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## The origins of student misunderstanding of undergraduate electrical machine theory

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# **THE ORIGINS OF STUDENT MISUNDERSTANDING OF UNDERGRADUATE ELECTRICAL MACHINE THEORY**

by

**David Neil Kockelbergh**

**Doctoral Thesis submitted in partial fulfilment of  
the requirements of the degree of  
Doctor of Philosophy  
of Loughborough University**

**August 2014**

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**School of Electronic, Electrical and Systems Engineering**

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# **The origins of student misunderstanding of undergraduate electrical machine theory**

## **Abstract**

This thesis is concerned with student understanding of key concepts in electrical engineering teaching within higher education. Anecdotal evidence suggests that many students struggle to understand threshold concepts and therefore encounter difficulties in learning theoretical models which are underpinned by such theoretical concepts. This research utilised a mixed methods approach to investigate the factors that influence student understanding of key theoretical concepts within electrical engineering. The initial study used a questionnaire to evaluate student understanding of concepts which were identified by teaching staff as being core to a particular module. The study identified that students commenced the module with poor understanding and that instruction on the module ELC040 – Electrical Machines and Systems did not lead to improved understanding of core concepts. This suggests that the roots of student misunderstanding lay elsewhere.

Desk research was subsequently employed to explore the sources of student misunderstandings. Performance data was analysed and demonstrated that the roots of the student misunderstanding of Electrical Machine Theory lay in the pre-requisite module Electrical Power B. Students routinely failed to achieve high levels of understanding in this module and as a result were unable to successfully build upon it in the third year module.

Semi-structured interviews were then undertaken with Part C students who were undertaking the Electrical Machines and Systems module. In addition, structured interviews were administered with the Part B students. The interviews aimed to establish the study practices adopted by students across both years. The study showed that students found the ELA001 module difficult, and the majority believe that most other students felt the same way as they did. Students provided evidence of poor study techniques, by reporting last minute sessions to complete coursework and last minute revision for exams.

This research informed the development of an interactive learning tool which was piloted on a small cohort of students. The research has also established that there are many influences on the development of student understanding of threshold concepts within electrical engineering and argues for a more active style of teaching in order to address student misunderstanding.

## Acknowledgements

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The technical and administrative support staff within the Department are owed a huge debt, which can never be repaid, for putting up with me over the many years of my studies at the university and for allowing me leeway in so many areas.

Thanks must be extended to my mentor and supervisor Dr Keith Gregory, without whom this entire adventure would have been impossible. It is thanks to his dogged refusal to give up on me that I am in the position I am today, and without his support, motivation, guidance and friendship my academic career would have long since perished.

Further thanks must go to Dr Hilary McDermott who, being a trained psychologist, finally gave me the help I needed and without whom the required corrections to this thesis would have remained consigned to the “important” tray while my head remained buried firmly in the sand.

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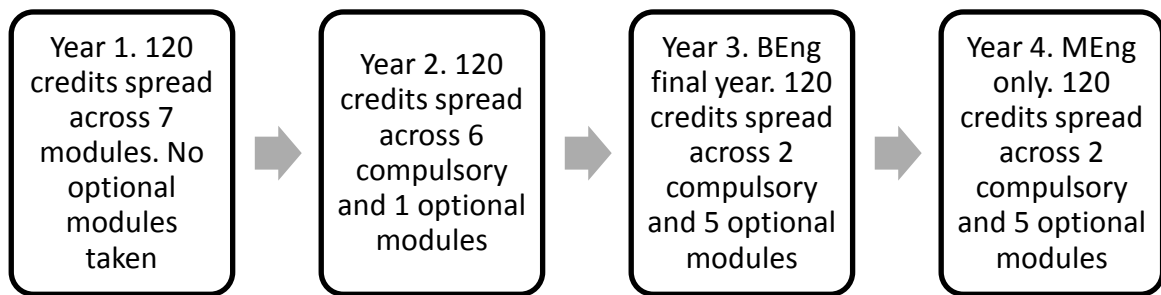
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# **1 Introduction**

## **1.1 The problem**

Electrical engineering traditionally is a field of engineering concerned with the use of electricity including electromagnetism and the use and application of electronics and electronic systems. This however is rapidly changing, and many who study in this field have begun to argue for a distinction between electrical engineering (essentially the generation and transmission of electrical power) and electronics (the use of electricity, usually for processing information). Evidence of this distinction is apparent in the names of various professional institutions on both a global and national scale, for example, the Institute of Electrical and Electronic Engineers. In addition, such a distinction is also applied within many academic institutions with the academic department responsible for studies in this field at Loughborough University in the UK being called the School of Electronic, Electrical and Systems Engineering. Any reference to electrical engineering in this thesis should be read with that distinction in mind.

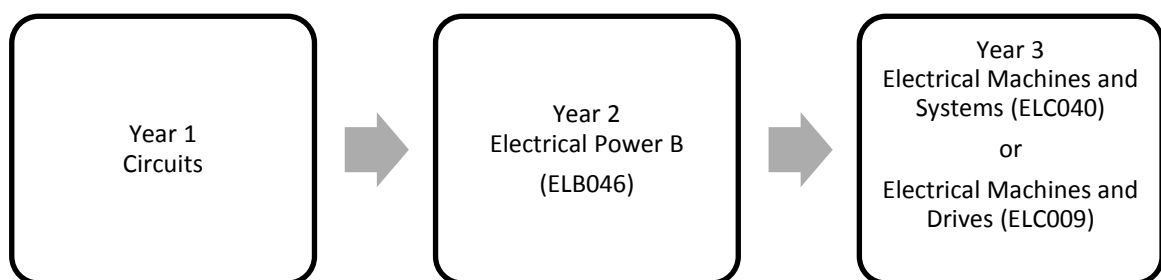
The School of Electronic, Electrical and Systems Engineering accommodates some 600 full time undergraduate students on three courses that can be studied as either an MEng (4 years or 5 with placement) or BEng (3 years or 4 with placement). These courses are Electronic and Electrical Engineering (EEE), Electronics and Computer Science (ECS) and Systems Engineering (SE). The courses have a modular structure, with many of the modules shared by the different courses. Each year of the course consists of a number of compulsory modules, which, especially in later years, are supplemented by optional modules, chosen by the student to tailor the course to their own interests and career aims. A breakdown of academic progression is shown in Figure 1.1.



**Figure 1.1 - Modular course structure**

This thesis focusses on student understanding of key concepts within electrical engineering, in particular the theory of electrical power and electrical machine theory. Both are fundamentally important fields of electrical engineering which provide a foundation for understanding everything from the most elementary circuits involving a battery and a light bulb through to large scale power generation and distribution grids.

Both theories are taught primarily through the modules available on the undergraduate EEE courses. The same modules may also be taken as options on the other courses offered (ECS and SE) by the School. This thesis concentrates on two modules which are taught in the second and third years, namely Electrical Power B and Electrical Machines and Systems respectively.



**Figure 1.2 - Progression of Electrical Power theory**

All taught modules are assessed by coursework, examination or a combination of the two. The module mark is a weighted average of the coursework and examination marks and a student's year mark is a weighted average of the included module marks. A

student's degree mark is the weighted average of the final two or three year marks, depending upon whether he or she is enrolled on a BEng or MEng programme. A copy of the module specifications can be found in Appendix A.

Students enrolled on the Electrical Machines and Systems module (ELC040) in the School of Electronic and Electrical Engineering are assessed through a combination of methods incorporating examination and coursework. Academic records indicate a high pass rate with most students attaining the required pass mark of 40% or more.

However, anecdotal evidence suggests that whilst students can demonstrate sufficient knowledge to attain a pass during assessment, during formative sessions (including informal discussions) they routinely fail to demonstrate a high level of understanding of the core concepts contained within the module.

Understanding is difficult to assess [1, p. 463] [2]; it requires questioning the students about subjective matters and furthermore requires any examiner to invest considerable time to interpret the student responses, decide which data are being referenced (possibly indirectly), and whether or not they are being referenced correctly. Assessment questions asking for definitions of terms are suited to assessing knowledge, whereas questions asking for explanations of phenomena, for example, or for conjecture/hypothesising are particularly suited to assessing understanding.

Misunderstanding is equally troublesome [3] for similar reasons. Knowledge however is considerably easier to assess as it can be measured objectively and the examiner need spend no more time on the answer than to ascertain whether it is correct or not. Under such circumstances quantitative questions are the most appropriate.

Assessment methods designed to test knowledge can be modified to assess understanding as well by inserting a question in one of two alternative styles into the examination. Such a question may ask the student to explain a phenomenon that had not been explicitly covered during the course of instruction, or ask students to perform calculations and apply knowledge to questions in a format with which they are unaccustomed. Both of these styles of questioning should be answerable by a student who fully understands the material i.e. a student who was able to apply the knowledge.



A student who has failed to reach a sufficient level of understanding would be unable to answer that question correctly.

When a student is asked to apply knowledge to a novel scenario (as could be used to assess understanding) it is evident that in some cases students will give a response which appears to be to an entirely different question. This is possibly an indication of failure to properly read the question, instead searching the question for key pieces of information which will fit into their existing solution schema. These students would be attempting to answer the novel question using the commonly employed methods of rote learning and habituation, with which they are able to answer other questions on the same paper, sufficient to earn a passing grade on the assessment. This demonstrates how assessment results can fail to identify a lack of understanding.

## **1.2 The Scope of the Thesis**

Electrical machine theory is of fundamental importance, particularly in the field of power generation and distribution. With the surge in micro generation, generated in part by government incentives such as feed-in tariffs this significance is continuing. However, anecdotal evidence suggests that students of electrical engineering struggle to fully understand the key theoretical concepts underpinning electrical machine theory. Without a full and comprehensive grasp of these concepts students will be unable to apply theoretical knowledge to areas of electrical machine theory.

This thesis is concerned with the factors that can influence student study practices and ultimately their understanding of key theoretical concepts. The changing landscape of tertiary education within the UK dictates that this is a fundamentally important field to address. With the advent of high fees students have become consumers and as such educators have become service providers. Educational policies must therefore take account of student study practices and learning needs.

## **1.3 Research Aims**

This research aimed to extend existing knowledge relating to student understanding of fundamental threshold concepts within electrical engineering. The specific objectives of this research were to:

- Establish common factors underpinning students' inability to grasp the concepts of Electrical Machine Theory
- Identify students' learning strategies whilst undertaking the Machines and Systems module and how these learning strategies have developed over time
- Establish temporal trends in attainment levels of students undertaking the assessment components of a pre-requisite module "Electrical Power B"
- Develop a teaching and learning tool to support students' understanding of Electrical Machine Theory specifically related to synchronous machines

## **1.4 Development of Research**

Work presented in this thesis is in three themes which were iterative in nature. The first theme reflects the literature based research into cognitive development, teaching and learning styles and approaches to learning. The second theme reflects the quantitative analysis of data presented by previous cohorts from the pre-requisite module. The third theme reports the qualitative analysis of data gathered from students in the second and third year. Each theme informed the development of subsequent work generating questions to be answered, and ultimately influenced the development of the teaching and learning tool and the way in which it was used.

## **1.5 Thesis Structure**

This thesis is presented over 9 chapters. Following this introduction and the methodology of the studies the further chapters are structured as follows:

Chapters 3 and 4 review the published literature relevant to the aims and objectives of this thesis. Chapter 3 outlines an underlying model of memory and offers a critical reflection on the limitations of human cognitive function. It also presents a review of cognitive development. Chapter 4 presents the literature on teaching and learning which informs our current understanding of pedagogical approaches to learning and teaching within STEM areas. It offers detailed consideration of threshold concepts and cognitive development. In addition the wider education literature is critically reviewed.

Chapter 5 presents the findings from a questionnaire study which was undertaken with third year engineering students.

Chapter 6 offers the quantitative findings from desk research which was undertaken to analyse student performance data to give a historical picture of student attainment.

Chapter 7 presents the findings from semi-structured and structured interviews which were undertaken with students enrolled on the modules Electrical Power B and Electrical Machines and Systems.

Chapter 8 outlines the software developed as a result of this work and presents an evaluation of the same.

Chapter 9 presents a synthesis of results and offers a reflective discussion in relation to the application of these findings for teaching of Electrical Engineering. This chapter also details the conclusions drawn as a result of this programme of work. Suggestions for future research are presented together with a critical discussion on the contribution made to knowledge by this work.

## **2 Methodology**

### **2.1 Introduction**

This chapter explains the framework employed for the research presented in this thesis, and justifies the research methods employed at each stage. The philosophical position of the thesis is discussed, providing a basis for the

### **2.2 Research design**

Pedagogy is the study of teaching, learning, assessment of learning and courses in different contexts and cultures [4]. It is important as it results in higher calibre graduates to enter the workplace and research communities [4].

Electrical engineering is dominated by a positivist paradigm whereby knowledge is derived from empirical evidence. This thesis however combines the positivist attitudes inherent in that field with the interpretivist paradigm of the social sciences. A mixed methods approach was utilised whereby qualitative methods and quantitative methods were combined to achieve the universal research aim. Such an approach is not without its critics as some researchers believe that it is inappropriate to combine qualitative and quantitative methodologies. However a mixed methods approach within a single research agenda has inherent strengths as the weaknesses of any single method are outweighed by the strengths of the other methods.

Quantitative methods allow the data to be analysed from a single specific viewpoint, to indicate the presence (or absence) of a particular phenomenon. This thesis utilises quantitative data analysis to identify student understanding and to identify trends within student performance. Such an approach was appropriate for the following reasons. Firstly, quantitative studies provide descriptive data and can facilitate a snapshot of a user population: in this case a student cohort [5]. Interpretation of such data can identify trends and monitor performance. Such measures were important for this thesis to identify gaps in student understanding and support the research question.

Qualitative research is a method of inquiry used in many academic disciplines [6]. It uses methods to answer the whys and hows of human behaviour, opinion, and experience [7]. These methods were used to explore in more detail the phenomena

identified by the quantitative research and identify experiences and perceptions of it in order generate understanding so that recommendations can be made.

Mixing these two approaches, despite the controversies about doing so [8], is a valid approach, as the two types of data collection and analysis can be combined to complement each other [9] [10]. It allows the strengths of each method to compensate for the weaknesses of the other. It allows for a more thorough investigation of a particular phenomenon [11].

The research used a flexible approach, with each stage influencing the data collected in the following, to allow a fluid and natural progression.

### **2.3 Techniques of Data Collection**

The research aims of this thesis are twofold, on the one hand to demonstrate that student understanding of electrical machine theory is weak, and that performance on electrical power modules is down relative to other modules taught at the same time and on the other hand to identify the causes of it. The first of these aims can be answered using quantitative research methods in order to quantify student understanding and performance. The second aim is addressed using qualitative research methods to explore the factors underpinning student understanding or misunderstanding. The combination of methods in this manner is known as an exploratory design of mixed methods [12, p. 185].

Quantitative data was obtained from self-completed closed-response questionnaires, the responses from which were statistically compared. This gives an indicator of student understanding, and is an appropriate technique as it allows the recovery of large amounts of data from large groups of participants in a short time period. The drawbacks of using self-completed questionnaires, especially when administered to a group en masse include response bias [13](the tendency of a respondent to give the response they *feel* they should give rather than the one they *actually* should give). The potential for response bias in these studies was addressed by making the questionnaires anonymous [14] and the possibility that the questions are interpreted in different ways [13]. The closed-response format restricts the respondent in how they answer, which may result in

either a failure to answer or the participant giving a false answer, all be it with good intent [15].

Since quantitative sampling effectively produces a snapshot of a sample population at the time of testing, giving the same test to the same cohort at multiple time intervals results in temporally displaced snapshots, and comparing the two can generate a picture of change. This is known as longitudinal research [15]. If the samples are anonymous this gives a picture of the change of the group as a whole, if the individual responses can be tracked through the samples then this can give an individual picture [15].

Desk research was undertaken to examine trends in student attainment over the course of several years across several modules. This is analysis of data from secondary sources which are sources of data that have been collected by others, not specifically for the research question at hand [16] [17]. Obviously the main drawback to using this method is that the researcher has no control over the data, and it is usually impossible to go back and fill in any gaps [15, p. 296], which may lead to an incomplete analysis. The main benefit to using pre-collected data is the speed at which one can turn out completed analysis, and this is particularly apparent when the data is numeric or quantitative when analysis is generally much faster.

Qualitative data can be generated from a multitude of sources, including interviews, questionnaires and focus groups [10] [18]. All of these techniques however can also be used to generate quantitative data. The difference is the nature of the questions asked [4] [12]; if the questions are closed response the data generated will be quantitative, coded into numbers which can then be subjected to statistical comparison and used to measure phenomena. If the questions are open response, where the respondent has the freedom to reply in any manner they see fit, the data generated will be qualitative, and analysis allows the researcher to explore phenomena [10].

Qualitative data is generated from interviews, both structured and semi-structured (or semi-standardized). Interviews are in effect “*conversations with purpose*” [4, p. 31] and questions are phrased in an open manner, allowing the respondent freedom to respond how they please, rather than forcing a choice of several options (closed questioning). Semi-structured interviews follow a basic plan, but the wording and ordering of

questions can change between interviews [19]. This allows for the interviewer to expand upon points raised during the interview, and generate large quantities of highly relevant data. The downside to this approach is that the volume of data generated can make the analysis time consuming and difficult [20].

Face to face interviews, regardless of the level of structure, enable the interviewer to generate a rapport with the interviewee, and with less structured interviews this rapport can lead to more honest responses [21]. The drawback of the rapport is that it can easily cause distraction from the line of questioning which should be pursued [20] and turn the interview into a conversation without purpose. This rapport and trust can easily be disrupted by such simple things as the interviewer taking notes, and cause the interviewee to revert to providing socially desirable responses.

The first of these drawbacks (distraction from the line of questioning) was mitigated by training and by keeping the interview schedule in front of the interviewer. The second (disruption to rapport) was mitigated by the interviewer reminding participants that interviews were considered strictly confidential and any personal references would be removed at the analysis stage. Furthermore, the interviews were audio recorded with the participants permission, and this allowed a verbatim transcription of the interview, and readily enables thematic analysis [20] [22] [23] [24].

Structured interviews present each interviewee with the same questions, using the same wording and order. This restricts the potential for in depth answers, but retains the inherent strengths of qualitative data for uncovering themes and individual points of view and avoiding the oversimplification of complex issues or ‘putting words in mouths’. In this thesis the structured interviews were carried out in a similar manner to a mailed survey, whereby the respondents were each issued with a printed interview schedule of open questions and responses invited. This approach combined the strengths of a questionnaire (generation of large quantities of data in a short time period) with the strengths of open questioning.

The main advantage of face to face semi-structured interviewing compared to structured self-response interviewing as conducted in this thesis is the ability to probe the data as it is delivered, ensuring clarity of understanding between researcher and respondent [18].

However, this advantage is countered by the marked disadvantage of the time required to conduct the survey in the first instance and to transcribe and analyse the data afterwards.

For each study all the students enrolled on the module being investigated were invited to participate with the study. The face to face interview participants were invited to participate via a mass email sent to the entire class, all other studies were administered in a scheduled class period, and students who attended the class given the opportunity to decline to participate at that point. This approach was deemed appropriate despite the usually associated drawbacks as the invitation to take part was extended to the entire population available for each study.

## **2.4 Data analysis**

The first batch of quantitative data was analysed using chi square analysis to look for significance in the responses to each question about key concepts. The analyses from each iteration of the questionnaire were compared to each other, giving a view of how understanding as a whole had changed overtime.

The second batch of quantitative analysis used the performance data of all students registered for the second year of the electrical engineering department. This data allowed the comparison of marks achieved on the module of interest in two distinct ways, terms student-centric and module-centric. The student-centric analysis is generated by comparing creating a distribution (in each assessment component) consisting of the average marks each student achieved and comparing that to the marks they achieved in the module of interest. This is made possible as the students can all be identified by arbitrary (non personally identifiable) designations.

The module-centric comparison is more involved and requires the creation of a hypothetical generic module, based on normalised distributions of marks in the three assessment components (coursework, examination and combined) in all modules undertaken. This generic module accounts for the performance of all students in the year, and is a basis for comparing modules with different students (and different numbers of students) enrolled on each.

