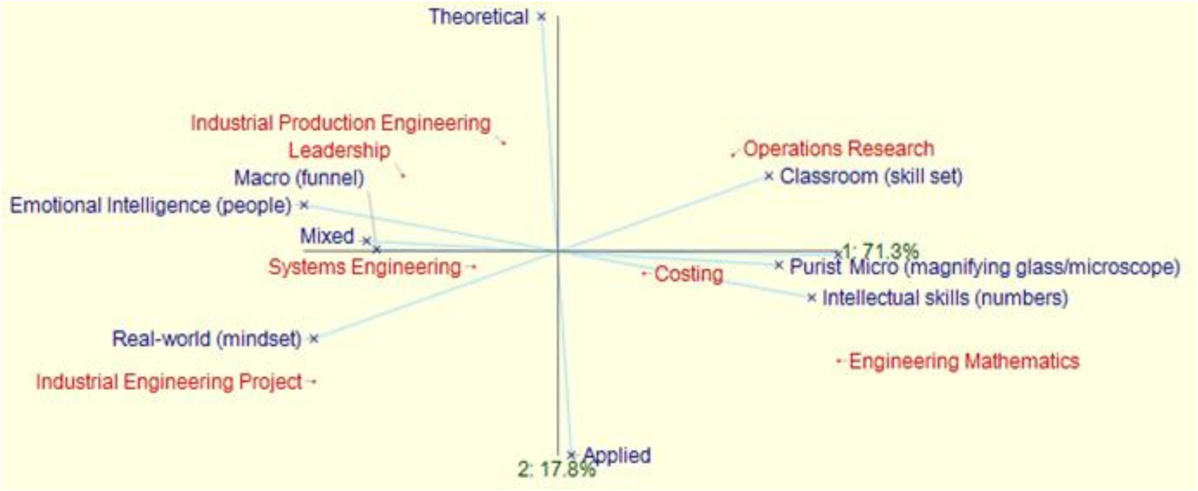


Figure 3: Principal Components Analysis Output for Participant 1

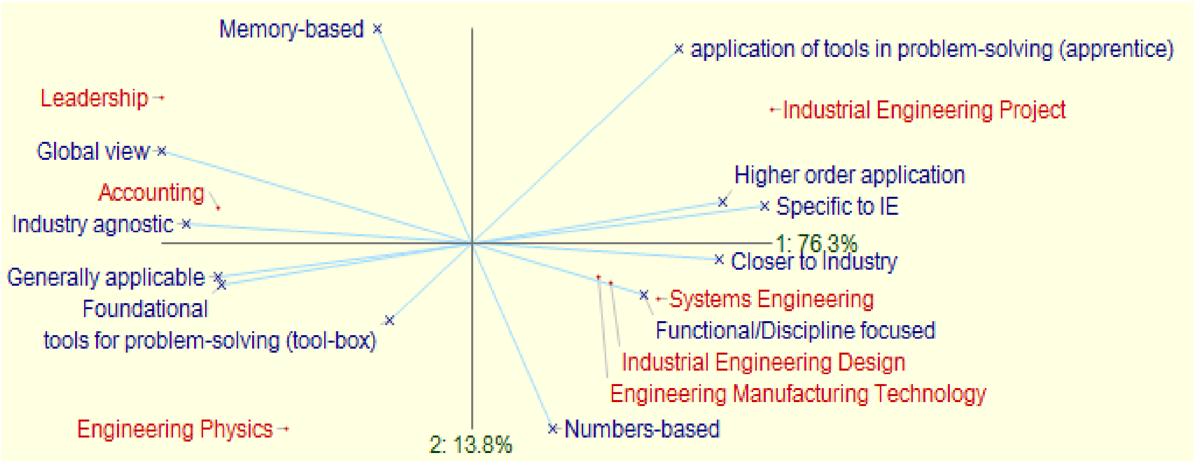


Figure 4: Principal Components Analysis Output for Participant 1

4 DISCUSSION

If, as assumed, complementary courses are different to ‘core’ engineering subjects, one would expect to see them clearly separated from other types of courses when analysed using the repertory grid technique. This is not the case in our present study. For example, Participant 1’s construal of the Leadership (complementary) and Industrial Production Engineering (non-complementary) courses as being similar is very interesting. This is firstly shown by the Cluster Analysis in Figure 1 where the two courses form a distinct branch based on the educator’s ratings. The principal components analysis in Figure 3 then confirms this by showing that the educator was inclined to see both courses as leaning towards the people-focused/real-world constructs. A course such as Costing (complementary) is seen as being less similar to Leadership even though they are both considered to be complementary. This could be due to the fact that Costing involves a lot more numbers and calculations when compared to a course like Production Engineering. This indicates how unclear the distinction between complementary and non-complementary courses can be.

On the other hand, Participant 6's construal of the Accounting and Leadership courses as similar is not as surprising. This is in agreement with the generally accepted classification of these courses as complementary in the curriculum. The educator was inclined to see these courses as being further removed from industry when compared to a course like Engineering Manufacturing Technology, as shown by the principal components analysis in Figure 4. The meaning of 'industry' for the educator was within the context of a manufacturing or factory set-up where most industrial engineering graduates end up working. This closeness to industry is generally seen as an attractive feature of any course as this implies that the graduate can directly use what they learn in the workplace. Another interesting construct that was elicited from the educator was the 'Generally applicable vs Specific to IE ' construct. As can be seen in Figure 4, the educator does not see the complementary studies courses as being specific to industrial engineering (IE) which could make them less attractive as well.

5 CONCLUSION

The aim of this study was to understand how engineering educators understand, or construe, complementary studies courses which have been found to be problematic in the curriculum. This was done by analysing repertory grids that were obtained through interviewing engineering educators from an industrial engineering programme. The most significant finding is just how varied the understanding of complementary subjects is, with the participants having different constructs and ratings that are associated with them. There was general consensus that complementary studies are different from the other engineering courses although there were some unique cases where educators construed them to be the same. It was also interesting to see how when asked to pick a course they would like to teach, none of the educators picked a complementary studies course.

This study does not yet get to the root-cause of why complementary studies courses are found to be problematic by some educators, and students alike. It does however provide a good starting point by first exploring how educators understand, or construe, these courses. In order to get to the root-cause, it might be necessary to go back to the participants with the results of the analysis and confirm if the conclusions are indeed a true reflection of their perceptions. It would also be valuable to carry out a similar study with a group of educators in other engineering disciplines where complementary studies are not as integrated into the curriculum as is the case with industrial engineering.

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