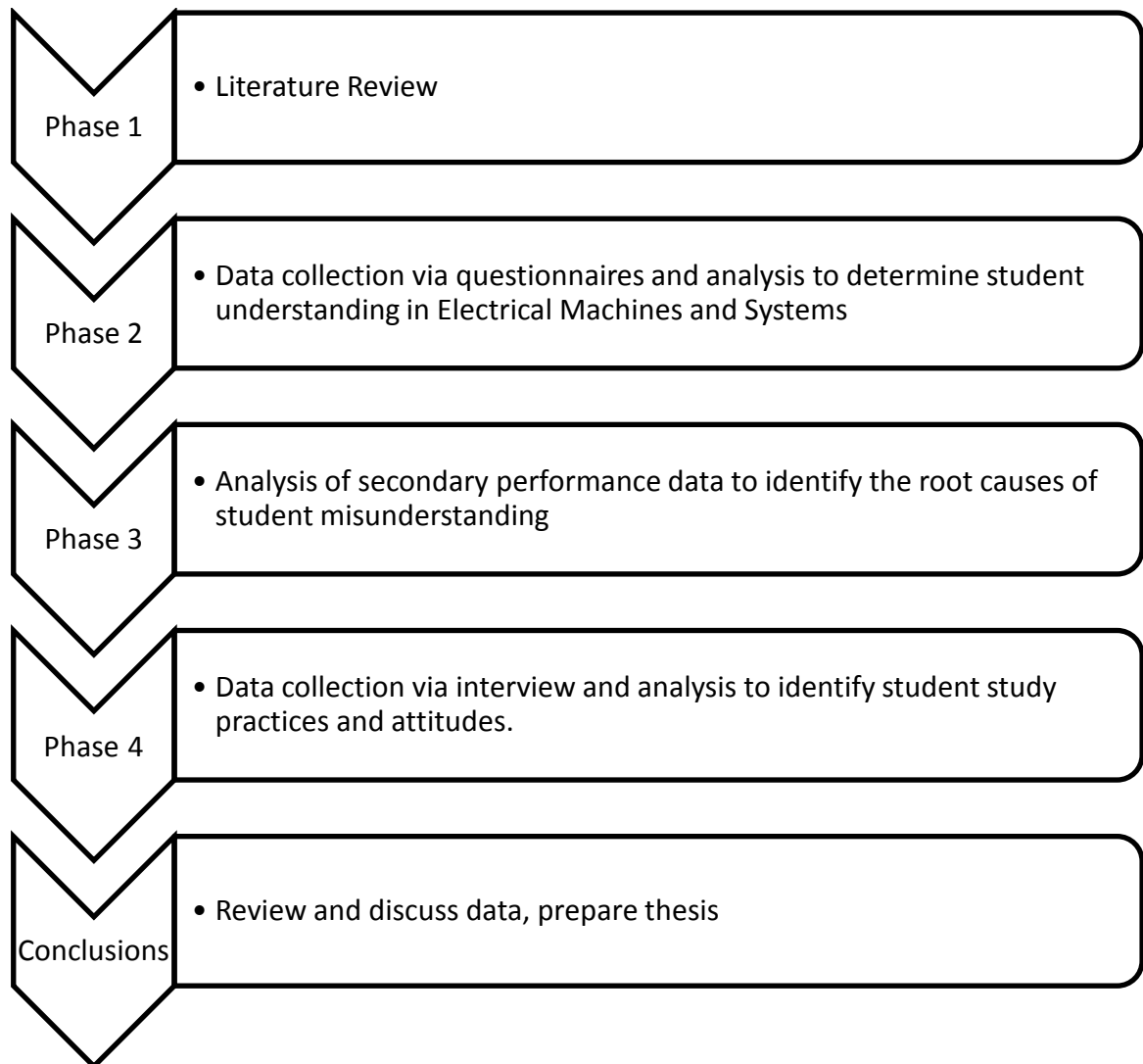


The qualitative data generated by the interviews was subjected to thematic analysis. Thematic analysis is a method of identifying and analysing patterns found in qualitative data, best demarcated and described by Braun and Clarke [23]. There are six steps to a good thematic analysis:

- Familiarisation – Transcribing recordings, reading written accounts and making initial notes on potential themes (ways of coding the data)
- Generating initial codes – Formalising the initial ideas already noted down into a large coding structure and collating data into that structure
- Searching for themes – Using the coded data and analysing which of the codes naturally belong with each other
- Reviewing themes – Checking the themes to ensure they generate a good picture of the whole data set and are consistent within themselves and disparate from each other
- Defining and naming themes – Deeper analysis to identify the specifics of the theme and its location within the whole data set
- Producing the report – Linking each theme with the literature and selection of demonstrative examples

## 2.5 Research Process

The research process is outlined in Figure 2-1 below, and shows the 4 phases of research in the order they were envisioned at the outset of the project. The iterative nature of the data collection means that the results of one study influence the choice of the sample and the questions asked in the following.



**Figure 2-1 – Research summary**

The first phase of research was a literature review conducted to identify the prevalent models of learning and cognitive development. As well as the models of learning and cognitive development a second focus was on the methods of teaching and learning (ie how to exploit the models of learning and cognitive development and recognise/demonstrate levels of development and understanding). This formed the basis

for the development of a teaching aid which was developed to aid understanding of the notoriously difficult electrical power modules.

The second phase of the research was to identify how effective the instruction that was occurring in the modules was at imparting understanding to the students. It was assumed that there would be a level of understanding, even if that were flawed, as there were prerequisite modules for the modules under investigation.

The third phase of the research was secondary data analysis to determine whether the instruction of the module was falling short as a result of the cohorts undertaking the module (in which case performance could be assumed to reduce across the board) or whether it was something confined to the single module of interest.

The fourth phase of the research was the qualitative phase, designed to explore the factors identified in the previous phases of research. The reasons for the failure of instruction were identified in this phase of research, and relating the whole project to the literature provided grounding for the application of the teaching aid developed.

## **2.6 Ethical Issues**

This research was subject to and in compliance with the requirements of the Loughborough University Ethical Advisory Committee. The University ethical clearance checklist was completed for all phases of the research. Informed consent was obtained from all participants and they were made aware that all data would only be reported in an anonymised form.

### 3 Individual Differences in Cognition

This chapter outlines two main approaches to conceptualising and understanding human memory. Whilst the factors discussed do not offer a complete explanation they are relevant to understanding how student understanding can be influenced by an interaction of cognitive factors such as encoding and the requirement for structural change. The chapter also considers the relevance of cognitive development in explaining individual differences in understanding.

#### 3.1 Theoretical models of memory

##### 3.1.1 Multi-store model of memory

One of the most influential models in the field of cognitive psychology is suggested by Atkinson and Shiffrin [25]. Through their studies on the audio-visual-linguistic (a-v-l) memory system (they did not separate the three components as a visual cue is easily translated into audio/linguistic cues), propose a three stage model for the transfer of information into what they call the “Long Term Store” (LTS), but which in lay terms is known as “committing to memory”. The three stages proposed by Atkinson and Shiffrin are defined by capacity, retention time and mechanism of coding.

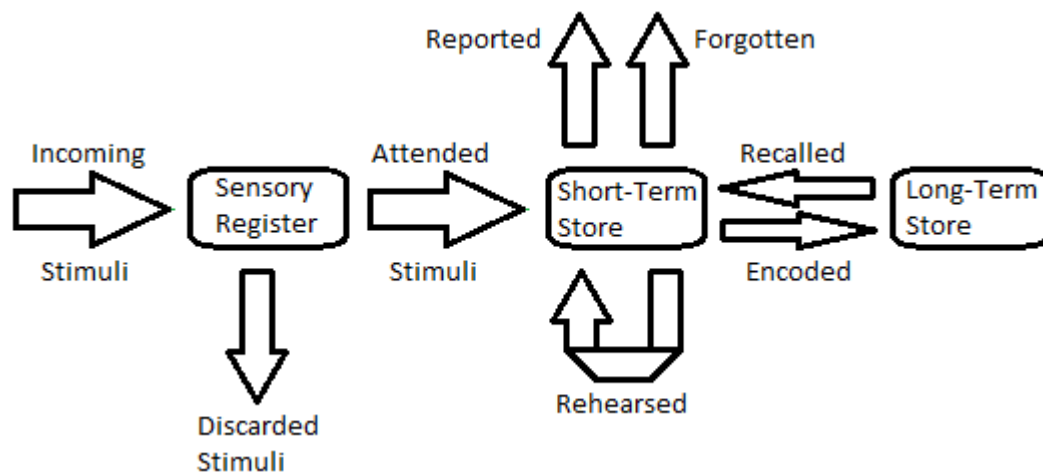


Figure 3.1 – The multi-store model of memory [25]

##### 3.1.1.1 Stage 1 – Sensory Register

The first stage is known as the Sensory Register (SR), which is a very high capacity system with minimal, if any, coding possible. The retention time of the sensory register

is measured in milliseconds and the loss rate is extraordinarily high. Echoic [26] and Iconic [26] [27] Memory are two readily recognised examples of the SR. The sole purpose of the register is to accumulate and store all incoming stimuli, not just those of which the individual is aware (background noise) but also those which the individual is only subconsciously aware of (heart rate) and, via precoding [1], determine which are of a high enough priority to pass forward to the short term memory. The precoding and transferral of information occurs in a fraction of a second, and will depend upon not only the stimulus (someone shouting “FIRE!” will always grab attention) but also upon the general psychological state of the individual (in a high state of anxiety an individual will perceive things as potentially threatening that in any other situation would be dismissed out of hand). It is only after the information is precoded and passed to the short term store (also called working memory) that it is consciously recognised and able to be processed.

Evidence for the SR and precoding can be found in the following example and, is described in accordance with a model set forth by Deutsch and Deutsch [28]. In a crowded social situation, people naturally split into small groups and converse within those groups. Whilst focussed upon your own group and the conversation carrying on therein, you can hear the other conversations around you, but only as an incoherent noise which you must speak over so that other people can hear you. The other conversations are not as important to you as your own. Until you hear your name, or somebody mentions something that you are particularly knowledgeable about or interested in, both of which can be considered of high importance to you. Suddenly your attention switches, you find it increasingly difficult to avoid attempting to listen to both conversations (and usually you will fail at listening to either one satisfactorily). If the other conversations were truly incoherent then you would never notice your name being mentioned. They are incoherent because they are precoded to be so, and the information that you actually hear is lost prior to transferral to Short Term Store (STS). Precoding allows concentration on both conversations after this point, assigning equal priorities (or almost equal priorities) to both stimuli, and passing both through to STS, whereupon they conflict with each other in a process known as interference [29] [30], and cause the inability to listen to either.

It is an interesting argument as to whether or not this precoding is influenced by existing structures within the Long Term Store (LTS). It is arguable that there is communication at least in one direction between the SR and LTS which facilitates the precoding operation, and, if the memory trace provoked by the SR is sufficiently strong, that information is passed from LTS to STS at the same time as the initial stimulus is transferred into STS. Presumably a weak memory trace will influence precoding as well, but in a more negative context, reducing the priority applied to the stimulus and increasing the likelihood that it is lost prior to transferral.

### ***3.1.1.2 Stage 2 – Short-Term Store***

Atkinson and Shiffrin call the second stage of their model the Short Term Store (STS), and it is characterised by limited capacity and short retention times. Peterson and Peterson [31] provide evidence for the short retention time of the short-term memory store in an experiment in which the participant is given a consonant trigram to remember and a simple arithmetic task to complete until given the cue for recall. The purpose of the arithmetic exercise is to eliminate the possibility of the participant using repetition (either vocal or sub-vocal) to remember the trigram, however, it must be simple enough that it does not overwhelm the limited capacity of working memory [32] and cause the removal of the trigram. For a fuller discussion on the limited capacity of the short term store, see §3.1.2.1. The recall intervals tested were every 3 seconds up to 18, and the results indicate that, as one would expect, a shorter recall interval yields more correct responses. It is interesting to note however that there is a marked increase in correct responses following a latency period (the period between the recall cue and the response) of between 2 and 4 seconds, a period comparable to the recall interval. This increase is present at all recall intervals, but the effect becomes far less pronounced as the recall interval increases. Peterson and Peterson [ibid] also investigate the effect of repetition on short term memory. The same experiment is carried out but with a period of time between the presentation of the memory item and the beginning of the arithmetic task. Participants were split into two groups, one explicitly instructed to rehearse (aloud) in the period between presentation of the memory item and arithmetic task and the other given no instructions. The results indicate, particularly for the explicitly instructed vocal group, that repetition improves retention in the short-term memory, and there was no statistical difference between the vocal and non-vocal

groups, which would seem to suggest that participants were using repetition in both groups. The vocal repetition was not corrected at any stage by the examiner, and presented evidence that the rehearsal method is not perfect and, while it improves retention, this is only beneficial if the repeated information is correct. This repetition is incorporated in the Atkinson-Shiffrin model as the primary method for keeping information active in the short term store, so that it can be used again either explicitly (as a phone number for example) or implicitly (as an intermediate step in arithmetic calculations for example).

### ***3.1.1.3 Stage 3 – Long Term Store***

The third and final stage of Atkinson and Shiffrin's multi-store model is the Long Term Store (LTS), supposedly a structure of infinite capacity and indefinite retention. It is claimed that once something has been encoded from short term to long term memory structures it cannot be forgotten, however it may take considerable effort to recover the information. This is likely to be a function of time since the memory was last accessed, and indeed accessing one long lost memory may make it considerably easier to access other memories because of their associations. A suitable analogy would be some object of interest lost within a forest. The object is there and not visiting does not change that fact, but as the path to it becomes more overgrown through lack of use, the object becomes harder to find, until such a point that the trail becomes indistinguishable and the object has become forgotten. The fact that the object still exists within the forest however remains true. Rediscovering the object (whether by the original path or a new one) may lead to the subsequent rediscovery of other nearby objects that had also become lost, and the forging of new paths both between these objects and to the forest edge.

Atkinson and Shiffrin acknowledge the existence of long-term memory in other modalities than a-v-l (citing the ability of individuals to recognise taste and smell) and even extrasensory modalities (citing research by Yntema and Trask [33] into temporal memory) but restrict themselves to a-v-l as it is the most extensively studied and tested. The proposal is that transferral to LTS happens any time information is in STS. Evidence for this can be found in Peterson and Peterson [31] (the asymptote of recall at 0.08 for recall intervals approaching and exceeding 18 seconds) and other examples of "incidental learning". For example, Atkinson and Shiffrin cite experiments in which

participants presented with the same digit sequence over the course of several short-term memory trials gradually learned that sequence. It is assumed that because the format in which the sequence was presented was a short-term trial, there would be no effort directed to transferring the information to long-term memory, and the information would be held in the STS by way of repetition.

#### ***3.1.1.4 Retention and Recall***

It is of course not possible to clearly identify the processes by which an individual deliberately transfers (encodes) information to the LTS (in the same way it is not possible to test and identify the processes used in precoding), however, it is possible to infer features of LTS based upon the responses to Long-Term Memory (LTM) tests in the same way it is possible to infer features of SR and STS from tests conducted on Short-Term Memory (STM). The simplest model for the retrieval mechanism is an all or nothing trace return. If encoding was successful, and the right cues have been provided, then a complete and correct trace will be returned. If encoding was unsuccessful, no trace at all is returned.

The “tip-of-the-tongue” phenomenon with which a large number of people are familiar would seem to suggest that a partial retrieval is possible, and the observation of recognising the final part of the trace when presented with it suggests that the fault lies in the retrieval of the memory trace rather than the initial storage of it. Atkinson and Shiffrin [34] propose a multi-copy model that has merit in its ability to explain several observances. It is important to note that this does not preclude or imply the falsehood of the “all or nothing” retrieval or encoding mechanisms. The only implication of a partial trace return is that the two mechanisms are not perfect.

Just as the process of transferring information from the SR to the STS is known as precoding the equivalent general process for transferral from STS to LTS is known as encoding. How this new information is encoded changes from person to person, even assuming the two people know the same information prior to presentation of new information. The way it is encoded depends upon how information previously presented (and pertinent to the new information) was encoded, as well as the associations the individual makes at the time (or soon after) the information is presented. Encoding can take one of two forms, intrinsic or extrinsic, depending on whether the information can



be incorporated into existing mental structures, or whether the structures need to be adapted to accommodate the new information.

In the first instance, encoding should be relatively straightforward however in the second instance it may be very difficult to encode, depending upon the magnitude of the structural change required and indeed the structure required to change as some will be harder to change (more ingrained) than others. This attribute can be viewed as a function of how many substructures have been generated from it.

Those items of information that require structural change in order to be accommodated can be thought of as troublesome knowledge. When the information is of such fundamental importance that it provokes a change of such magnitude that it changes not only associations between items within that structure, but also relationships within indirectly related structures, and even between structures themselves, then this information can be considered as a threshold concept [35] [36]. Without understanding this concept, development stalls and further higher level understanding of any topic dependent upon this concept is either halted or becomes inherently flawed. This has significant implications in relation to student understanding of key concepts within electrical engineering whereby concrete changes in structure are required to promote understanding. Difficulties may arise where fundamental associations between established structures and new information conflict.

### **3.1.2 Levels of Processing Approach**

A second viewpoint from within information processing theory is that suggested by Craik and Lockhart [37], who take the standpoint that the features used to distinguish memory stores in a multi-store model, namely capacity, coding and forgetting characteristics, and the evidence used to do so, are inadequate. They present evidence showing blurring of the apparently clean distinctions of the multi-store model, and instead propose an approach where there is but a single store and a continuum of processing levels which are reflected in the testing mechanisms.

#### **3.1.2.1 Capacity**

Capacity is a highly contentious subject. Craik and Lockhart suggest that capacity should be constant regardless of how it is tested. Working or short term memory is

routinely considered to have a capacity of approximately seven items, however as Miller acknowledges this “magical number” is “plus or minus two” [32], and this variation of peak capacity is exhibited by most individuals as a consequence of the stimulus under investigation. Miller begins by considering what he calls the channel capacity of his participants in response to various uni-dimensional absolute judgement stimuli (things that require a this/that/other type answer on single scale), and concludes that although some stimuli generate channel capacities as low as 2 bits (corresponding to just 4 uniquely identifiable items) others have channel capacities of almost 4 bits (corresponding to 16 uniquely identifiable items). He determines the average of these uni-dimensional absolute judgement channel capacities to be 2.6 bits with a standard deviation of 0.6, corresponding to “about 6.5 categories, one standard deviation includes from 4 to 10 categories, and the total range is from 3 to 15 categories.” [32]

Miller goes on to look at multi-dimensional absolute judgement stimuli, and concludes that the combination of judgements results in an increase of channel stimuli, but below the level that would be expected by the addition of the individual channel capacities. Miller’s conclusion is that “as we add more variables to the display, we increase the total capacity, but we decrease the accuracy in any one variable. In other words we can make relatively crude judgements of several variables simultaneously”.

When looking at the “span of immediate memory” Miller proposes a theory that the total number of bits of information should be constant, regardless of the form those bits take. As one can recall about seven decimal digits, and each digit is worth 3.3 ( $\log_2(10)$ ) bits, the total number of bits that can be recalled is approximately 23. An isolated English word is worth approximately 10 bits of information (as it is one from a list of 1000) then, if the theory is right, only two or three should be able to be recalled. Results indicate that the span of binary items is about 9, making for a total store of 9 bits, whilst for the 10 bit words the span is about 5, a total span of 50. Clearly the theory proposed and tested was disproven, which led to the development and adoption of the chunking idea, whereby rather than the total amount of information (bits) being constant as it is for absolute judgements, the number of information items (chunks) is constant.

The chunks used depend upon the data that is presented, and the individuals knowledge of the data (and things associated with it). For example, a string of 16 binary digits is

viewed differently depending on the level of knowledge of the person viewing it. To a person entirely novice to the concept of binary numbers it is a string of 16 ones and zeroes seemingly at random and will be reduced to chunks the individual can easily comprehend (say four chunks of four bits, where each chunk will be recognised, and probably reported, as the decimal version of the chunk e.g. one hundred and eleven rather than the decimal translation seven), whilst to a person highly competent in the concept it can, with sufficient time, be reduced into a single chunk and recognised (and again probably reported) as the hexadecimal translation.

The way in which the incident information is translated and stored into increasingly complex chunks is known as recoding, and as illustrated in the example above is a function primarily of the level of comfort the individual exhibits with the incident material, and the schema that is required to be used, rather than some extrinsic factor such as the level of intelligence, although this of course will aid the individuals as higher intelligence lends itself readily to more complex encoding schema.

By subscribing to the notion of chunks of memory, one removes the requirement of the short-term memory to be adaptable in size, reverting instead to a structure of known and relatively constant size (seven items plus or minus two) and shifting the requirement of adaptability to the chunks themselves. That being said, it can be argued that one item contains no more information than another (the word pineapple contains no more information than the digit 4), it is merely the associations with that item in the long-term memory that holds the extra information. This argument is somewhat confounded when you look at two chunks of different size containing the same type of data (a single digit versus a string of three or four digits), however, this is easily reconciled when one realises that the concept of thousand is as comfortable to most people as is the concept of single digits.

The difficulty arises when the string of digits that must be remembered has no inherent meaning to the individual, for example, the string 501 may have meaning as the score from which one plays in the game of darts and 147 may have meaning as the score achieved in a perfect snooker break. The similar sized strings of 216 and 546 however have no associations to go with them. Does this mean that the first two chunks hold more information than the second two? Clearly the fact that the first two strings have

known associations will make them easier to remember, and therefore allows them to be remembered as single chunks, where the second two strings without associations will be harder to remember as chunks.

### ***3.1.2.2 Coding Characteristics***

Coding in the multi-modal store, particularly within the Atkinson-Shiffrin model [25] which focuses on the audio-visual-linguistic, system is said to change from acoustic in STS to semantic in LTS. This change can be visualised most easily by the difference in short term memory of a list of a few words, or a recently looked up telephone number, compared to remembering a story involving the same elements as in the list, or a telephone number with which one has a high level of familiarity (one's own for example). In the first instance the list or string is encoded and rehearsed audibly, even if subvocally, in Baddeley's phonological loop [26] (also referred to as the articulatory loop [38]), whilst in the second the meaning and associations between them is remembered at least as much as the items themselves are.

Baddeley [38] presents evidence in favour of the different encoding techniques with a study showing acoustically similar word lists are very much more difficult to recall from STM than control lists of dissimilar words (9.6% success rate compared to 82.1%) while semantically similar lists are only slightly more difficult to remember than a control list (64.7% compared to 71.0%). This confirms the earlier work of Conrad [39]. The equivalent tests for LTM use larger lists of the same form, with a digit span test between presentation of the list and recall to remove any effects of STM, and a final test 20 minutes after the final of the four initial recall opportunities. Acoustic similarity had no reliable effect on the success rate when compared to the control rate, whilst the semantically similar lists show a marked difference in success rates (less than 60% compared to over 80%).

Shulman [40] designed and carried out an experiment to show not only that semantic encoding in STS is possible, but also that the encoding process is time dependent. This was carried out by presenting words for varying time periods, and making the participant aware prior to testing that they would be required to answer yes or no to whether or not the cue word presented was identical to, a homonym of, or synonymous with one of the words in the list. This was not a span or retention test, so the presented

lists were short and no restrictions were placed upon how participants rehearsed (or did not) the items. Synonymity is recognised in 72.4% of trials over all serial positions and presentation times, rising to 92.8% of the time at the most recent serial position. This combined with the shape of the retention functions for the semantic and phonemic information that exhibit strong recency effects suggest that it is unreasonable to attribute the evidence to long-term memory.

Shulman suggests that the absence of evidence of semantic encoding in prior studies (such as Peterson and Peterson [31]) is a result of the mechanisms used to prevent rehearsal not allowing the participant sufficient time to encode the data semantically. They provide evidence for the time dependence of this encoding by decreasing the presentation rate (final presentation rate had stimulus durations of 1.3s followed by 0.1s before the next stimulus) and showing an improved recognition from the semantic probe condition not matched in the phonemic conditions). Reaction times to the questions seem to indicate that not only is the process of encoding the semantic information slower, but so is the process of decoding it. That is to say it takes almost half as long again to match a pair of words on a semantic basis as it does to match them based on their identity or sound.

This evidence of semantic encoding in STM throws doubt on the viability of encoding practices being a basis for differentiation between memory stores, however, it is still more than acceptable to suggest that the preferred method of encoding in STM (if one subscribes to the premise of multi-store memory) is acoustic rather than semantic, and semantic encoding is through necessity more than choice, time available or any other mechanism.

### ***3.1.2.3 Characteristics of Forgetting***

Craik and Lockhart [37] suggest that forgetting characteristics should be invariant with respect to the method of testing, but do not go so far as to suggest they should be invariant with respect to presented information. While acknowledging that the “invariance has not been rigorously tested” they cite experiments by Waugh and Norman [29], in which rehearsal was only permitted for the previously presented item and expressly forbidden for items prior to that, which show that the probability of correct recall is independent of the presentation rate, and therefore time between initial

presentation and recall, but dependent upon the number of intervening items. The conclusions of this experiment and their analysis of free recall data show that items not rehearsed are rapidly lost, and further that the primary cause of forgetting is interference rather than decay [30, p. 74] [38].

At first this seems at odds with the work presented by Peterson and Peterson [31], which seems to suggest that memory trace decays with time when repetition is removed. Upon closer examination one can see that the relative frequency of correct recall for recall intervals of 12s or more is close to 0.1 (see Fig. 3 of [31]) which correlates with the results of Waugh and Norman where the probability of recalling item 12 from the end of a series is about 0.07. In this context it seems that the simple arithmetic problem Peterson and Peterson use to prevent rehearsal constitutes an intervening item in terms of interference.

Discrepancies in retention time are most apparent when looking at the visual memory system in isolation (i.e. not linked with the auditory or linguistic systems). A series of experiments carried out by Sperling [27] began with two full report experiments using a variety of stimuli, which verified that the immediate (working) memory span of his participants averaged at 4.3 letters and was independent of presentation duration. Further experiments circumvent the limitations imposed by immediate memory span by using a partial report methodology, such that the maximum report does not exceed the maximum span of immediate memory. The key point to ensure that a partial response is valid and indicative of the total amount of available information is a report in response to an instruction given at the end of the stimulus. The instructions given must be random, but cover the whole of the stimulus and multiple trials must be given such that a good picture of the available information can be obtained.

Using the partial report procedure all participants showed “the available information calculated from the partial report is greater than that contained in the immediate-memory report”. The full report on the 4/4/4 stimulus (3 rows of 4 letters each) yielded average spans of 3.9-4.7 (4.3 average) letters, where using the partial report method, the number of letters available increased to 8.1 to 11.0 (9.1 average). The partial report procedure is used again, but with varying time intervals between the end of the stimulus and the instructional cue. Sperling presents results that indicate the decay of the

available information down to the level expected from the full recall experiments if the instructional cue is delayed until 1s after the stimulus, as well as show evidence for strategies employed by the participants. These strategies are paying equal attention to the whole stimulus as required by the experiment instructions or either guessing which row will be selected and only looking for that row, or not guessing but just preferentially anticipating one row, both of which will result in something akin to all or nothing reporting.

One participant in the series of experiments reported switching his strategy from whole stimulus to row specific for stimulus-instruction intervals in excess of 0.15s, however the results for that participant indicate the strategy switch should have occurred sooner to maintain optimal performance. Further experiments investigated the effect of bright post exposure fields (which reduced the report accuracy), however, the mechanism for this interference is unclear.

Finally, an experiment was conducted asking the participant to respond to stimuli of mixed letters and numbers (equal frequency) by listing just letters or numbers. Responses in this experiment failed to be more accurate than the full recall responses even though it is a type of partial recall response. This implies that the iconic memory used to report full lines of the stimulus is not associative, and asking a participant to make associative judgements requires some level of processing which reduces the possible output to the level associated with working memory.

Phillips and Baddeley [38, p. 207] used a 5 by 5 array of squares coupled with pattern masks to avoid iconic memory effects and naming schemes when they investigated the duration of visual memory. They determined that forgetting occurred, levelling out after 9 seconds [41]. The difference in retention time between iconic memory and short term visual memory (again isolated from the audio-linguistic systems by experimental design) are obvious, and Craik and Lockhart [37] suggest that these are not separate memory systems at all, but rather the same memory system under different test conditions.

#### ***3.1.2.4 Short-Term Memory Equivalent***

“Shallower” processing occurs when the time available for processing is limited, as would be in traditional short term or working memory tests, and revolves primarily about the primary sensory features of the stimulus (loudness, brightness, shape, size, etc). As the processing time increases, the stimulus is exposed to analysis leading to matching then pattern recognition and finally semantic and associative analysis. As an example, the presentation of the word “orange” is at first just a collection of lines on the page. Given a short amount of time, associative connections are made and the iconic memory is replaced as the letters are recognised, then the word, then the semantic memory of the colour, shape, taste etc, and the associative memories of related colours and fruits. Clearly the potential depth of the analysis is limited by the past experience of the individual, and there is no reason why the analysis need be limited to verbal or written material. The same processes of analysis will be applicable to other sensory modalities; it is just convenient when it comes to discussion of the processes to use verbal or written examples due to their familiarity and ease of understanding.

The same data which, when viewed from the multi-store viewpoint, seems to lend support to that model, lends equal support to the levels of processing approach when interpreted differently. The discrete differences exhibited in the multi-store model for such things as short and long term memories are viewed as a product of the testing regime, and as such are often found because the test is designed to look for them. When the testing regime is changed to look for evidence of other (deeper) processing as done by Shulman [40] then that is found too. The argument put forward by the multi-store proponents is that short-term memory is versatile and one would expect to see multiple encoding methods, depending upon the incident data and testing requirements. Both theories and viewpoints are as correct as the other.

Recency effects are explained by suggesting that the items most recently presented in a short-term memory trial are still active in primary memory, and can be maintained at a phonemic level of encoding. Prior items have to be subjected to increased levels of analysis in order for retention to take place, and due to the nature of material used for these tests (nonsense syllables, individual numbers etc) this analysis can prove troublesome. It is suggested that retention can be increased by increasing the



amenability of the data to deeper analysis by using real words (even if they are unrelated) or otherwise providing some form of context for the data.

### ***3.1.2.5 The Limited Capacity Processor***

The limited capacity of the multi-modal short-term memory, categorised primarily by short retention periods, high recency effects and limited capacity is explained by a limited capacity central processing unit in the levels of processing approach and the apparent number of items is dependent upon the “mode” in which the processor is operating. At greater depths it is possible to make much greater use of past associated experience and rules, and therefore the information effectively takes less space and more can be retained.

The rehearsal loop associated with various memory modalities (most notably the audio and linguistic systems) is explained by the independent processor remaining at the same level and effectively not processing any further, but importantly not stopping processing. Retention in primary (working) memory only occurs while the data is attended to, once the attention is lost the data is lost at the rate appropriate to the level at which it was being processed (slower for deeper processing levels). This type of processing, termed “type 1”, involves the repetition of analysis (or at least the results of the analysis) and “prolongs an item’s high accessibility without leading to formation of a more permanent memory trace” and is contrasted with type 2 processing which involves ever deepening analysis and will improve memory performance in line with the total time hypothesis [42].

### ***3.1.2.6 Incidental Learning***

Incidental learning in the multi-store model refers to the generation of long-term memory traces as a result of the information being present in the short term memory stores. There is no explicit desire to create these long term traces and it may not be desirable to do so, but that does not necessarily mean that it is disadvantageous. In the levels of processing model, because of the continuous nature of both processing and memory the requirement for it to be a long-term effect is removed, and the definition changes slightly to include short-term retention of data other than that which is required by instruction (for the testing method for example).

The argument in favour of the levels of processing approach comes from data that shows that orienting task influences the level of retention, with orienting tasks requiring deeper analysis proving to create more resilient memory traces. Orienting tasks that require only a cursory level of analysis have comparatively poor retention characteristics. These results are not routinely found without designing experiments to detect them.

Tresselt and Mayzner [43] present the results of an experiment in which 4 groups of participants studied the same list of 100 words for varying tasks, three of which require a different level of analysis. The first group was required to cross out the vowels in the words (denoted by V), the second merely to copy the list out verbatim (denoted by H), the third and fourth (denoted I and D respectively) to give each word a score from 1-7 that corresponds to how well the word fits into the concept of “economic”. None of the groups were expecting to be asked to recall the list. The first three (V, H and I) were asked for immediate recall of all the words from the list that they could remember, while the fourth (D) were asked for recall some 48 hours after completing their task on the list. The processing demands are lowest for group V, and highest for the I and D groups.

Results indicate that as the level of processing required goes up the average number of words immediately recalled by the participants increases too. The 48 hour delay before recall causes a marked decrease in the number of words recalled, however, even given the delay the mean number of words recalled was in excess of the number immediately recalled by the group who were required to cross out vowels. The paper does not say whether this difference, between the V and D groups, is statistically significant but it does say that the differences between the immediate recall groups are statistically significant.

The average number of words incorrectly recalled varies inversely with the correct responses for the immediate recall group, and again these differences are reported as significant. The group asked to provide recall after 48 hours recall significantly more incorrect words than both the I and H groups (but less than the V group).

The interesting thing to note is that the total number of responses, correct and incorrect, is relatively constant. Analysis of the incorrect responses indicates that the mechanism by which they are generated differs in the 4 cases, with approximately 80% of the words incorrectly recalled being unique in groups V and H, dropping to 60% unique in group I and down to about 51% in group D. The higher commonality in groups I and D indicates that the orienting task influences the production of the incorrect reports.

If the orienting task has such a profound influence on the incorrect responses then it should also have an effect on the correct responses. The orienting task performed by groups I and D can be used to score the list words for how well they belong to the concept of “economic”. The most frequently recalled words should score highly, and conversely the least frequently recalled words should relate poorly to the concept. Analysis shows that this is indeed the case, and for group I the mean score for frequently recalled items is significantly higher than the score for infrequently recalled items and for group D this difference is even larger. The difference in scores for groups V and H is not significant.

The final question that is addressed is that of whether this is a true phenomenon of incidental learning or simply some form of free production thematically influenced by the orienting task. A group of 25 participants were asked to generate a free production list of words belonging to the concept. The mean number of words produced was 58.2, and this is significantly different from the recalled list which had a mean of 16.86 words. The 20 most frequently occurring words in the free production list have only three or four in common with the top 20 most frequently occurring words in the recall lists, indicating that free production is not a predominant technique for the generation of the recalled lists.

### ***3.1.2.7 Sensory Register Equivalent***

The sensory register of high capacity and minimal retention fits neatly into the levels of processing approach due to its third identifying characteristic, namely that of minimal encoding. Minimal encoding from the multi-store standpoint implies minimal processing from the levels of processing standpoint, and minimal processing leads to minimal retention. In the same way as non-attended information in the cocktail party scenario mentioned earlier is unintelligible and forms no memory traces, non-attending

information in this sense is not processed sufficiently to leave a memory trace lasting more than a second or two. The levels of processing model does not seem to provide an explanation of precoding, which is an important process in the multi-store model and easily recognised as existing.

### **3.1.3 Conclusion**

The human memory can be conceptualised as a model (Atkinson and Shiffrin) or as a process ( Craik and Lockhart). Both offer intuitive explanations of the abstract workings of the human mind. It can be suggested that human memory is dynamic whereby short term memory is limited in capacity but where memory traces can be strengthened by strategies (rehearsal, repetition and chunking). Long term memory on the other hand has unlimited capacity, and can store information for up to a lifetime.

Both Atkinson and Shiffrin's model and the levels of processing approach espoused by Craik and Lockhart account for individual variation in recall. This may also underpin individual variants in student understanding. Concrete evidence of this association has not been empirically demonstrated, however both approaches provide valuable questions which this research aims to address.

## **3.2 Cognitive Development**

This section offers a review of the literature on cognitive development. Three main theories are described with a critical consideration of their relevance to the acquisition of knowledge and understanding. This chapter also explores the contribution these theories offer in explaining individual differences in cognition.

### **3.2.1 Stage Development Theories**

#### **3.2.2 Piaget**

##### ***3.2.2.1 Piagetian Overview***

Based largely upon the seminal work by Jean Piaget, stage development theory espouses a model of cognitive development in which an individual develops linearly through a series of fixed stages, each of which is characterised by the way in which the individual thinks. Piaget's focus on learning through experience has been influential in

the development of contemporary pedagogical theory. Piaget's early work centred on the development of children (based largely upon his observations of his own children), and Piaget's stages account for cognitive development from infancy through to adulthood. They are, in order, [44]

1. Sensori-motor (0-18months)
2. Concrete Operations (18months-12 years)
  - a. Pre-operational (18months-7 years)
    - i. Pre-conceptual (18months-4 years)
    - ii. Intuitive (4 years – 7 years)
  - b. Concrete Operations (7 years – 12 years)
3. Formal Operations (12 years onwards)

Clearly the ages are not prescriptive, an individual+ does not advance from one stage to the next simply by celebrating a birthday, but are instead generally descriptive.

However the linear nature of them is salient. This thesis focusses on student understanding of key concepts and the influences which shape student cognition.

Students within tertiary education are expected to operate at the formal operations stage of thinking. The early stages are beyond the scope of this project, but will be covered for the sake of completeness.

Key assumptions of stage development theory, are that

1. Stages proceed in a linear and irreversible manner
2. Stages are stable, and once attained the child thinks at that level
3. Domain generality means that the way a child thinks in one discipline should be indicative of the child's general thought processes and abilities.

As a result of these assumptions the child is labelled as performing at a certain level or in a certain stage until he progresses to the next. If a child's performance in a task is below the level at which he is said to operate it is an exception and known in Piaget's terminology as a *décalage* (see §3.2.2.7). Biggs and Collis [45] report students proffering middle concrete responses in mathematics and concrete generalizations in geography. Furthermore they claim that some students will give formal responses followed a week later by middle concrete responses in the same subject area. This is an

observation that poses some problems for Piaget's theory of development, however, the theory remains highly influential.

### ***3.2.2.2 Sensori-motor stage***

This occurs at the very earliest stage of development, up to the acquisition of language at approximately 18 months. Essentially this stage begins with the use of the senses and motor functions to make some sense of the world about the infant ranging from the automatic reflexes of gripping something touched to the palm of the hand or suckling something placed at the lips. Development proceeds with secondary circular reactions (movements reproduced after prior trials resulted in a desirable outcome) such as reaching for objects the child desires. If the action results in failure (because the object is out of reach) the action will be repeated as the secondary reactions are not coordinated and the child has no concept of the object being out of his range. At the conclusion of the stage the child has developed the concepts of object permanence (something continuing to exist even if out of the visual/tactile range of the child) and causality (the association of an occurrence with their behaviour, whether there is causality or not)

### ***3.2.2.3 Pre-conceptual sub-stage***

Following the acquisition of language the child is able to begin using language to assign the values and attributes of one item to those of another. The use of concepts is limited and often confused, based on similarities of action/experience rather than the similarities that we as adults would use to group items into concepts. It is in this stage that children play in imaginative roles, however, this is not the same as viewing something from the perspective of another. The best example of this is the child pretending to host a tea party for her stuffed toys. She assumes the role of "mother" (as opposed to hostess) but if she and her mother were looking at the same object on a table (something like a teapot) from opposite sides then she would describe her view, and the view of her mother identically (e.g. spout to the left). Swapping their positions would result in different but still identical descriptions (e.g. spout to the right), despite the child having just seen it from the other perspective and therefore knowing that from her mother's new position the spout is to the left.

#### **3.2.2.4 *Intuitive sub-stage***

This stage follows when the child has a firm grasp of language and uses it to ask questions exploring relationships. Thought is illogical and often seemingly contradictory as the child jumps from one opinion to the next (and back again) without realising that they are exclusive. Relationships are one dimensional and egocentric making it impossible for the child to make objective comparison accurately. As children lack the ability to perform mental operations they make judgements based on their perceptions, and will judge a problem based upon one aspect of it regardless of whether or not they know better. An example of this is two equal groups of counters, one spread across a wide area and one collected tightly together. The child will say the more spread out group contains more as it covers more area. This stage is also called the pre-operational stage [45]

#### **3.2.2.5 *Concrete operations sub-stage***

This stage is marked by a massive increase in the use of “traditional” logic, that is logic that seems consistent to the outside and experienced observer. This logic is expressed by the development and use of several processes, including seriation (the ability to create groups without resorting to pairwise comparison), decentering (focussing on more than one aspect of the problem), and the elimination of egocentrism (the ability to view something from the perspective of another). It is during this stage that thought and mental operations become more the norm than experience, and this internalisation is essential for relating concepts to each other (length relating to width, and combined relating to area) and allows development later in life, by relating new abstract concepts to those already learnt. Without internalisation each and every concept would be unique and it would be impossible to relate something abstract to something already learnt (which of course may be another abstract concept).

#### **3.2.2.6 *Formal operations stage***

This stage, according to Piaget, is the highest stage achievable, and one that is not achievable by all. The transition into it is initiated through co-operation with others, and is characterised by a softening of the rigid boundaries that guide the child (the development of understanding that a person can be good and bad congruently for example) and the ability to accept an untrue proposition for the sake of argument. He is

able to formulate and test abstract hypotheses based on his current knowledge and how it is related to new information presented to him, and most importantly for students of further education becomes aware of his own thinking and able to reflect upon it to justify himself and his arguments. It is this stage that we are most interested in as this is the level at which we hope most university students are operating.

Biggs and Collis present a modification of the above [45, p. 19], with seven stages, which follow essentially the same pattern. They declare the first two stages as “not particularly relevant” to their work) and thus imply that they are the same. They confusingly seem to use the same terms as Beard [44] to refer to different stages, claiming the sensorimotor stage is “followed by an intuitive stage lasting two or three years” which would correspond in age terms to Beard’s pre-conceptual stage. Beard’s intuitive stage would correspond with the pre-operational stage of Biggs and Collis. The concrete operations sub-stage is broken down into early and middle concrete, and the formal stage is broken into concrete generalizations and formal.

Age (approximate)	Beard’s description of Piaget	Biggs and Collis’s description of Piaget
0-18 months	Sensori-motor	Sensorimotor
18 months-4 years	Pre-conceptual	Intuitive
4-7 years	Intuitive	Pre-operational
7-9	Concrete Operations	Early Concrete
10-12		Middle Concrete
13-15	Formal Operations	Concrete Generalizations
16+		Formal

**Table 3.1 - Comparison of Beard with Biggs and Collis for Piaget's stages.**

### **3.2.2.7 *Décalages***

It can be suggested that the *décalages* between subjects are perhaps not as surprising as they first seem, and even not as contradictory to the theory as they seem. Piaget’s theory of development holds true for general development, and does not begin to break down until children reach a level of formal education in which subjects are separated from each other. It is at this stage that development in one field, for which the child has



a particular aptitude, can outstrip development in other fields, or in general. Décalages within the same field can be explained anecdotally at least by various influencing factors which can affect the level at which the child is operating at the time of testing, but which do not affect the underlying level at which the student can operate. These would presumably include physiological factors such as fatigue and hunger, and also psychological factors such as depression. The factors can be combined under the catch all term motivation.

### **3.2.3 Neo-Piagetian Alternative**

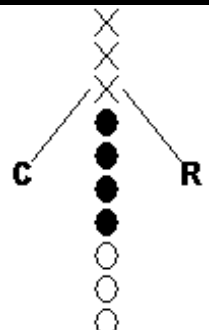
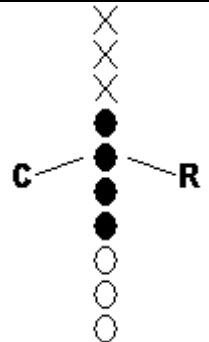
An alternative framework for stage development is put forward by Biggs and Collis [45]. The assertion that Piaget's theory is flawed due to the décalages, and apparent inability of some to reach formal operations at all is resolved by shifting the emphasis from the student to the responses that the student gives. It is important to note at this juncture that although this framework has been introduced as an alternative strictly speaking it is not; it can comfortably be accommodated alongside Piaget's theory as it is a description of a slightly different aspect. Piaget is used, and indeed was developed, as a measure of the generalized or hypothetical cognitive structure (HCS) and predicts the very highest level at which a child or student can operate. Biggs and Collis propose a structure based on the actual responses given to learning tasks and call this the Structure of Observed Learning Outcomes (SOLO) and propose an analogy of ability vs attainment to explain the difference, where HCS is equivalent to ability and SOLO to attainment.

Table 3.2 shows how the levels of the SOLO taxonomy compare to the stages of Piaget (as identified by Biggs and Collis), alongside the key features which identify those levels. Capacity refers to the amount of working memory, or immediate memory span available, and is required for responses of that level. The relating operations, listed below, are how the cue and response are related.

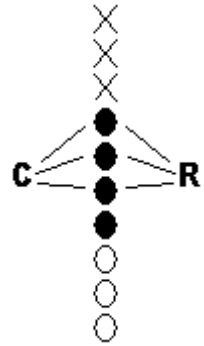
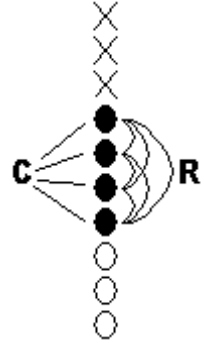
- Denial – refusal to engage in the task
- Tautology – repetition of the question in the form of an answer
- Transduction – an illogical leap to the answer via some unrelated piece of information, usually that which strikes the child most forcibly at the time. Older children learn to assess relevance before including data.

- Induction – drawing logical general conclusions based on the data given in the question or prior instruction
- Deduction – drawing logical conclusions from relevant abstract information not given directly in the question or previous instruction

Closure and consistency are drives that influence responses (and are evidenced by those responses). Closure is the need to come to a conclusion (rapidly) which leads to the omission of either relevant data or links between relevant data. As the pressure to reach closure reduces more data can be included leading to higher level answers. Consistency has very little sway at lower levels, where the drive to achieve closure is far higher than any need to achieve consistency. As the drive for closure abates the drive for consistency increases until the realisation that consistency and closure can only be reached under specific constraints and therefore achieving them whilst desirable is no longer imperative.

HCS (Piaget) level	SOLO description	Capacity	Relating Operation	Consistency and Closure	Response Structure <sup>a</sup>
Pre-operational (4 – 6 years)	Prestructural	Minimal: Confusion between cue and response	Denial, tautology, transduction. Bound to specifics	No felt need for consistency. Closes without even seeing the problem.	
Early Concrete (7 – 9 years)	Unistructural	Low: Cue+ one relevant datum	Can “generalize” only in terms of one aspect	No felt need for consistency, thus closes too quickly; jumps to conclusions on one aspect, and so can be very inconsistent	

...cont/.

HCS (Piaget) level	SOLO description	Capacity	Relating Operation	Consistency and Closure	Response Structure <sup>a</sup>
Middle Concrete (10 – 12 years)	Multistructural	Medium: Cue + isolated relevant data	Can “generalize” only in terms of a few limited and independent aspects	Although has a feeling for consistency, can be inconsistent because closes too soon on basis of isolated fixations on data, and so can come to different conclusions with same data	
Concrete Generalizations (13 – 15 years)	Relational	High: cue + relevant data + interrelations	Induction: Can generalize within given or experienced context using related aspects	No inconsistency with the given system, but since closure is unique so inconsistencies may occur when he goes outside the system	

...cont/.

HCS (Piaget) level	SOLO description	Capacity	Relating Operation	Consistency and Closure	Response Structure <sup>a</sup>
Formal Operations (16+ years)	Extended Abstract	Maximal: cue + relevant data + interrelations+ hypotheses	Deduction and induction. Can generalize to situations not experienced.	Inconsistencies resolved. No felt need to give closed decisions – conclusions held open, or qualified to allow logically possible alternatives.	

**Table 3.2 – Piaget vs SOLO [45, pp. 24-25]. C is the cue data given to the student, R is the response data given by the student <sup>a</sup>Kinds of data used: X = irrelevant or inappropriate; ● = related and supplied (as part of the question); ○ = related hypothetical, not given**

### **3.2.4 Conclusions**

Two different but closely related stage development theories have been introduced. to the reader. Piaget defined his stages in terms of the thought processes exhibited, whilst other characteristics were a result of those thought processes. Biggs and Collis define their levels in terms of other characteristics such as memory capacity, and thought processes are a result of those characteristics. In this context the level of understanding is easily quantified, it is the level at which you think (in Piaget's model) or the characteristics which you possess and can demonstrate (for Biggs and Collis).

With SOLO being amenable to variation in "scores" day to day and subject to subject the level attained should be defined as one which is attained regularly, rather than the peak attained on a particularly good day. The two viewpoints of information processing and stage development can easily be related to one another, as with increasing maturity comes increasing cognitive abilities, and therefore progression through stages (or levels) of stage development theory, the ability to process data to greater depths thereby creating stronger memory traces, better relationships between data and better retention in long term memory.

Student understanding is a result of the interaction of cognitive development and the transfer of knowledge into memory structures. These combine to produce the individual learner, and successful development of that student relies upon effective teaching and learning.

## **4 Teaching and Learning**

### **4.1 Introduction**

This chapter provides a review of the published literature in relation to teaching and learning, with particular emphasis on teaching and learning within engineering, both in the UK and worldwide. The chapter discusses teaching and learning environments, and offers a comparison of the traditional passive teaching environment with the more modern active teaching environment. Special cases of the active paradigm (i.e. Cooperative Learning (CL) and Microprocessor Based Learning (MBL)) are covered and the benefits and drawbacks of each approach are considered. Teaching and learning styles are discussed as well as the conceptions of and approaches to learning. These factors are considered in light of their potential influence on student acquisition and retention of knowledge and understanding within Electrical Engineering.

### **4.2 Threshold Concepts**

Understanding, especially in higher education, is based upon the comprehension of conceptual building blocks. These conceptual building blocks are routinely referred to as key or core concepts, and are frequently listed on educational specifications. These concepts must be understood to allow progression, yet they don't necessarily result in a qualitatively different view of the subject matter [46].

Threshold concepts however, do provide an "attractive perspective on teaching and learning" [47] and help to explain the acquisition of ways and practising within the disciplines [48] which give rise to things such as discipline specific discourse. They are fundamentally different to core concepts, and result in, among other things, a qualitatively different world view. Meyer and Land [46] [49] list five properties of threshold concepts:

- Transformative – Once understood a significant shift in the perception of a subject occurs
- Integrative – Once understood it exposes the previous interrelatedness of already learned items
- Irreversible – The change in perspective occasioned by understanding of the threshold concept is unlikely to be forgotten
- Bounded – Any conceptual space will have terminal frontiers, bordering with thresholds into new conceptual areas

- Troublesome – Containing at least one form of troublesome knowledge (see below)

Meyer and Land suggest that a threshold concept is “probably irreversible”, “possibly often (though not necessarily always) bounded and “potentially (though not necessarily) troublesome [49].

Knowledge, if not immediately acquired by a student can be considered troublesome. The reasons however for one item of knowledge being troublesome may be very different to the reasons why a second item is, however, broadly speaking the reasons drop into one of the following six categories [46] [49] [50].

- Ritual knowledge
- Inert knowledge
- Conceptually Difficult knowledge
- Alien knowledge
- Tacit knowledge
- Troublesome language

Ritual knowledge has a “*routine and meaningless character*” [50]. It is how one answers questions because that’s the way it’s done, or the routine which one blindly applies to get a particular result. Examples of ritual knowledge are names and dates, and routines such as the product-over-sum rule for combining resistors in parallel.

Inert knowledge is knowledge which is passively stored, not linked to anything else, and only ever used sporadically when directly quizzed [50] [51]. The problem with inert knowledge is linked to the problems of transfer of learning where knowledge and skills acquired in one context are applied to another [52]. The failure to make connections between items of knowledge may relate back to the integrative characteristic of a threshold concept [49] whereby in order to integrate one must first have all the pieces, but in the time between acquiring the first piece and achieving integration the information remains inert.

Conceptually difficult knowledge is hard to grasp, usually as a result of the complexity of the concept combining with misimpressions or mistaken expectations already held by the student [50]. It is reported that conceptually difficult information is more common in mathematics and science [51] which is a cause of concern for engineering educators and students as the concepts from these disciplines form the foundations of engineering [53]. Ritual or rote learned responses are usually given to definitional and quantitative answers, while flawed



understanding is exposed as intuitive beliefs which resurface in qualitative and out-of-classroom contexts. [50]

Alien knowledge is that which comes from a perspective which conflicts with one held. It is not the concepts that are inherently troublesome here, it is instead the viewpoint that one must adopt in order to understand. Perkins [50] suggests that an example is presentism in history: viewing events of the past through the lens of modern knowledge and values. This is similar to acknowledging multiple viewpoints exist for the interpretation of qualitative data, each of which are equally valid despite potentially confounding to each other.

Tacit knowledge [50] is that which is shared by a community of practice but which remains personal and implicit. During education this is rarely made explicit, but is collected and employed as a result of acquisition of other concepts throughout education. It is often related to the context in which discussions take place, particularly when those discussions use troublesome language. The troublesome aspect arises as a result of the presumptions made by the learner and teacher not being the same, and being missed by the other party.

Troublesome language [49] comes about when certain terms have a meaning in everyday non-technical use which differs to their meaning in the technical sense. An example is the mathematical concept of a limit, which in everyday parlance is something obtainable but in mathematics is the exact opposite, something infinitely approachable but never obtainable. By using the specific discourse in novel ways it is possible that an otherwise simple concept can be rendered difficult due to the conflict of meaning.

Perkins [51], a strong advocate of constructivism, suggests methods of countering some of these forms of troublesome knowledge, including providing ‘anchoring intuitions’, lucid explanations and engaging activities [50]. These methods serve to highlight the logical discrepancies in understanding, or between theory and observation (What is making the car slow down? Why does the table exert a force on the bowling ball but not the fly?). Ultimately however, despite a teacher’s best efforts “*those learners who find themselves interested less and struggling more tend to make knowledge troublesome for themselves*” [50, p. 45].

The acquisition of threshold concepts, due to their transformative and integrative properties can often occasion a shift in the learner’s perspective, which presents by way of changing the way in which students think and practice [48]. This transformation presumably is at least

partially completed during education, and partially during work after education, when the student is fully integrated into the relevant community of practise.

The transformation which occurs as a student integrates a threshold concept into their mental structures is not necessarily straightforward. It can often be protracted and involve apparent oscillations between states facilitated by mimicry and temporary regression to earlier (known and comfortable) states. This period of transition is known as being in a state of liminality, where the student is largely stuck [54].

There exists an obvious parallel between this state of liminality and the state of disjunction espoused by Savin-Baden [52]. It can be seen as a troublesome learning space which is caused by forcing students to engage with troublesome knowledge or by failure to conquer a threshold concept. It is hypothesised by Savin-Baden that there are four mechanisms for coping with disjunction:

- Retreat – Not engaging, taking up and defending a lesser position
- Temporising – Postponing the activity in the area of the disjunction
- Avoidance – Temporising whilst actively looking for ways to avoid the disjunction
- Engagement – Acknowledges the disjunction, deconstructs it and tries to resolve it

The mimicry exhibited by students whilst in states of liminality is possibly an example of a strategic approach to learning, and used by students in an attempt to gain understanding, not just an intention to reproduce information. Meyer and Land propose two types of mimicry; compensatory mimicry whereby the learner rehearses that which is known and understood but not relevant (to examination) in an effort to reassure themselves that they do understand, and conscious mimicry, where the student is aware of their lack of understanding but their only hope of success is in the “mimicry of pretension” [54]. The first of these mimics is retreating from disjunction, the second more closely related to temporising.

Threshold concepts, due to their integrative and transformative nature, occasion a shift in the learner, which can manifest as a shift in self-perspective, i.e. the shift from thinking of oneself as a student of physics to thinking of oneself as a physicist. Such transitions in self perception will be caused by the acquisition of ways of thinking and practising [48] which are shared by a community of scholars [47]. Ways of thinking can be interpreted as either the application of key concepts (note these are distinct from threshold concepts as mentioned

earlier) or as seeing and experiencing phenomena in a way which is peculiar to the discipline. Ways of thinking and practising is an evolution of these, and includes not only the application of key concepts and experiencing of phenomena, but also the underlying processes which are routinely used in order to solve problems, generate hypotheses or formulate responses to questions [47].

It has been suggested that the ‘taken-for-granted’ nature of threshold concepts means they are often troublesome in the same way as tacit knowledge [47] [56], and that learners can only acquire an understanding of these concepts by ‘reading between the lines’ which makes them hard to identify. It is suggested that because of the transformative nature biographic interviews or reflective diaries might reveal threshold concepts as the students reach points where they appreciate the ways in which communities think and practise [47]. The problem with this approach is that it is reliant upon a student passing through a concept suddenly and appreciating the importance of the moment the penny drops, which is hard. It’s more common for the acquisition of the concept to be a long drawn out affair, and the exact moment that the penny drops is hard if not impossible to identify.

Threshold concepts which influence ways of thinking and practising are often tacit in that one is not taught the rules of a specific discipline, rather they are acquired unconsciously and the transition from being a student of a discipline to a practitioner of a discipline is subtle and akin to the transition from juvenile to adulthood. The liminality associated with acquisition of threshold concepts and becoming a practising member of a discipline is akin to puberty, and the same sort of mimicry/oscillation is observed.

Taylor [57] describes acquiring threshold concepts as recognizing the significance of isolated islands of knowledge and making links between them. She suggests that as more links are made the student moves further into the discipline, and learning becomes increasingly contextualised and motivating, and the links easier to generate.

If discrete packets of knowledge form islands, and threshold concepts the bridges (or network of bridges) between them, then who is to say that if those islands are in different places (due to prior knowledge, or different emphasis attached etc) then the bridges will also be different. That is to say that the threshold concept identified by the expert (who long since transitioned it) will not necessarily be the same for the learners with disparate backgrounds.

There is evidence that the way in which a threshold concept is first presented may have implications for the future learning of that concept [58]. Poor initial understanding can lead to misconceptions which persist, and may stall the development of correct understanding. The practise of introducing a simplified version which is progressively developed may set students onto a path of ritualization and ultimately the initial presentation “*forms a barrier to the acquisition of the concept in a transformative sense*”. This is particularly true when the concept being introduced uses troublesome language, as the definition of the concept may change dependent upon whether one is using the technical or non technical definition.

Initial presentation of concepts in a simple way is often done using analogy. The new concept is likened to a concept which the learner is presumed to already have grasp of, and the analogous concept used as a launching point from which the new concept may be developed. However, in the same way an initial misunderstanding persists, incorrect conclusions can be developed from relating too closely to an analogous concept (which may only be analogous at the surface level). “*As a cognitive process, analogies are successful some of the time, but can be misleading.*” [59]

Despite so much work being aimed at helping students transform their understanding , and the importance of generating new ways of thinking and practising Lucas and Mladenovic [60] argue that resistance to changing understandings is not necessarily a problem; there is nothing wrong with holding an everyday “alternative” understanding which may be in contradiction to the “authorised” understandings of the discipline so long as it is possible to identify the organising framework and identify within it an appropriate conception i.e. a context specific understanding.

Negative preconceptions (about accounting) are present anecdotally and a body of work confirms their existence [60]. The preconceptions are related to a focus on learning the technique rather than the underlying meaning, which in turn is a form of mimicry whereby students present a superficial understanding (surface approach) or ritual knowledge. This reflects a lack of motivation brought into the study rising from perceptions of the discipline as dull and boring, routine driven and involving little judgement.

*“Furthermore it would seem from research into students’ learning that students still construe learning tasks as predominantly assimilating and reproducing material supplied by*

*academics, rather than engaging with what is meaningful for them and forming experience for themselves” [52].*

### **4.3 Environments**

“Teaching and Learning Environment” is the term used to encompass every aspect of the situation in which a student is expected to learn (and by implication a teacher expected to teach). The teaching and learning environment consists of a number of inter-related aspects which can be physical or expectational in nature. The physical aspects include considerations such as the number of students present, the nature of the teaching space (fixed banks of seating or open plan with movable seating). Expectational aspects can be split into social, which include how and when the students are expected to interact with their peers and teaching staff, and academic which include the expectations of the institution in terms of their academic attainment and progression. It is important to note that the academic and social aspects extend beyond the classroom, and include the environment in which students work outside the teaching space (or, if society dictates, don’t work outside it). Teaching spaces commonly in use can, to a large extent, be defined by the teaching field, i.e. art courses will tend to be taught in large open plan studio settings. However due to high enrolment in tertiary education it is a widely accepted method to teach large classes within a lecture theatre [61]. This is especially true in the foundation stages of undergraduate engineering degree programs.

#### **4.3.1 Active vs. Passive**

A passive learning environment is one in which learners are presented with information in bulk and where they have no engagement with that presentation. The best example of this is the widely renowned lecture theatre, in which large groups of learners sit and read the notes which they may have been presented with whilst listening to the lecturer and occasionally making some small note of their own [62]. The development of presentational hardware (both analogue overhead projectors and their digital equivalents) and software helps the lecturer and provides more stimulation for the learner, but does not necessarily stop the learner being passive [63] [64] [65]. This is recognised both anecdotally and in the literature as inferior to other instructional paradigms [65] [66] [67], but persists because of a combination of the perceived obstacles to implementing an active paradigm [68] [65] and the lack of training in teaching resulting in lecturers resorting to that which they know best [66] [65].

Conventional lecturing, with assessed coursework assignments (including practical laboratory sessions) throughout the year and a final examination, is frequently seen as the main instructional method in higher education institutions in the UK. In the United States of America the assessment criteria is slightly different, involving weekly homework assignments contributing, mid-term examinations and a final examination. The only aspect of activity from the student's perspective is the assessment, completed out of class, and as a result the emphasis in class is switched from the student learning to the active party; the lecturer.

The problems with traditional instruction and assessment were identified by a group of researchers at Tufts University and are given by Thornton [69]

- The criteria assessed by standard examinations are inadequate for demonstrating functional understanding
- Rote use of formulae is a common outcome of traditional instruction, a coherent conceptual framework is not
- Conceptual difficulties are not overcome
- Growth in reasoning ability is not exhibited
- Connections between the abstract concepts, their formal representations (diagrams and equations) and their application in the real world are often lacking
- Teaching by telling (a passive environment) is ineffective for the majority of students

Active Learning is a broad label given to teaching styles which switch the emphasis from the teacher to the learner, and involves the student engaging in “higher order thinking tasks such as analysis, synthesis and evaluation” [68] rather than trying to passively absorb knowledge as it is presented to them. This is done to create in the student a greater personal responsibility towards their own learning, and give them the skills required to make use of their knowledge [70]. This is achieved in a number of ways, which in certain areas overlap each other, can be either a full-scale paradigm shift away from traditional lecturing or just a minor adaptation within the classroom, and in general greater involvement is expected to yield greater learning.

Many lecturers attempt to insert some form of activity into their lectures by asking questions of the learners usually requiring a response in a form that ensures the learner must be engaged

with the material in order to provide the answer, and has the added benefit of allowing the lecturer to gauge comprehension. This is frequently met by a wall of silence because students lack the confidence to respond [71]. This may be a result of a general lack of confidence exhibited by the learner, or it is a result of the learner failing to follow the delivered material closely enough to provide an answer.

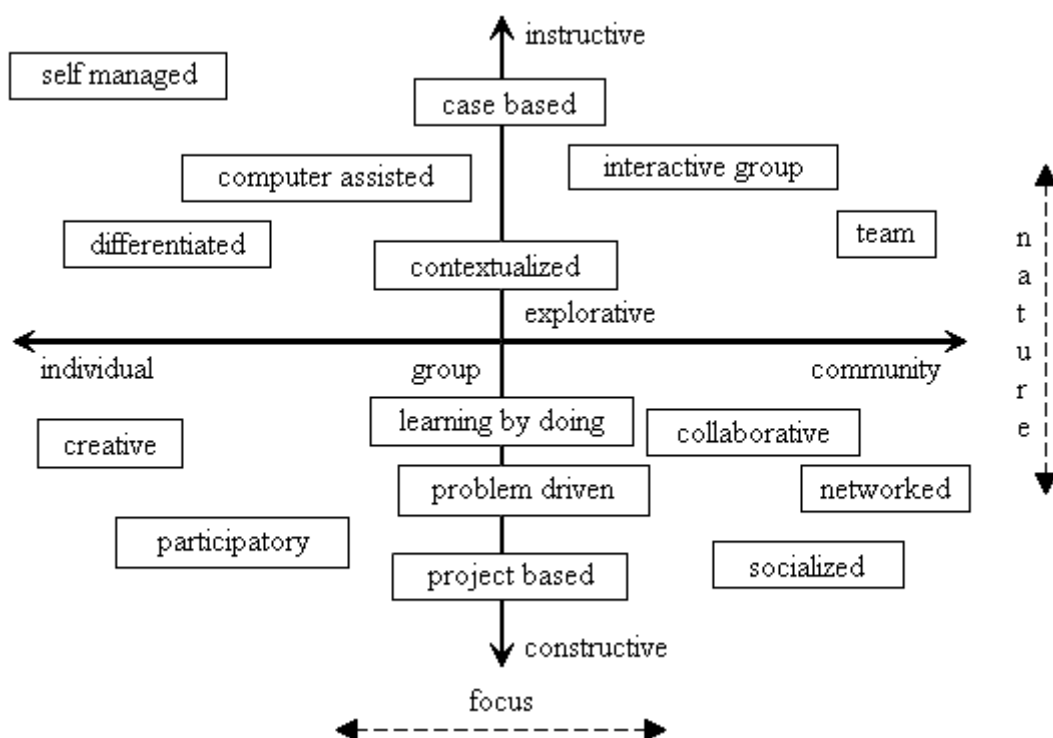
Other common ways of increasing activity within a course are the practical laboratory session and the tutorial session. Laboratory sessions are sessions in which the student has responsibility to execute a series of experiments, record and analyse the resulting data whilst supervised and assessed by a qualified academic. These sessions can be worth up to 30% of the overall grade for an electronic engineering module at Loughborough University and form part of the coursework assessment component. Tutorial sessions (small group work) are for the students to work through problems similar to those that will be seen in the examination and to discuss the meaning of those theoretical problems and results and how they apply to real world situations. The questions are provided in advance of the tutorial with the expectation that the student will work through them and bring solutions (or attempts at solutions) to the session. This is a formative exercise and there are no repercussions should the student fail to complete the exercises before the tutorial class (or fail to attend the sessions). Feedback given as part of formative assessment helps students become aware of any gaps that exist between their desired goal and their current knowledge understanding or skill and guides them through actions necessary to obtain the goal [72].

In the United States active engagement in the course material is ensured by weekly homework graded to count for 10-15% of the final module mark, a mid-term examination contributing some 45% and a final examination contributing 35-40% [73].

Felder [74] suggests an approach to maximise student attention spans by breaking the lecture up and providing a brief period in which the class breaks into small casually arranged groups to find the solution to a problem posed which relates to the lecture (or part thereof) recently delivered. It is suggested that this approach removes the fear factor associated with asking individuals for responses without prior warning. This is especially useful if the questions asked (and responses) are designed to provoke higher level thought processes [71].

Horváth et al [75] display a topography of approaches to active learning as part of their paper, and it is reproduced below in Figure 3.1. The axes represent two independent aspects and show how active learning incorporates a very wide variety of stratagems based upon how many learners are involved and how (by whom) the activity is directed.

The educational benefits of active learning approaches are that the student is able to follow his or her own learning path and, particularly in active paradigms that involve group work, receive immediate confirmation or correction of the way in which he has incorporated new data into his existing mental models and schema. The group structure will also aid in the student's preparation for professional life, where he will be expected to work both in a team and in a hierarchy where communication is essential.



**Figure 4.1 – Approaches to active learning [75]**

### 4.3.2 Cooperative Learning

A special case of active learning is termed cooperative learning (CL). This again is a reasonably broad term, and as the name suggests there is a requirement for the learners to be organised into groups; the main difference between cooperative learning and other forms of



group based active learning is the formality of the group. In cooperative learning the group is formed at the beginning of the course, following guidelines to promote heterogeneity and remains intact throughout the course. This is not a requirement in other forms of active learning where the groups are often formed informally based on arbitrary criteria such as seating position, however the benefit of doing it in this manner is that it allows the groups to be given more complex tasks to complete.

Cooperative learning techniques exhibit five defining characteristics [74] [67] [76]

1. Positive Interdependence – Underperformance of an individual results in negative consequences for the team as a whole
2. Individual Accountability – Each member of the team is required to understand the whole as well as their individual contribution
3. Face to face interaction – Tasks must be structured such that interaction is required
4. Teamworking/collaborative skills – Conflict resolution, leadership, and communication are essential
5. Team self-assessment – Periodic and ongoing to maximise effectiveness

Cooperative learning can be seen to work as a result of generating an environment where the students' inherent drive to succeed and compete is used in a beneficial manner to bring along the less able students in an encouraging peer led learning environment. This results in higher levels of participation within the class environment [62] and is of particular importance to under-represented groups who may feel more intimidated and unable to participate in more traditional paradigms.

An effective way to police all 5 characteristics within cooperative learning in a fair manner is to take into account individual effort within the group structure, however, the only reasonable way to do this is to have the group members themselves rate each other. Kaufman and Felder propose a solution to the problem [77] which involves peer review of the contributions from each group member and is shown to work well and account for problems of hitchhiker students (who do very little work on group assignments) and of agreed ratings (where each student gives the same rating to the others).

When CL is implemented well it is shown to increase retention and satisfaction with the discipline [62], resulting in more students completing their courses, as well as the obvious

increases in activity on the part of the learner. It has also been used to increase out of class studying time [78], which understandably correlates with increased performance. There is also evidence for increased propensity to study in small groups in the future (CL without the explicit desire of the instructor and therefore without specific goals set by them).

#### **4.4 Micro-computer Based Laboratory Teaching**

As discussed previously, traditional instruction is ineffective at developing both important concepts and students. This has been noticed in particular in physics education where students who are able to solve algebra or calculus based problems fail to agree with physicists on simple conceptual problems, and enter and leave courses with fundamental misunderstandings [69]. This may have relevance for Electrical Machine Theory where similar conceptual misunderstandings arise.

Micro-computer Based Laboratory (MBL) tools have been used in small groups to reduce the load on students in terms of data collection and analysis (this is often possible to do in real-time), in predict-observe-explain (POE) learning cycle exercises. This requires the students to predict the outcome of an experiment either in the form of discussion or written, along with their reasons for making those predictions, then, once the experiment is concluded and the data available, compare the observed outcomes with their predictions. The groups can work to explain any unexpected phenomena, and if necessary obtain guidance from the instructor in the form of leading questions encouraging them to identify the true causes of observed behaviour and thus the underlying concepts for themselves thereby empowering the student.

Effectiveness of MBL tutorials is assessed using multiple choice questionnaires (MCQs) both prior to and subsequent to instruction, which feature the correct response and common misconceptions as distracters. This means that students getting the right answer have either guessed or have a firm understanding. If the sample size is large, correct guesses can be assumed to cancel with incorrect guesses and have no overall effect on the scores. The MCQs are teamed with long-answer exam questions in which students are expected to explain and discuss their answers [79].

Results indicate that MBL tutorials (as little as one hour a week) have positive effects on students understanding of fundamental physics concepts, far in excess of those possible with increased traditional instruction time, even when the traditional instruction time is greater

than the extra time attributed to the MBL tutorial sessions. Further improvement is possible with increased MBL time.

However, it can be shown that simply using MBL tools in isolation purely as a technological tool to remove the need to manually record and analyse data is not effective, and can lead to confusion [80]. If MBL tools are to be used then they must be used both as a technological and a cognitive tool with an associated change in teaching styles to exploit their advantages.

Another use of MBL tools, when restrictions in equipment or time make the full scale implementation of MBL sessions either impractical or impossible, is the use of those tools within a traditional lecture, creating an Interactive Lecture Demonstration (ILD) [69] [81]. This is when there is one equipped computer and some form of display device is coupled with a series of experiments to explore the conceptual foundation of a topic.

The key active component is the POE cycle and involvement is elicited by requiring students to fill out prediction sheets individually then again after a short time of group discussion, before being collected, and groups chosen to express their predictions to the whole class. These predictions occur after the experiment has been described and demonstrated by the instructor without the MBL tools engaged, so take the form of “sketch the graph of acceleration with time for object 1”, something which very easily can be seen to be true or false when the experiment is repeated with the MBL tools engaged.

Following the experiment with MBL tools engaged, the results are discussed by the students, and the class record the results on a results sheet (which they keep as a reference for themselves). The instructor runs through some analogous physical situations with different surface features (other examples of the same concept). Evidence suggests that learning as a result of ILDs incorporated into otherwise traditional courses vastly improves, and the learning is long term, meaning the ILDs have fundamentally changed the conceptual understanding with which students view their environments. If this is true, it is a highly significant result as Meyer and Land [35] define a threshold concept as one which changes the way in which the student sees the world, and based upon the results without ILDs, troublesome.

## **4.5 Teaching and Learning Styles**

### **4.5.1 Overview**

It is widely acknowledged that not all learners learn in the same way [82]. These individual differences are characterised as learning styles. Learning style can be broadly defined as the way in which a learner (student) prefers to receive and process information. It is a long term and relatively fixed trait [83], related to both general cognitive ability and personality (more so personality). Since both of these are heritable [84] [85], the implication is that there is at least some genetic basis for learning style.

However, both general cognitive ability and personality can be influenced by external environmental factors, by up to 50% [84], as evidenced by the trend towards increasing IQs [86], above that which would be expected from inheritance alone, and the change in personality associated with children adopted from abusive families [84]. Given the adaptability of these two traits it is highly likely that related traits (learning styles) are also adaptable, but this is subject of debate with various models offered as explanation.

It is important to note that many researchers undertaking studies of learning style attempt to categorise models according to some feature or other within them. This frequently results in a family of learning styles known as approaches or strategies (to learning).

It would be remiss to talk about learning styles without also talking about approaches and strategies to learning; however it is equally erroneous to talk about them as though they were representations of the same thing. The fundamental difference is that approaches or strategies are context specific, short-term, and quite possibly go against the preferences of the learner.

### **4.5.2 Models**

A recent comprehensive review undertaken by Coffield et al [87] identified close to 9000 references about learning styles, of which almost 900 met the inclusion criteria for review. From this comprehensive literature review the authors were able to identify 71 distinct models, the following 13 of which they deemed to be highly influential by virtue of their high citation count, widespread adoption, and fertility.

1. Allinson and Hayes' Cognitive Styles Index (CSI)
2. Apter's Motivational Style Profile (MSP)
3. Dunn and Dunn model and instruments of learning styles
4. Entwistle's Approaches and Study Skills Inventory for Students (ASSIST)
5. Gregorc's Mind Styles Model and Style Delineator (GSD)
6. Herrmann's Brain Dominance Instrument (HBDI)
7. Honey and Mumford's Learning Styles Questionnaire (LSQ)
8. Jackson's Learning Styles Profiler (LSP)
9. Kolb's Learning Style Inventory (LSI)
10. Myers-Briggs Type Indicator (MBTI)
11. Riding's Cognitive Styles Analysis (CSA)
12. Sternberg's Thinking Styles Inventory (TSI)
13. Vermunt's Inventory of Learning Styles (ILS)

Of the 71 more than 50 were able to be grouped into five families, which the authors present on a continuum based on “*the extent to which the authors of the model claim that styles are constitutionally based and relatively fixed*” (left hand end), “*or believe that they are more flexible and open to change*” (right hand end) [87]. The authors of the study acknowledge however that “*it is not perfect and some models are difficult to place*” and “*the scope of this project did not allow us to examine in depth all of these and there is therefore some risk of miscategorisation.*” The family of styles at the extreme right of the table is the previously mentioned approaches and strategies family, which are covered later in this thesis.

Styles and preferences are constitutionally based including the four modalities.	Styles reflect deep-seated features of the cognitive structure, including 'patterns of ability'.	Learning styles are one component of a relatively stable personality type.	Learning styles are flexibly stable learning preferences.	Move on from learning styles to learning approaches, strategies, orientations and conceptions of learning.
<ul style="list-style-type: none"> <li>• Dunn and Dunn</li> <li>• Gregorc</li> <li>• Bartlett</li> <li>• Betts</li> <li>• Gordon</li> <li>• Marks</li> <li>• Paivio</li> <li>• Richardson</li> <li>• Sheehan</li> <li>• Torrance</li> </ul>	<ul style="list-style-type: none"> <li>• Riding</li> <li>• Broverman</li> <li>• Cooper</li> <li>• Gardner et al.</li> <li>• Guilford</li> <li>• Holzman and Klein</li> <li>• Hudson</li> <li>• Hunt</li> <li>• Kagan</li> <li>• Kogan</li> <li>• Messick</li> <li>• Pettigrew</li> <li>• Witkin</li> </ul>	<ul style="list-style-type: none"> <li>• Apter</li> <li>• Jackson</li> <li>• Myers-Briggs</li> <li>• Epstein and Meier</li> <li>• Harrison-Branson</li> <li>• Miller</li> </ul>	<ul style="list-style-type: none"> <li>• Allinson and Hayes</li> <li>• Herrmann</li> <li>• Honey and Mumford</li> <li>• Kolb</li> <li>• Felder and Silverman</li> <li>• Hermanussen, Wierstra, de Jong and Thijssen</li> <li>• Kaufmann</li> <li>• Kirton</li> <li>• McCarthy</li> </ul>	<ul style="list-style-type: none"> <li>• Entwistle</li> <li>• Sternberg</li> <li>• Vermunt</li> <li>• Biggs</li> <li>• Conti and Kolody</li> <li>• Grasha-Riechmann</li> <li>• Hill</li> <li>• Marton and Säljö</li> <li>• McKenney and Keen</li> <li>• Pask</li> <li>• Pintrich, Smith, Garcia and McEachie</li> <li>• Schmeck</li> <li>• Weinstein, Zimmerman and Palmer</li> <li>• Whetton and Cameron</li> </ul>

**Table 4-1. The continuum of learning styles. From Coffield et al 2004 [87]**

Curry proposed an onion metaphor to cope with the layers of learning style, with the innermost layer being the hardest to measure directly, most important in complex learning and most resistant to external influence. This is the cognitive personality style layer, defined as “as the individual's approach to adapting and assimilating information” [88]. It is measured with tools such as the Myers-Briggs Type Indicator, a well known tool, exhibiting high face validity but attracting criticism for its construct validity [87], used for identifying personality type, from which learning style is inferred, and the Embedded Figure Test used by Witkin to identify Field Independence/Dependence, a trait with which several learning characteristics are said to associate but is often said to be more a measure of ability and aptitude than style[ibid].

The second layer of the onion is the information processing style, measured with tools such as Kolb's Learning Styles Inventory, which often attracts criticism for low reliability (particularly test-retest). The counter argument is that the inventory is reflective of a sound theory which centres on dynamic progression and thus low reliability is to be expected. It is the characteristic way in which students prefer to assimilate information about a problem, which is often measured on a scale from small, sequential bites which are linked with previously learned bites, to a “big picture” approach where learners seek patterns and trends in a large amount of data, progressing by looking closer at each subsection to build up the same level of understanding as the sequential learners. It is proposed that this level is more readily modified by learning style [88].

The outermost layer of the metaphor is the instructional preference, an individual's choice of environment in which to learn. This is the most easily modified of the layers and affected by all the environmental interactions (including those outside of educational environments) of the individual to that point. It is entirely possible that the instructional preference of a student may vary according to subject matter.

#### **4.5.3 Models of interest**

Dunn and Dunn present a model of learning style, which is possibly one of the most complex (they would argue complete) available. They identify 5 “*biologically and developmentally imposed*” key factors [89], each with a number of variables, which combine to generate the whole style, however, it may be that some of the aspects of style identified are superfluous; It

stands to reason that a student needs to be physically comfortable in order to study effectively.

Some of the other equally basic aspects are impossible to accommodate, especially as one progresses into formal education and class sizes get larger, as they are particular to individuals. The learning style identified, including all the environmental and physical aspects, is “*as individual as a signature*” [89]. There are correlational studies between learning style and hemisphericity, such that dichotomous terms such as global/analytical are synonymous with right/left (referring to active hemispheres of the brain). Thus a right hemisphere learner is also referred to as a global or deductive, and a left hemisphere learner is referred to as analytical or inductive[ibid].

If it is true that modes of thinking are linked to brain hemispheres, several questions arise: How does this change as a learner increases in age, particularly before and during puberty? Is it reasonable to say that post-puberty, as with a majority of other anatomical attributes, brain structure can be assumed fixed? Will a student who prefers activity as a child still prefer it as an adult, or will something physiologically have changed, or will it have been trained out of him by years of rigidity in education?

Gregorc proposes a two dimensional model of learning [87] [90] which reflects a person's preferences for perception and ordering of information. Perception measures preferences for concrete perception of information, through the physical senses vs. abstract perception, generated from understood concepts and internal reasoning. Ordering contrasts the preference for sequential ordering, utilising logical, planned and traditional approaches with random ordering which utilises novel and seemingly illogical approaches. Gregorc is an advocate of matching instruction to learning styles, and claimed that ignoring your “*God-given learning style*” could result in illness [83]. Given the rise in stress of recent years, he may have a point, despite his flawed reasoning for the origin of style!

This is another model linked to hemisphericity of the brain, with abstract perception linked to the right hemisphere, and concrete perception to the left. The orthogonal dimension, ordering, is linked to Pask's serialist-holist model (which categorises learners purely along that one dimension). There is evidence that learners in science, particularly the physical sciences, tend to be serialist thinkers, preferring to use information piecemeal and gradually constructing the

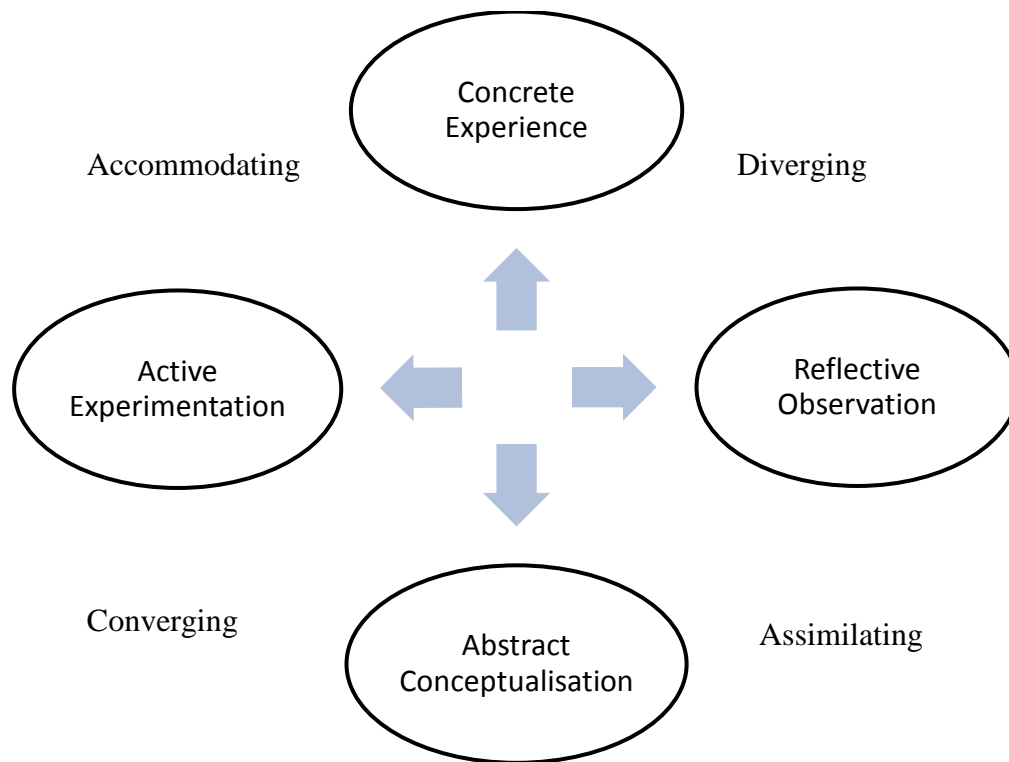


‘big picture’ where holists tend to use more information to generate large chunks which are combined later to attain the same level of understanding. It is important to recognise that these two approaches are not seen as one better than the other, unlike Field Dependence [91].

Field dependence is however closely linked to cognitive ability [90], meaning that although one can determine from this traits and behaviours that a learner is likely to exhibit, that is more a reflection of the stage of their cognitive development than it is a reflection of how they will always learn.

Other models which use a single dimension to categorise learners include Kirton’s Adaption-Innovation dimension, Kaufmann’s Assimilator-Explorer dimension (where adaptors/assimilators try to do things better in ways they already know and innovators/explorers prefer to do things in novel ways), and Allinson and Hayes’ Intuition-Analysis dimension [90]. Allinson and Hayes base their model on the assumption that the tendency to be analytical or intuitive is the super-ordinate dimension of learning style, and is based on brain asymmetry in the same way as Gregorc and Dunn and Dunn. The difference between the three is that Allinson and Hayes readily admit that learning style can be influenced by culture and experience, and even overridden in certain situations. Gregorc measures a second dimension, and Dunn and Dunn measure a multitude more [89].

Kolb’s experiential learning theory has been highly influential in education. It centres on a two dimensional model, and contests that, although learners have a preference on each dimension, learning is a process that requires the resolution of conflict on each dimension, by progressing through the other. The dimensions are prehension, whether one prefers to obtain information from abstract conceptualisation or external experience, and transformation, what one does with the information in order to further understanding. Kolb asserts that a learner will progress from the concrete experience standpoint to the abstract conceptualisation standpoint, via reflective observation, and back to concrete experience via active experimentation.



**Figure 4-2 – Kolb’s Experiential Learning Model.**

There are four learning styles associated with this model, which the learner must utilise in pairs as they progress around the cycle:

- A diverging style is required to move from the concrete experience stage to the reflective observation stage, that is to find meaning from the new information garnered through concrete experience.
- An assimilating style is required to incorporate the new understanding with the existing schema, if necessary modifying the schema to fit, in order to generate a new conceptual understanding.
- A converging style is required to generate testable hypotheses and associated testing techniques
- Finally, an accommodating style is required to implement the testing techniques to verify the conceptual understanding by generating new concrete experiences

As learning is viewed as a cycle in this model, and all of the styles are equally important, it is important not to label a learner as any one of the four types. Labelling, while useful in other models which advocate matching teaching to learning, is a definite danger in this model, and

matching positively disastrous. To match a learner in this model would lead to stagnation, and thus prevent further learning. A preference may be exhibited for one or two (always a sequential pairing and usually diverging/assimilating or converging/accommodating) but this just means that the learner must strive to develop the other styles. The most effective learner is equally adept in all four styles.

Honey and Mumford adapt the work of Kolb [92], and transfer the learning styles to the poles of the domains, which alleviates the transient nature of the transformation dimension. Thus an activist learns through active experimentation, a reflector through reflective observation, a theorist through abstract conceptualisation, and a pragmatist through concrete experience. This work can be viewed as an improvement on the original model as it retains the strengths of the original design and cycle, while addressing the weakpoints.

Myers-Briggs Type Indicator is a development which formalises Carl Jung's theory based on observations and anecdote [93]. It is a measure of personality, not of cognitive style directly. It is incredibly widely used, in both educational and corporate situations. It uses 4 dichotomous scales to indicate a preference in each one, and it is the way in which they combine which results in the final personality type. In other words it is not possible to take any one scale independently of the others.

Very closely related to this is the Kiersey Temperament Sorter [94], developed independently of the MBTI, but correlating well. Kiersey describes four temperaments, each with two roles, each of which has two role variants (resulting in 16 total role variants). Myers and Briggs, following Jung, emphasised the Extravert/Introvert dimension, while Kiersey emphasises the Concrete/Abstract dimension.

Because of the different emphasis placed on the dimensions, the temperaments associated with Kiersey's work do not map succinctly with any aspect of the Myers-Briggs typology, no function or pair of functions is consistently dominant for any temperament, hence the rather strange labelling of SP, SJ, NF and NT for the Artisan, Guardian, Idealist and Rationalist temperaments respectively.

Apter's Reversal Theory [95] maps people onto four dichotomous domains, but suggests that states are dynamic and the inherent variation of the states effects the way experiences are quantified within the self. The 4 domains are:

- Means-ends
  - Poles are seriousness and play
  - Refers to motivation by achievement or process.
- Rules
  - Acquiescence and resistance
  - Whether one likes to operate within a rigid structure or push against boundaries
- Transactions
  - Power (or mastery) and love (or sympathy)
  - Motivated by power, competition and control or care and compassion
- Relationships
  - Self-oriented and other-oriented
  - Motivated by self interests or an internal sense of responsibility or altruism

Clearly some of these states are more amenable given certain situations (for example, a task which one normally enjoys but has “been going wrong” can result in a switch from a playful disposition to a serious one) and environments (it might be difficult or impossible to be motivated by altruism when working individually).

#### **4.5.4 Summary**

The wealth of information and competing models for learning styles is indicative of the fact that no two students will learn exactly alike. The differences between the styles, be they superficial differences in terminology, or more substantial differences rooted in the underlying theories, highlight the breadth of research in the field, and reflect the philosophical and psychological leanings of the authors.

Some researchers suggest that the most effective way to teach students is to match the instruction offered to the learning styles of the students, and that failing to do so risks damaging the student or results in poorer performance. Others argue the opposite, and suggest that matching instruction results in students who are able to only function in a single manner, and are thus weaker. Mismatching, they argue, is a valuable, if not essential, tool in producing well rounded students who are able to function proficiently in their chosen field, with people who may learn differently to themselves.

Given the large class sizes in education, and the increasing need for structure as education progresses, individually tailored instruction proves impractical. It is highly unlikely that all students within a class will wish to learn in a similar manner, and thus it is inevitable that mismatching between teaching style and learning style will occur for some students. It is therefore imperative that teaching staff are aware of the limitations of their preferred approach, and take steps to use a variety of techniques such that all learners are included and reached.

#### **4.6 Quantifying Learning**

How well one has learnt something can be classified in two ways, quantitative or qualitative. All the testing used to explain structural features of memory, such as capacity, retention time, recency effects and even the encoding techniques investigated by Shulman rely upon quantitative testing, that is to say how many items of a list can be remembered over what time period. It is easy to categorise one response of this nature as better than another simply by the number of items remembered. Categorising responses for quality is considerably more difficult and a problem that is faced by educators worldwide. Bloom led a group of educators aiming to classify educational goals and objectives, which results in a taxonomy of six levels, each of which describes a different quality of response [96]. The levels, in increasing order of complexity, are defined most elegantly by Biggs and Telfer [1, p. 463] as

1. Knowledge – rote reproduction of the correct response;
2. Comprehension – explaining the response in the student's words;
3. Application – applying the knowledge to a practical situation;
4. Analysis – isolating crucial components of the knowledge;
5. Synthesis – recombining elements to yield new knowledge;
6. Evaluation – applying higher order principles to test the worth of the new knowledge

This taxonomy is revised by Anderson and Krathwohl [97] to give essentially the same levels but instead of nouns being used to label them, verbs are used. This is because the revised taxonomy makes a distinction between the knowledge and cognitive domains where the original did not, and the noun forms are unsuitable as descriptors of cognitive processes, and although subtle, is an important change. Another seemingly minor change is the renaming of the Synthesis level to “Create” which implies the active construction of meaning and plans of

action to carry out rather than simply making new knowledge fit with existing. Because of this emphasis on constructing meaning Create is moved to the top level of the revised taxonomy. One final change as a result of the emphasis on meaning is the change from Comprehension to Understand, which stays in the same place in the revised taxonomy [97], making the final revised taxonomy of cognitive processes

1. Remember – Retrieve relevant knowledge from long term memory
2. Understand – Construct meaning from oral, written, and graphic messages
3. Apply – Carrying out or using a procedure in a given situation
4. Analyze – Break material into constituent parts, determine how the parts relate to one another, and to an overall structure or purpose
5. Evaluate – Making judgements based in criteria and standards
6. Create – Put elements together to form a coherent or functional whole; reorganise elements into a new pattern or structure

These taxonomies were written as frameworks to allow university examiners to produce assessments that yielded qualitative judgements on students, and have since become widely used in many fields. It is not required, or even expected, that a student climbs to the highest levels of the taxonomy, indeed, for many it will be sufficient to reach level 2 or 3; A mechanic does not need to understand the thermodynamic processes of the internal combustion engine to change a spark plug.

#### **4.7 Conceptions of Learning**

It is widely recognised that individuals approach learning in different ways and qualify their approaches in a variety of manners. The most widely recognised approaches to learning are the surface and deep approaches [98], in which the learning outcomes can simplistically be defined as being able to reproduce information accurately and being able to apply understanding respectively. These approaches will be returned to later, but for now the focus should be on the conceptions of learning (as these influence approaches and thus outcomes, not the other way about).

A conception of learning is simply what the learner believes learning to be and can be grouped broadly into two areas, quantitative and qualitative. The quantitative conceptions generate a surface approach to learning and reproductive learning outcomes. The qualitative

conceptions correspond to the so called higher order thinking skills, lead to a fundamental change in the self, and are characterised by constructive outcomes which require a deep approach.

Säljö [99], identifies five conceptions of learning stemming from interviews with adults and children of various educational levels, in which they are asked to define “What do you mean by learning?”. The conceptions are identified as a pseudo-hierarchical series as follows:

1. An increase in knowledge
2. Memorizing
3. An acquisition of facts or principles
4. An abstraction of meaning
5. An interpretive process aimed at understanding reality

The first conception is over-arching, simply answering the question with a synonym. The second two conceptions are quantitative, depicting knowledge as a collection of ready made external constructs which must be reproduced either in isolation or together with other pieces of knowledge to answer questions for assessment. The final conceptions are qualitative, depicting knowledge as a raw material which the learner must selectively use.

When the sample interviewed is taken from an educational background ( i.e. students) then the context of the initial question is changed, from a general sense to the more specific sense of educational learning. When students enrolled in a social science course are interviewed [100] the original five conceptions are identified along with a new sixth conception.

1. Increasing one’s knowledge
2. Memorizing and reproducing
3. Applying
4. Understanding
5. Seeing something in a different way
6. Changing as a person

Marton et al [100] attempted to define the conceptions more narrowly, and in so doing split the conceptions into two groups of three. The first group is quantitative, characterized by the collection of discrete pieces of ready-made knowledge, while the second group is qualitative,

characterized by the generation of meaning. The first conception is not bounded in the external world, implying that there is no distinction between learning and life in general, where in the second there is a boundary that distinguishes learning from life created by an anticipated need to reproduce the acquired knowledge for some form of assessment. The third conception is the last of the quantitative conceptions, and can be partnered with the first in as much as the external world boundary is absent. This conception can be distinguished from the first by the emphasis on application rather than acquisition, and from the second by the lack of an external boundary restricting the application to a prescribed test situation.

The final three conceptions can be easily differentiated from the previous based on the lack of ready-made knowledge. In the remaining conceptions meaning, which is not present prior to the learning situation, is constructed by the learner from the given information and information already present within the learner. The distinguishing feature between conceptions 4 and 5 is the external boundary, present in 4 restricting the development of meaning to the study situation (compare with conception 2 where the application was restricted to the test situation) and not present in 5 where the development of meaning is applied to the world as a whole. The final conception of learning, change as a person, comes as a result of developing new insights into phenomena causing one to view those phenomena differently, which in turn causes one to view themselves differently.

It should be noted that this sixth conception was found in a group of part-time social science students, and the educational context has been shown to have an effect on the conceptions of learning. Eklund-Myrskog [101] reports differences in the conceptions shown by a group of student nurses compared to a group of student car mechanics (nursing students show a higher propensity for higher order conceptions) both at the start and the end of a period of instruction. The conceptions appear to evolve throughout the period, indicating that instruction itself has an effect on the conceptions of learning, but the disparity between the two groups remains. It is interesting to note however that even the student mechanics with their predominantly quantitative conceptions fail to exhibit evidence of the first conception presented by Säljö.

In an engineering context [102] the first conception is again missing, however the five remaining conceptions are found again. In this study the conceptions can be grouped into quantitative and qualitative the same as Marton et al [100], with the two quantitative



conceptions forming a pair, one focussed on the acquisition of knowledge and the other the application of knowledge. This pairing can be seen in the first two of the qualitative conceptions too, while the final conception of change as a person stands in isolation.

The external boundary found by Marton et al restricting learning to the educational context (found only in some conceptions) is removed from the definition of the conceptions entirely. As the respondents in the Eklund-Myrskog [101] and Marshall et al [100] studies are all from an educational background, the question, although using the same words, implies educational learning, where in the Säljö [99] (and thus Marton et al [100]) study this implication was not present.

These conceptions change the focus of the learning activities. For the quantitative conceptions the focus is on the reproduction of the learned materials and the lower order thinking skills given in the Bloom and SOLO taxonomies [96] [45] [§3.2.3][§4.4], while for the qualitative conceptions the higher order thinking skills are emphasised.

#### **4.8 Approaches to Learning**

Marton and Säljö [98] identify several levels of outcome and two levels of processing from a phenomenographic approach. This approach essentially is to have the students study a passage of prose and subsequently interview them with an aim to finding out both which features of the prose are recalled but also the strategies used to aid in that recall. The learning outcomes identified correspond to the levels of the SOLO taxonomy [103], which is to be expected, despite the fundamental differences in approach (namely the prior quantisation of learning outcomes and the differences between them in the SOLO taxonomy).

The levels of processing identified are termed “surface-level” and “deep-level” and correspond to the aspects of the learning material on which the student focuses. A surface level approach focuses upon the text itself referred to as “the sign”, while a deep level approach focuses upon the intentional content of the material, referred to as “the signified”. As expected a surface level approach precludes the achievement of the highest level learning outcomes, while a deep approach allows the achievement of the highest level outcomes (and as the outcomes are hierarchical lower level outcomes too).

Von Rossum & Schenk [103] studied a group of psychology students, grouping them according to how they approached a text, judged from their answers to open questions to that effect. The distribution of approaches was roughly equal, and the studying approach was influenced by what the student perceived the content of the question would be, knowledge more important for surface approaches and insight more important for the deep learner. This study also correlates the deep approach with the higher order learning conceptions, as defined by Säljö [99].

In correlating the learning outcomes with the learning approach, all of the surface learners were classed on the SOLO taxonomy as providing a Multi-Structural response, characterised by answering with several main points of the answer but not with any relationships between those points. The deep learners provided a majority of Relational responses, including the main points of the surface learner but importantly also providing the relationships between them. Some learners achieved the higher level of Extended Abstract, bringing in abstractions from outside the learning material and coherently including them in their answers.

The approach to learning is influenced not only by the conception of learning, but also by the assessment anticipated by the learner. Marton and Säljö [98] provide a quote from one of their subjects “It would’ve been more interesting if I’d known that I wasn’t going to be tested on it afterwards, ‘cos in that case I’d’ve more, you know, thought about what it said instead of all the time trying to think now I must remember this and now I must remember that” which shows that the student had adopted a surface level approach because he was anticipating assessment of his factual knowledge.

This is expanded upon by the same authors [104] where students are exposed to three texts without instruction on how to study. Between the second and third texts the students are given an assessment focussing either on the factual content of the texts, or on the implications of the text. This is shown to influence the students approach to the third text, particularly in the case of students exposed to questions on factual content and the authors conclude that “Students adopt an approach determined by their expectations of what is required of them”.

Following on from this work Entwistle and his team [105] state that “*the methods of teaching and the assignments given contain explicit and implicit messages to the students about the*

*target understanding that is required*", the implication of which is that the approaches used by the students are also influenced.

Case and Marshall [106] present a joint paper showing results indicating two further approaches to learning (one found by each author in independent studies) that lie between Marton and Säljö's deep and surface approaches [98]. These new approaches are called "*procedural*" and "*algorithmic*" and are generated as a result of combining study habits and techniques with motivation or intentions of using those techniques. These approaches are similar to each other and differentiated by the intention of developing understanding (at some future point) through application in the former approach and the preclusion of such in the latter.

These approaches are qualitatively different to the strategic approach of Rowe [107] where the intention is to obtain the highest possible grades by gearing work to the preferences of the teacher, and learning to pass the test rather than learning the material required to do so which echoes the achieving approach presented by Biggs [108].

These approaches are all different to the approach exemplified by the paradoxical Chinese learner [109], whereby the educational process inherent in the student's native culture emphasises rote learning (ordinarily considered a surface learning technique) and yet examination yields high grades indicative of a deep approach to learning. The cultural emphasis seems to produce a far stronger association of rote learning with developing understanding than the more western viewpoint of rote learning being associated with the regurgitation of factual knowledge.

## **4.9 Teaching and Learning Conclusions**

This chapter has introduced the teaching and learning environments encountered by undergraduates as expounded upon in the literature. The evidence suggests that passive environments abound despite the proven superior nature of active environments. Active environments enhance the learning process and can be implemented in a wide variety of ways, depending upon constraints imposed by the material, class structure, and institution. Technology can often be used in an attempt to promote active learning, frequently in the form of enhanced presentation tools, but sometimes in the form of interactive tools for the use of either students or faculty.

It is now widely accepted that students learn in qualitatively different ways, and these are either exploited or hindered by the different ways in which faculty teach. Evidence is presented showing that effective learning occurs when these styles are all exploited in conjunction with one another, rather than in isolation from one another. In other words, there seems to be an interaction between the factors that influence student understanding. Effective teaching encourages the exploitation of all learning styles, instead of relying upon a single style in which the teacher is most comfortable. It is important to maintain this variety even when the overall paradigm is shifted away from passive lectures.

It is important to take into consideration the way in which students view learning and how individual motivation affects the way in which an individual will study, and consequently perform, especially when the viewpoint of student and faculty fail to correlate. Opposing viewpoints about both what the student should understand by “learning” and the way in which the student should go about it will result in significant difficulty and low performance as assessment will be constructed to determine how well a student matches criteria he was never intending to match. This chapter has therefore identified a number of important factors which may influence student learning. However, concrete evidence of the extent to which these factors can affect student understanding of key concepts within electrical engineering remain unknown.

## **5 Identifying Student Understanding**

### **5.1 Introduction**

The previous two chapters have outlined the literature on cognitive processes and teaching and learning relevant to the acquisition of knowledge and understanding within electrical engineering. They form the basis for the research outlined in this chapter which aimed to identify how students gain understanding of key concepts within the machines and systems module.

There has been limited research offering an application of the pedagogical literature to understanding key concepts within the field of electrical engineering. An exploration of the different ways in which students approach their studying may offer insights into study practices which would enable teaching staff to provide tailored support to students as they make the transition through threshold concepts.

### **5.2 Outline of research presented in this chapter**

This chapter presents the findings from a questionnaire study which was undertaken with third year engineering students registered for the electrical machines and systems module at Loughborough University, UK. This module was chosen as it provided the opportunity to examine a small cohort of students studying a module in which key concepts could be easily identified by teaching staff. In addition, performance data indicated that student attainment during assessment of these key concepts was routinely poor over consecutive years.

This initial study involved administration of a bespoke questionnaire at three time points to students registered on the electrical machines and systems module during the academic year 2008/2009. Data were gathered from the students at the outset of instruction, a point approximately two weeks after the outset of instruction, and at a point approximately half way through the instruction, towards the end of the first semester. The questionnaire was designed to evaluate student understanding of concepts which were identified by teaching staff as being core to the module and to the topic of Electrical Machine Theory.

### **5.3 Aims and objectives**

The objectives of this study were to identify the understanding exhibited by students registered on the module 09ELC040 (Electrical Machines and Systems) in relation to three core theoretical concepts which form the basis for understanding electrical machines, namely

1. magneto-motive force (mmf)
2. inductive reactance, and
3. phasors

Hypothesis 1. There will be no difference between the responses obtained from the questionnaire and those which would be expected by chance.

### **5.4 Participants**

All final year students registered for the electrical machines and systems module during the academic year 2008/2009 were invited to participate with the study. In total 23 students agreed to take part and completed the pre-sessional questionnaire. Attrition was low and a total of 19 participants completed the second pre-sessional and mid-sessional questionnaire. Attrition was due to participants' non-attendance at scheduled lecture classes during which the questionnaires were administered by academic staff. Participants were thanked for their contributions, and were informed that all responses would be reported anonymously

### **5.5 Methods**

#### **5.5.1 Pre-sessional questionnaire**

A questionnaire was developed which consisted of four multiple choice questions, designed to test student understanding of the key concepts outlined above prior to the module. These questions were developed through consultation with academic members of staff. A self-completed questionnaire was considered the most appropriate research tool to use as it facilitated the collection of data from a relatively large group of students in a short time period and offered the potential for a high response rate.

The first question tested understanding of mmf and asked students to select which of four answers best described what they understood mmf to be. The range of answers included, the correct answer (the mathematical definition) and three incorrect answers that were attractive

distractors (the analytical definition, the analogy to emf [electromotive force, which “drives” current around a circuit] and the definition often given in textbooks).

The second question tested student understanding of the concept of inductive reactance by asking students to select between six possible answers. The answers included the correct response (an invented element reflecting the effects of a magnetic field created by a second circuit) along with five attractive distractors (AC equivalent of resistance, an invented element reflecting the effects of a magnetic field created by the same circuit, the definition of impedance, and two incorrect definitions of impedance).

The third question tested student understanding of the concept of phasors and asked students to select one of five possible answers to reflect their understanding. The correct response to this question was a pictorial representation of a quantity which varies sinusoidally, in either time or space. There were two correct responses for this question, alongside three incorrect distractors (the definition of a vector, and two distractors which miss the salient point of sinusoidal variation).

The final question asked students to select which of 11 statements covering all three concepts they believed to be true. The statements covered different aspects of the concepts than those covered by the first three questions.

A copy of the questionnaire can be found in Appendix B.

### **5.5.2 Pre-sessional questionnaire 2**

Following the initial data collection and subsequent analysis it was decided to re-administer the questionnaire to the same student group but with slight alterations to two of the questions (the second and fourth). This was because there was insufficient evidence to suggest the students were answering the questions based on their understanding of the concepts. Instead, the analysis suggested that the students may have been guessing.

The analysis of question 2 did not yield a significant result. This could imply that either the students were guessing answers or that understanding of the concept of inductive reactance was poor at the time of the test. To remove this potential for bias the second iteration of this

question was introduced to reduce the degrees of freedom on the chi-squared test by collapsing the three least popular answers into a single response option.

The fourth question initially gave a series of statements about the concepts and asked the students to identify which of the statements they believed to be true. The question was modified by removing some of the statements and asking for a true or false response to each remaining statement.

The replacement questions were administered to the students after the data from the first questionnaire had been analysed, during which period the students had received instruction on the topic of transformers.

A copy of the modified questions can be found in Appendix B

### **5.5.3 Mid-sessional questionnaire**

The mid-sessional exercise (see Appendix C) consisted of the original first and third questions, and the altered second and fourth questions. The same students who participated in the pre-sessional questionnaires were invited to continue their participation in the study by completing this further questionnaire approximately half way through the period of instruction. This questionnaire, as with the pre-sessional questionnaires, was administered during a scheduled lecture by academic staff, and participants were again reassured of the anonymity of their responses.

## **5.6 Analyses**

The data from all of the questionnaires (pre-sessional, pre-sessional 2 and mid-sessional) were collated and a hand calculation of chi-square ( $\chi^2$ ) was undertaken (Table 4.1). The chi-square test was chosen as the most appropriate for this data set as the data was non-parametric and comprised unpaired data. Chi-square tests for significance of an observed frequency against an expected frequency in any given category.



## 5.7 Results

### 5.7.1 Pre-sessional questionnaire

Answer	$\Pi_j$	Observed ( $Y_j$ )	Expected $n\Pi_j$	Observed - Expected
1	0.25	14	$23 \times 0.25 = 5.75$	8.25
2	0.25	7	5.75	1.25
3	0.25	2	5.75	-3.75
4	0.25	0	5.75	-5.75
Sum	1	23	23	0

$$\chi^2 = \sum \frac{(O - E)^2}{E} = \frac{8.25^2 + 1.25^2 + (-3.75)^2 + (-5.75)^2}{5.75} = 20.31$$

**Table 4.1 – Example Chi Square calculation (question 1)**

The results of the initial pre-sessional exercise (Table 4.1) show that for the first question on the definition of mmf there is a statistically significant response ( $\chi^2(3, n=23) = 20.31$ ,  $p < 0.001$ ).

The results for the second question did not yield a significant result. This may suggest that student understanding of the concept of inductive reactance was poor at the time of the study but it is impossible to draw definitive conclusions from a statistically insignificant result.

Multiple responses were given by a number of respondents to the third question. The responses to this question were statistically significant ( $\chi^2(4, n=34) = 43.98$ ,  $p < 0.001$ ), the overwhelming majority of respondents chose an incorrect, but not wholly incompatible option. In other words, students selected an attractive distractor as opposed to a correct answer.

In relation to the fourth question, some students failed to respond to the statements. The reason for this was not determined but consideration is given in the discussion below.

### 5.7.2 Pre-sessional Questionnaire 2

The results of the second version of the pre-sessional questionnaire indicate that the students demonstrated a far clearer understanding of inductive reactance, and that at the time of this second test the initial misunderstandings highlighted in the initial questionnaire had been corrected. The changing patterns of the answers that remained available between iterations

also shows that students were not remembering the answers they gave previously or attempting to provide the answers they think are expected of them.

Inductive reactance question ( $\chi^2(3, n=19) = 14.88, p<0.001$ )

Statement	True/False	$\chi^2$
A	10/8	Not significant
B	14/4	( $\chi^2(1, n=18) = 5.5, p<0.02$ )
C	10/7	Not significant
D	9/9	Not significant
E	5/11	Not significant
F	3/14	( $\chi^2(1, n=17) = 7.12, p<0.01$ )
G	12/4	( $\chi^2(1, n=16) = 4, p<0.05$ )
H	13/5	( $\chi^2(1, n=18) = 3.555, p<0.05$ )
I	9/8	Not significant

**Table 4.2 – Chi square results**

### 5.7.2.1 *Synthesis of findings*

The results obtained from the first two questionnaires were combined to produce statistically significant models of the student understanding of the three core concepts under investigation at the outset of instruction. This would allow for a comparison with time point three data thereby allowing the student conceptual development to be mapped throughout the course of instruction.

### 5.7.3 Mid-sessional

Question one returned a significant result. ( $\chi^2(3, n=21) = 10.81, p<0.02$ )

The results from question two were significant. ( $\chi^2(3, n=21) = 14.62, p<0.0025$ )

Analysis of question three returned a significant result. ( $\chi^2(4, n=31) = 9.81, p<0.05$ )

Analysis of question four is summarised in Table 4.3.

Statement	True/False	$\chi^2$
A	11/9	Not significant
B	13/7	Not significant
C	12/7	Not significant
D	12/8	Not significant
E	3/16	$(\chi^2(1, n=??) = 8.89, p<0.005)$
F	3/16	$(\chi^2(1, n=??) = 8.89, p<0.005)$
G	12/8	Not significant
H	19/2	$(\chi^2(1, n=??) = 13.76, p<0.001)$
I	10/10	Not significant

**Table 4.3 – Chi square results**

## 5.8 Discussion – Summary of key findings

Consistent with the aims of this Thesis, the key findings from this initial study were:

- Participants demonstrated a low level of understanding in relation to the key concepts required to fully comprehend Electrical Machine Theory.
- There was consensus among participants as to how mmf should be defined but this consensus was inherently incorrect.
- Participants also demonstrated consensus in how phasors were defined but again this was based on an incorrect assumption.
- The course of instruction appeared to be ineffective in addressing this low level of understanding

In the first question there was a clear consensus given by the students on what they believe mmf to be. The option chosen is however the incorrect analogy to emf. This is not surprising given the similarity of the names and the fact that the two concepts are often introduced as analogous. The fact that the mid-session questionnaire also exhibits the same response pattern (students choosing the analogy with emf over the correct response) indicates that instruction received through the first half of the course is insufficient to correct incorrect understanding. Those students who didn't choose the incorrect analogy response chose the correct analytical or mathematical responses instead.

In the first pre-sessional questionnaire, analysis of the responses for question 2 did not yield a significant result. This would imply that understanding of the concept of inductive reactance was poor at the time of the test. The reasons for this poor understanding could include (but are by no means limited to) dimensional equivalency, where reactance, resistance and impedance all share the same units, and the introduction of the concept with phrases such as “*The inductance behaves as if it had a resistance*” and by direct analogy to Ohm’s Law [110, p. 40]. These two factors could combine to form memory connections resulting in the misconceptions.

Because of the insignificant result, and the inability to draw conclusions from an insignificant result, the question was redesigned and re-administered in the second pre-sessional questionnaire. The results from this iteration did produce a statistically significant response which showed that the students had a much clearer understanding of what they believed inductive reactance to be. The changing patterns of the answers that remained available between iterations also shows that students were not remembering the answers they gave previously, or attempting to provide the answers they think are expected of them.

Comparing the pre-sessional and mid-sessional questionnaires for this question shows that the majority students had not fully grasped the concept of inductive reactance, choosing the attractive distractor of a self-induced effect over the correct answer of an externally induced effect, and that the instruction received to time point 3 was ineffective at resolving that poor understanding. Whether this is a result of the academic staff not being aware of the students’ error and thus failing to correct it or the result of the students being resistant to attempts at correction is unclear.

The most common option selected by participants for question 3 (that phasors and vectors are equivalent) is understandable in as much as a phasor (the correct answer) and a vector (the incorrect answer) are visually similar. It is therefore likely that as a result of this similarity the semantic coding process applied when learning about phasors relates the two so closely that they become indistinguishable. The salient point missed by students in this question is the sinusoidal variation, which is of fundamental importance to a solid understanding of the concept, and any concept based upon phasors. It is indicative of failure to modify existing memory structures to accommodate the new information inherent in the concept when first presented with it.

Whilst the analysis for both the pre-sessional and mid-sessional questionnaires return significant results, the  $\chi^2$  value for the mid-sessional questionnaire is much lower ( $\chi^2(4, n=34) = 43.98$  compared to  $\chi^2(4, n=31) = 9.81$ ). This would seem to show a drop in the level of understanding of the concept of phasors, but is almost entirely due to the drop in the frequency of responses for the first option (22/34 in the pre-sessional compared to 12/31 in the mid-sessional). This of course was an incorrect option, and when taking this into account it becomes clear that confusion about this concept is reduced. The fact that the frequency counts of the correct options (options 3 and 5) don't both show a large increase, suggests that while confusion is lessened by instruction, understanding is not necessarily furthered.

In all questionnaires some students failed to respond to some of the statements contained in question 4. The reason for this is unknown, but it could simply be that as it is the last of the questions the students simply lacked motivation to engage properly with the questionnaire, or that the student had no understanding of the concept (and thus no opinion on whether or not the statement was true or false). If it is the case that the students who failed to make a decision on the veracity of the statements had no understanding of the concept, then the very fact that other students did make a decision (all statements received responses in both questionnaires) is indicative of the different levels of development of students (or different levels of attainment in previous years) presented by the students at the start of third year study.

The fourth question on the first pre-sessional questionnaire was constructed in such a way that it was very difficult to draw definite conclusions on the conceptual understanding of the subjects as it remains unknown whether the students who failed to identify the statements as true did so because they believed it to be false, or simply failed to answer the question. The same is not true of the second iteration or mid-sessional questionnaire though, where each statement asked for the participant to select true or false and thus can be analysed individually. A significant result would indicate a consensus of opinion regarding the aspect covered by the statement; an insignificant result would indicate a lack of consensus and general confusion within the class group about the aspect.

The first four statements cover the topic of mmf. In the pre-sessional questionnaire one of these statements was significant, but in the mid-sessional none of the four were. This indicates a decline in student understanding of an already poorly understood topic.

The following three statements cover the topic of inductive reactance. The statement about inductive reactance being the same as inductance goes from a statistically insignificant response to a response statistically significant in favour of the correct option. The responses to statements about when inductive reactance has an effect in the pre-session questionnaire were significant, indicating a good understanding of the concept.

It is interesting to note that of the 8 students who answered false to statement 7, 6 of them also answered false to statement 6. The only conclusion to draw from this is that they think inductive reactance has meaning either never, or under DC conditions. The salient point is that the concept of inductive reactance is poorly understood, and the significant result for statement 6 can easily be misconstrued if taken without the partner statement 7. This is evidence of liminality and mimicry, whereby the student has begun to breach the threshold concept but not managed to master it.

The final pair of statements relate to phasor diagrams and show that students have a good understanding of the relationship between phasor diagrams and complex numbers. The relationship between the phasor diagram and the Argand diagram however remains poorly understood.

Statements 8 and 9 refer to phasor diagrams, a key construct used in electrical machine theory to visualise machine operation and physical characteristics (for example the load angle  $\delta$  is represented on the phasor diagram as the angle between the  $E_f$  and  $V$  phasors, and on the machine as the angular difference between the rotor and driving field orientations). The instruction appears to reinforce the correct preconception regarding the relationship between phasors and complex numbers, largely due to the frequent use of complex numbers in calculations that are then translated into the phasor diagrams, but fail to address the preconception of the link between the phasor diagram and the Argand diagram. Whether this is an important preconception to address, or one that should be addressed in the name of completion only is a matter for debate.

## **5.9 Limitations**

This study sought student cooperation during the first semester of the academic year 2008/9. In total 29 students were registered on the module and the three administrations of the

questionnaire resulted in 23, 19 and 21 returns respectively. This provides response rates of 79.3%, 65.5% and 72.4% accordingly.

In order for students to remain anonymous no demographic or identifying data were collected at any time-point. As a consequence it was not possible to match the data for individual students across the time-points. However given the high response rates it is highly likely that many of the students responded to all three questionnaires.

Despite this being a small study restricted to a single academic module at Loughborough University, the findings are illuminating and may provide insight for curriculum development for academics responsible for the teaching of electrical power theory, in particular the relatively narrow field of electrical machine theory.

The questionnaires used during this study were introduced by teaching staff and instructions for each question were printed on the questionnaires themselves. Although an attempt was made to avoid misinterpretation by participants this cannot be ruled out. In addition it is possible that some participants guessed the motives of the study and this may have influenced their answers.

## **5.10 Conclusions**

This study has highlighted that students demonstrate a low level of understanding of key concepts required to fully comprehend electrical machine theory. In addition instruction on the module fails to address the misunderstandings. This implies that the origins of the misunderstanding lie elsewhere. Therefore further investigation is required in order to establish the roots of student misunderstanding.

## **6 Desk Data to Explore the Sources of Student Misunderstandings**

### **6.1 Quantitative Analysis**

#### **6.1.1 Introduction**

The previous chapter described a questionnaire study which examined student understanding of Electrical Machine Theory. It was anticipated that the questionnaire would identify potential influences on the development of student understanding of key concepts throughout the course of the module. The study however, identified that students commenced the module with poor understanding and that instruction on the module ELC040 – Electrical Machines and Systems did not lead to improved understanding of core concepts. This suggests that the roots of student misunderstanding lay elsewhere.

In order to investigate this further and attempt to identify where the roots of student misunderstanding of Electrical Machine Theory lay, desk research was employed to analyse secondary data on student performances across a number of years of the pre-requisite module “ELB046 – Electrical Power B”. Desk research is a widely utilised method of data collection and was chosen as an appropriate method here due to the exploratory nature of the research and the ease of access to student performance records. Performance data is collected routinely in academic departments within the university as a means of monitoring module and student performance.

### **6.2 Method**

Student performance was examined via records of individual and cohort performance across four academic years. It was a straightforward matter to compare the performance of a student on a particular module to a second student on that module. If the module was marked as described earlier in this thesis, with a coursework mark, an examination mark and an overall mark from a combination of the two, then three factors could be compared very easily. Student A was better than B at the coursework, while B was better in the examination, and overall student B was superior as a result of their examination performance contributing more to the overall mark. This is the **student to student** comparison and highlighted in red in Table 5.1.



It was also straightforward to compare the performance of a student on a particular module to their average performance, and again the three comparison factors can be obtained. This was the comparison of a student to the mean of their scores in each assessment component across the year. This is the **student to student average** comparison and is highlighted in yellow in Table 5.1.

A third straightforward comparison is the **student to average student**, highlighted in blue in Table 5.1. This was effectively the comparison of a particular (real) student to a generic (hypothetical) student who scores the mean mark in each assessment component of the module.

Student	module 1			module 2			module 3			average		
	Cw	ex	tot	cw	ex	tot	cw	ex	tot	cw	ex	tot
A	97	0	49	35	73	54	69	80	75	67	51	59
B	54	40	47	84	71	78	47	70	59	62	60	61
C	64	31	48	94	48	71	75	54	65	78	44	61
D	8	65	37	73	26	50	35	54	45	39	48	44
E	55	39	47	63	95	79	89	53	71	69	62	66
Average	56	35	46	70	63	66	63	62	63	63	53	58

**Table 5.1 – Example table illustrating student to student comparisons**

When comparing two modules against one another, if the cohorts taking them were the same then direct comparisons could be made in a similar way. Average component marks, number of marks above an arbitrary threshold, and even goodness of fit testing between the mark distributions could be used effectively. If the module cohorts were different then the testing procedure became significantly less straightforward as this fundamental difference must be considered.

The fundamental difference of different cohorts could be addressed in one of two ways; either restricting the sample population to only the students common to the two modules, or normalising the populations so that all students on each module were included. The restrictive approach puts the focus of the comparisons on the student group common to both modules(or performance thereof) rather than the modules, and factors such as self-selection may have introduced a bias if this approach were used with the ultimate goal of comparing modules.

Given this argument it was decided that in order to perform a valid module to module comparison, the entirety of the student body exposed to the modules must be considered, not just those common to both. To account for the potentially different sizes of class on each module, any values that are relative to class size must be expressed in non-relative terms (i.e. normalised or percentage).

To perform a **module to average module** analysis, in the same way as a hypothetical generic student was invented who has component marks equivalent to the mean of all the students on the module, a hypothetical generic module was invented that has a mark distribution in each component equivalent to the mean distribution of all the modules in the year.

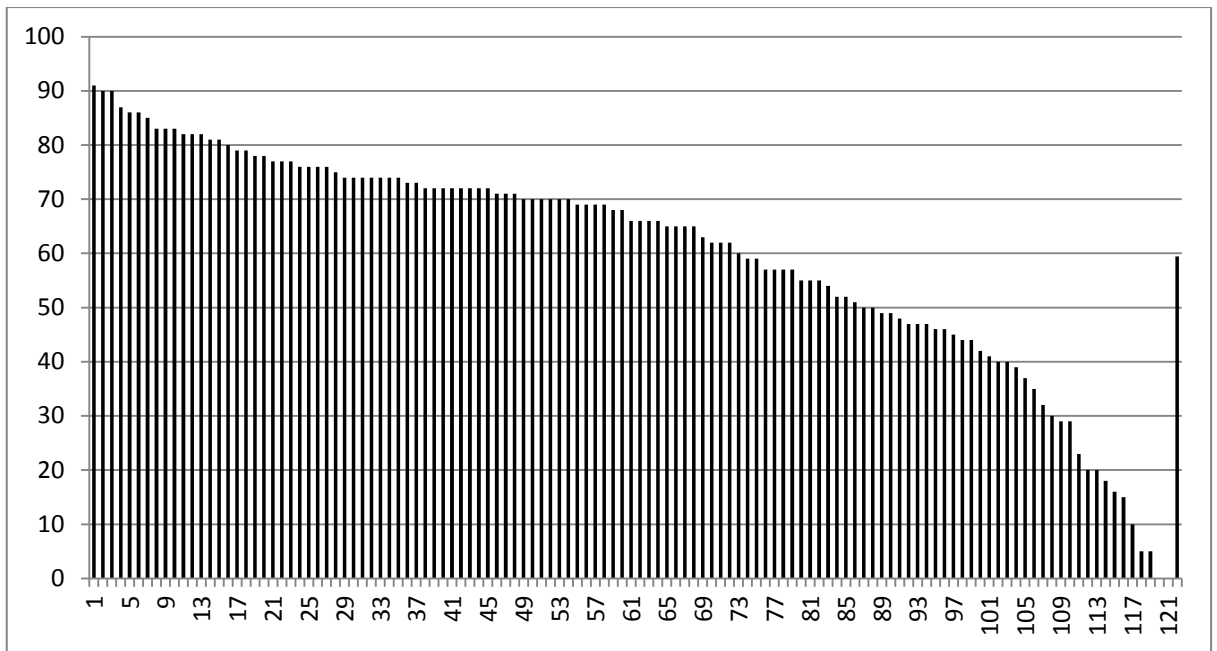
The distribution of marks can be visualised as either a bar chart of mark against arbitrary student identifier (Figure 5.1) or as a histogram in which the area of each column reflects the number of marks that fall into that bin, and the total area reflects the number of students enrolled on the module (Figure 5.2). Clearly the first representation is useful if the desired comparisons are student to student, and it can (especially when organised as below) give a general impression of the performance. The second representation gives a clearer indication of where the majority of marks are located but has no information beyond that. The first was a student centric representation and the second module centric.

To compare histograms of modules where the cohort was not the same the frequency counts must be normalised so that instead of absolute frequency counts the column areas reflect the proportion of students on the module who scored in the range defined by the bin. It was important to ensure the same bins are used with both modules.<sup>1</sup>

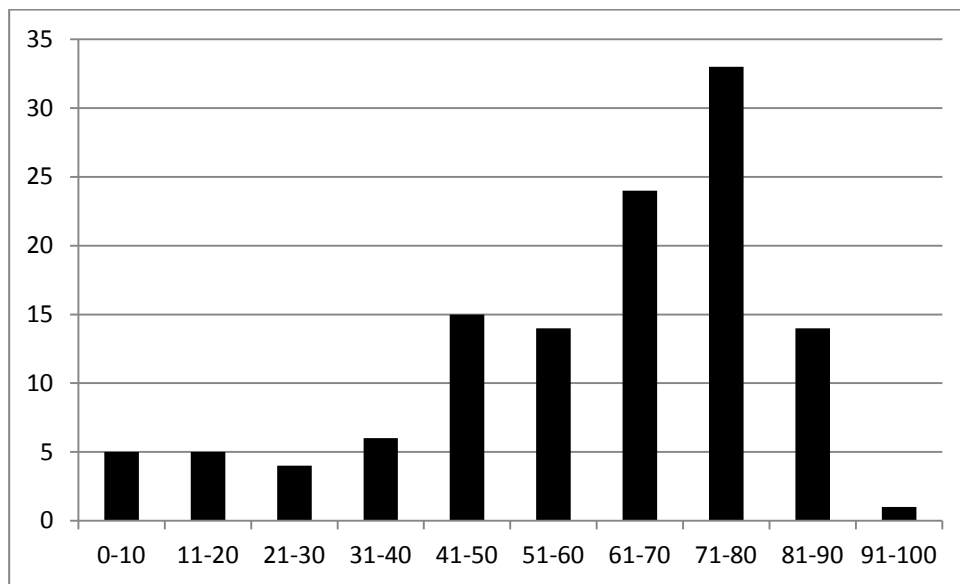
From these normalised histograms an average module distribution can be generated simply by taking the average of the normalised values in each bin across all the modules of the year. The final histogram is termed the **generic module model**.

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<sup>1</sup> For more on these normalised histograms see Appendix D – Normalised histograms and the Generic Module Model



**Figure 5.1 - Example distribution (mark against arbitrary identifier, in this case coursework rank. Outlying point is mean)**



**Figure 5.2 – Module 1 distribution histogram**

### 6.3 Data

The data analysed in this section consists of four year groups. In order to maintain anonymity each year group is represented by upper case letters A, B, C and D. Each letter is split into the three components for coursework, exam and module marks

denoted by lower case letters a, b and c respectively. The two values for each student corresponding to the achieved component mark and the average component mark are denoted by the numerals 1 and 2 respectively while the distributions of the generic module are denoted by 3. For example the designation A1a denotes the group of marks that were achieved by students in the “A” year group, in the “a” (coursework) component of the module of interest. Similarly C2c denotes the average marks of the “C” year group students in the “c” component.

At the end of the D year one of the lecturers responsible for delivering the ELB046 module took retirement. This proved an opportunity to remove the ELB046 module from the syllabus, and replace it with a similar module delivered entirely by a single lecturer (Dr Gregory) covering ostensibly the same material<sup>2</sup>. The assessment emphasis was also changed slightly, with the new module having a 40% weighting for coursework compared to the original 30%. The new module was designated ELB003. This is summarised in Table 5.2

	ELB046 Module			Student Average			Generic Module		
	C/W	Exam	Module	C/W	Exam	Module	C/W	Exam	Module
2006/7	A1a	A1b	A1c	A2a	A2b	A2c	A3a	A3b	A3c
2007/8	B1a	B1b	B1c	B2a	B2b	B2c	B3a	B3b	B3c
2008/9	C1a	C1b	C1c	C2a	C2b	C2c	C3a	C3b	C3c
2009/10	D1a	D1b	D1c	D2a	D2b	D2c	D3a	D3b	D3c
	ELB003 Module			Student Average			Generic Module		
	E1a	E1b	E1c	E2a	E2b	E2c	E3a	E3b	E3c

**Table 5.2 – Explanation of data labels**

Data were obtained on student performance across all modules undertaken by all second year undergraduate students registered in the School of Electronic, Electrical and Systems Engineering for the four years (2006/7-2009/10). The marks obtained by the students in ELB046 were compared with the student’s average mark across all modules they were registered for. The performance records from all modules were combined to

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<sup>2</sup> Compare module content using the online resources, <http://lboro.ac.uk/departments/el/undergraduate/modules/ELB046.html> for the original and <http://www.lboro.ac.uk/departments/el/undergraduate/modules/ELB003.html> for the replacement module

generate the hypothetical generic module, the mark distribution profile of which was then compared to the mark distribution profile of ELB046. In total, data was obtained on a total of 448 students representing the years 2006/7 (104), 2007/8 (93), 2008/9 (121) and 2009/10 (130).

### **6.3.1 Analysis results**

#### ***6.3.1.1 Analysis requirements***

The tests required are intergroup tests, which compare the distributions within the same year, and intragroup tests, which compare the same distributions across all years. All tests, unless otherwise stated, were carried out using SPSS (Statistical Package for the Social Sciences)<sup>3</sup>, a purpose built statistical package that can perform a wide variety of statistical analyses in a timely manner. These tests were designed to show whether students were performing worse in ELB046 than other modules in the first case and in the second whether there was any trend in performances across the 4 years.

Intergroup tests are further categorised into student-centric and module-centric tests, which correspond to the comparison of distributions denoted by 1 and 2, and by 1 and 3 respectively. The student-centric tests compare the component mark from the module of interest to the student average for the same component with either a paired samples t-test, or a one-sample test on the differences, if the distribution of differences can be assumed normal, or the Wilcoxon signed rank test on the differences if this assumption is invalid. The module-centric comparisons use chi-squared analysis to determine whether there is a statistical difference between the distribution of marks achieved in the module of interest and the distribution of the generic module.

Intragroup tests compare the components of all four years together. This is unpaired data, and requires analysis of variance (ANOVA) if the distributions are normal, or Kruskal-Wallis if not normal. If these results indicate a change across the 4 years then pairwise analysis should be carried out to determine where the change occurs.

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<sup>3</sup> This software, initially produced by Predictive Analytics SoftWare (PASW), was later acquired by the IBM group.

### 6.3.1.2 Testing for normality

Shapiro and Wilks developed a statistical procedure to test a sample for normality, and despite originally only specifying a way to calculate the test statistic with samples  $\leq 50$  [111], later developments by Shapiro and Francia [112] and Royston [113] have expanded this range, and SPSS is able to calculate the statistic for samples as large as 5000. This allows the computation of the statistic for the data sets in this study with relative comfort as they have sizes close to 100.

The test statistic is calculated as

$$W = \frac{(\sum_{i=1}^{W_s} a_i x_i)^2}{\sum_{i=1}^{W_s} (x_i - \bar{x})^2}$$

where  $\bar{x}$  is the mean of the sample and

$$a_i = \left(\frac{2}{c}\right) m_i \text{ for } 2 \leq i \leq W_s - 1$$

where

$$c^2 = 4 \sum_{i=1}^{W_s-1} \frac{m_i^2}{(1 - 2a_i^2)}$$

and

$$m_i = \Psi^{-1} \left( \frac{i - \alpha}{W_s - 2\alpha + 1} \right)$$

where  $\Psi$  is the cumulative distribution function of a standard normal distribution with  $\alpha = 0.314195 + 0.06336\beta - 0.010895\beta^2$  for  $\beta = \log_{10} W_s$

For the remaining cases of  $a_i$ , i. e. for  $i = 2$  and  $i = W_s$

$$a_1^2 = a_{W_s}^2 = \frac{\Gamma\left(\frac{(W_s + 1)}{2}\right)}{\sqrt{2}\Gamma\left(\frac{W_s}{2} + 1\right)}$$

$a_1$  is the negative root i. e.  $a_1 = -\sqrt{a_1^2}$  and  $a_{w_s}$  is the positive root i. e.  $a_{w_s} = \sqrt{a_{w_s}^2}$

	Statistic	df	Sig.
A1a-A2a	.968	104	.013
A1b-A2b	.986	104	.342
A1c-A2c	.981	104	.147
A1a	.930	104	.000
A1b	.986	104	.337
A1c	.986	104	.352
A2a	.765	104	.000
A2b	.986	104	.345
A2c	.938	104	.000

**Table 5.3 – Group A normality**

	Statistic	df	Sig.
B1a-B2a	.980	93	.157
B1b-B2b	.970	93	.030
B1c-B2c	.981	93	.182
B1a	.924	93	.000
B1b	.952	93	.002
B1c	.953	93	.002
B2a	.950	93	.001
B2b	.980	93	.166
B2c	.993	93	.892

**Table 5.4 - Group B normality**

	Statistic	df	Sig.
C1a-C2a	.978	121	.043
C1b-C2b	.993	121	.781
C1c-C2c	.991	121	.649
C1a	.909	121	.000
C1b	.895	121	.000
C1c	.972	121	.014
C2a	.843	121	.000
C2b	.980	121	.070
C2c	.991	121	.657

**Table 5.5 - Group C normality**

	Statistic	df	Sig.
D1a-D2a	.981	130	.069
D1b-D2b	.980	130	.058
D1c-D2c	.985	130	.167
D1a	.913	130	.000
D1b	.843	130	.000
D1c	.956	130	.000
D2a	.833	130	.000
D2b	.989	130	.412
D2c	.960	130	.001

**Table 5.6 - Group D normality**

In Table 5.3 to Table 5.6, the first three rows of each table correspond to the normality of the distribution of differences between student attained components and student average components, and therefore demonstrates the viability to run t-tests. Low significance values indicate there is evidence for the rejection of the null hypothesis, that the distribution can be assumed normal, whereas high values suggest that chance occurrences may account for any observed differences between the test and normal distributions. At the  $p=0.05$  level, the Shapiro-Wilks test returns significant results



(values below 0.05) for the Aa, Bb and Ca pairings, meaning they must be analysed using non-parametric methods. The Da and Db pairings are significant at the  $p=0.1$  level, so to be thorough these two pairings will be analysed using both parametric and non-parametric techniques. The remaining pairings, Ab, Ac, Ba, Bc, Cb, Cc and Dc have significance values in excess of 0.1, so can be assumed normal and thus analysed using only the parametric tests.

The last 6 rows of each table show the normality of the individual components, which are compared across groups. The parametric analysis for this is ANOVA which is robust enough to cope with a deviation from normal in one of the four components, provided the second assumption of ANOVA, namely homogeneity of variances is not also violated. The non-parametric equivalent is the Kruskal-Wallis technique. Significance values below 0.05 again indicate that there is evidence to reject the hypothesis that the distribution is normal.

At the  $p=0.05$  level the 1a, 1b, 1c, 2a and 2c groups all have more than one significant result in them, meaning they must all be analysed using the non-parametric technique. The 2b group has only one component significant at the  $p=0.1$  level, so ANOVA is a valid technique for this group, assuming homogeneity of variance. The hypothesis that the four components for ANOVA in the 2b group have equal variances is tested by Levene's Test and the results are shown below. The test statistic is calculated as

$$W = \frac{(N - k) \sum_{i=1}^k n_i (\bar{Z}_i - \bar{Z})^2}{(k - 1) \sum_{i=1}^k \sum_{l=1}^{n_i} (Z_{il} - \bar{Z}_i)^2}$$

where

$$Z_{il} = |X_{il} - \bar{X}_i|$$

and  $\bar{Z}_i$  is the mean of  $Z_{il}$  for group  $i$ , i.e.

$$\bar{Z}_i = \frac{\sum_{l=1}^{n_i} Z_{il}}{n_i}$$

and  $\bar{Z}$  is the mean of all  $Z_{ij}$ , i.e.

$$\bar{Z} = \frac{\sum_{i=1}^k \bar{Z}_i}{N}$$

where  $N$  is the number of samples in all groups,  $k$  is the number of groups,  $n_i$  is the number of observations in group  $i$ ,  $X_{il}$  is the value of the  $l$ th observation in group  $i$ , and  $\bar{X}_i$  is the mean of group  $i$ .

	Levene Statistic	df1	df2	Sig.
2b	5.208	3	547	.001

**Table 5.7 - Homogeneity of variances**

This result is significant at the  $p=0.05$  level, meaning there is evidence to discount the hypothesis that variances are the same. This means that the ANOVA test is not acceptable for the data presented and the non-parametric test should be used in its place.

### **6.3.1.3 Intergroup Comparison (Student-centric)**

This set of analyses compares the same component across the two distributions 1 and 2. The previous analysis has shown which of these comparisons can be done with and without the assumption of normality. If the assumption of normality is valid, the appropriate test is the well-known t-test and the non-parametric equivalent for use when the assumption of normality is invalid is the Wilcoxon signed rank sum test. Having determined which pairs of data are suitable for parametric analysis the corresponding tests were carried out on the data using SPSS. The results are shown in Table 5.8 and Table 5.9, for the parametric and non-parametric tests. The parametric test can be done either as a paired sample test or as a one sample test on the differences. For the paired samples test the test statistic is calculated as

$$T = \frac{D}{S_D}$$

where  $D$  is the difference of means ( $\bar{X} - \bar{Y}$ ) between the two distributions and  $S_D$  is standard error of differences, defined as

$$S_D = \sqrt{\frac{S_X^2 + S_Y^2 - 2S_{XY}}{N}}$$

where  $S_X^2$  and  $S_Y^2$  are the variances of the X and Y distributions, i.e.

$$S_X^2 = \frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N-1} \text{ and } S_Y^2 = \frac{\sum_{i=1}^N (Y_i - \bar{Y})^2}{N-1}$$

and  $S_{XY}$  is the covariance of the distributions, defined as

$$S_{XY} = \frac{\sum_{k=1}^N X_k Y_k - \bar{X}\bar{Y}}{N-1}$$

where

$$\bar{XY} = \frac{\sum_{i=1}^N X_i \sum_{i=1}^N Y_i}{N}$$

For the one sample test based on the differences, the test statistic is calculated as

$$T = \frac{\bar{X}}{S_{\bar{X}}}$$

where  $\bar{X}$  is the mean of the differences, and  $S_{\bar{X}}$  is the standard error of the mean given by

$$S_{\bar{X}} = \frac{S_X}{\sqrt{N}}$$

and  $S_X$  is the standard deviation of the distribution. Both tests give the same results.

The non-parametric equivalent is the Wilcoxon signed rank test, which can also be conducted on either paired data, or a single distribution of differences. For the paired test the differences and absolute differences are calculated as  $d_i = x_{i1} - x_{i2}$ , and  $|d_i| = |x_{i1} - x_{i2}|$  respectively, then for all non-zero absolute differences a rank is assigned such that the smallest absolute difference is assigned the rank 1. Any equal differences take the average rank of the values with that difference. Any zero

differences are removed.  $S_p$  is then defined as the sum of ranks assigned to positive differences, and  $S_n$  is defined as the sum of differences assigned to negative differences, and the average positive rank is defined as  $S_p/n_p$ , where  $n_p$  is the number of ranks assigned to positive differences. Similarly an average negative rank can be calculated. The test statistic,  $T$ , is calculated based on the lowest rank sum as

$$Z = \frac{S_p - \mu_T}{\sigma_T} \text{ or } \frac{S_n - \mu_T}{\sigma_T}$$

however, it is worth noting that

$$\frac{S_p - \mu_T}{\sigma_T} + \frac{S_n - \mu_T}{\sigma_T} = 0$$

The two unknowns are defined as

$$\mu_T = \frac{n_f(n_f + 1)}{4}$$

and

$$\sigma_T^2 = \frac{n_f(n_f + 1)(2n_f + 1)}{24} - \frac{\sum_{j=1}^l (t_j^3 - t_j)}{48}$$

where  $n_f$  is the number of ranks allocated, and  $t_j$  is the number of values sharing rank  $j$ . Clearly to carry out the test on a single distribution of differences only the steps after computing the differences are required.

	Paired Differences					Test Statistic T	df	Sig. (2- tail)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
A1b - A2b	-1.64279	11.33935	1.11191	-3.84801	.56243	-1.477	103	.143
A1c - A2c	-1.88439	9.32923	.91481	-3.69869	-.07008	-2.060	103	.042
B1a - B2a	4.48163	10.64813	1.10416	2.28867	6.67459	4.059	92	.000
B1c - B2c	-10.94451	8.90531	.92344	-12.77854	-9.11048	-11.852	92	.000
C1b - C2b	-17.02259	9.85503	.89591	-18.79643	-15.24875	-19.000	120	.000
C1c - C2c	-18.22326	8.59181	.78107	-19.76973	-16.67679	-23.331	120	.000
D1a - D2a	4.19434	12.40339	1.08785	2.04200	6.34668	3.856	129	.000
D1b - D2b	-12.20802	11.00390	.96511	-14.11750	-10.29853	-12.649	129	.000
D1c - D2c	-17.68939	9.52509	.83541	-19.34226	-16.03652	-21.175	129	.000

**Table 5.8 - Parametric intergroup results**

		N	Mean Rank	Sum of Ranks	Test Statistic Z	Asymp. Sig. (2-tailed)
A2a – A1a	Negative Ranks	84 <sup>a</sup>	54.29	4560.50	-6.193 <sup>p</sup>	.000
	Positive Ranks	19 <sup>b</sup>	41.87	795.50		
	Ties	1 <sup>c</sup>				
	Total	104				
B2b- B1b	Negative Ranks	11 <sup>d</sup>	12.73	140.00	-7.784 <sup>q</sup>	.000
	Positive Ranks	81 <sup>e</sup>	51.09	4138.00		
	Ties	1 <sup>f</sup>				
	Total	93				
C2a - C1a	Negative Ranks	43 <sup>g</sup>	44.50	1913.50	-4.495 <sup>q</sup>	.000
	Positive Ranks	77 <sup>h</sup>	69.44	5346.50		
	Ties	1 <sup>i</sup>				
	Total	121				
D2a - D1a	Negative Ranks	83 <sup>j</sup>	66.93	5555.50	-3.589 <sup>p</sup>	.000
	Positive Ranks	44 <sup>k</sup>	58.47	2572.50		
	Ties	3 <sup>l</sup>				
	Total	130				
D2b - D1b	Negative Ranks	12 <sup>m</sup>	38.42	461.00	-8.618 <sup>q</sup>	.000
	Positive Ranks	114 <sup>n</sup>	66.14	7540.00		
	Ties	4 <sup>o</sup>				
	Total	130				

a. A2a < A1a; b. A2a > A1a; c. A2a = A1a; d. B2b < B1b; e. B2b > B1b; f. B2b = B1b; g. C2a < C1a; h. C2a > C1a; i. C2a = C1a; j. D2a < D1a; k. D2a > D1a; l. D2a = D1a; m. D2b < D1b; n. D2b > D1b; o. D2b = D1b; p. Based on positive ranks; q. Based on negative ranks

**Table 5.9 Non-parametric intergroup results**

The significant results ( $p < 0.0005$ ) shown in all pairs except the Ab and Ac pairs demonstrate that there are statistical differences between the two measurements. The confidence intervals supplied by the parametric tests indicate the range in which the difference is likely to lie, a negative interval corresponding to better performance on average than in the module. The non-parametric tests do not yield a confidence interval, however, the test statistic being based on the negative ranks (the case for Bb, Ca and Db pairings) show that performance is better on average than in the module.

The Ab pairing is not significant at the  $p = 0.05$  level, or even the  $p = 0.1$  level. This suggests there is insufficient evidence to prove the distributions are different. The Ac

pairing is only just significant at the  $p=0.05$  level, suggesting that there is some evidence to support the hypothesis that the distributions are different, but that it is not very strong.

The significant results in the a pairings<sup>4</sup> for each group show that for the C group the performance is significantly below average. For the other groups performance is in excess of average, showing that the C group was anomalous in some respect. Reasons for this anomaly will be explored later.

The significant results in the b pairings<sup>5</sup> for each group except the A group show that the performance on average is significantly better. The anomaly here is the A group, where the lack of significant result means that the performance on the module is what would be expected from the averages. Again, reasons for this anomaly will be explored later.

The results for the c pairings<sup>6</sup> for each group show that the performance overall for the module is below average. The significance value for group A ( $p=0.042$ ) shows that the difference between the two marks in this group is not as large as the other groups (which all have  $p<0.005$ ) and indeed the confidence intervals show that the mean difference gets far larger from group A to C. The difference in group D remains approximately the same as group C.

#### **6.3.1.4 Intergroup Analysis (Module-centric)**

The generic module constructed as described previously (and in Appendix D – Normalised histograms and the Generic Module Method) cannot be subjected to the same analysis used in the averages model due to the incomplete nature of the distribution. It is instead subjected to chi square analysis comparing the distribution of the obtained module marks to the distribution of marks in the generic module. For the Chi square analysis the observed values are the frequencies in each class of grades for the module, and the expected values are given by the total number of students on the module multiplied by the percentage of the generic module in the same grade class. The

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<sup>4</sup> Aa, Ba, Ca and Da

<sup>5</sup> Bb, Cb and Db

<sup>6</sup> Ac,, Bc, Cc and Dc

grade classes are then collapsed to ensure that the expected frequency is generally  $\geq 5$  [114] to ensure the calculated statistic follows the chi square distribution. The degrees of freedom in each case is simply the number of classes minus 1 as no parameters of the expected distribution need estimating from the observed data. See Table 5.10 and Table 5.11 for an example of the collapsing and calculations for chi squared analysis.

Class	Observed A1a	Expected A3a	Class	Observed A1a	Expected A3a
0-5	0	1.872	51-55	3	7.2696
6-10	0	0	56-60	8	11.3048
11-15	1	0.5512	61-65	7	14.0712
16-20	0	0	66-70	6	22.3288
21-25	1	0.5928	71-75	13	13.676
26-30	0	0.8112	76-80	12	10.2544
31-35	2	0.7072	81-85	14	6.7496
36-40	0	0.364	86-90	12	4.2536
41-45	1	1.0504	91-95	6	2.2984
46-50	3	3.8792	96-100	15	1.9448

**Table 5.10 – Example uncollapsed table of observed and expected values**



Class	Observed A1a	Expected A3a	$O - E$	$(O - E)^2$	$\frac{(O - E)^2}{E}$
0-45	5	5.9488	-0.9488	0.90022144	0.151328241
46-50	3	3.8792	-0.8792	0.77299264	0.199265993
51-55	3	7.2696	-4.2696	18.22948416	2.507632354
56-60	8	11.3048	-3.3048	10.92170304	0.966112009
61-65	7	14.0712	-7.0712	50.00186944	3.553490068
66-70	6	22.3288	-16.3288	266.6297094	11.94106756
71-75	13	13.676	-0.676	0.456976	0.033414449
76-80	12	10.2544	1.7456	3.04711936	0.297152379
81-85	14	6.7496	7.2504	52.56830016	7.788357852
86-100	33	8.4968	24.5032	600.4068102	70.66269775

**Table 5.11 – Example table for chi squared calculation**

The chi squared statistic is simply

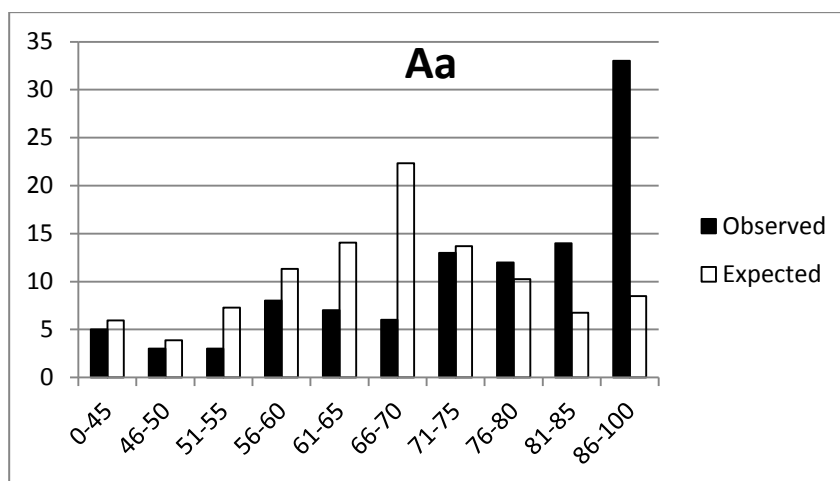
$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

and, knowing the degrees of freedom, the significance value can be found from standard tables. In this example,  $\chi^2 = 98.1$ , and with 9 degrees of freedom (10 classes minus 1) the critical value for  $p=0.001$  is given as 27.88. Clearly for  $\chi^2 = 98.1$ ,  $p < 0.001$ , and we can say there is strong evidence to reject the hypothesis that the two distributions are the same. Results for all chi squared analyses are presented in Table 5.12

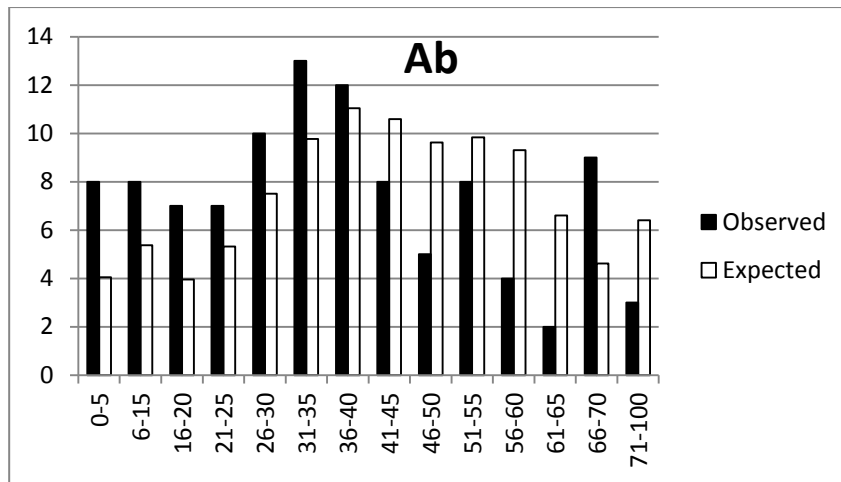
Comparison	Test Statistic	df	Sig.	Comparison	Test Statistic	df	Sig.
Aa	98.1	9	p<0.001	Ca	49.77	10	p<0.001
Ab	13.17	13	p>0.25	Cb	150.05	14	p<0.001
Ac	34.03	10	p<0.001	Cc	245.97	13	p<0.001
Ba	62.23	9	p<0.001	Da	79.13	11	p<0.001
Bb	48.94	13	p<0.001	Db	283.48	15	p<0.001
Bc	86.24	11	p<0.001	Dc	356.6	11	p<0.001

**Table 5.12 – Chi squared results**

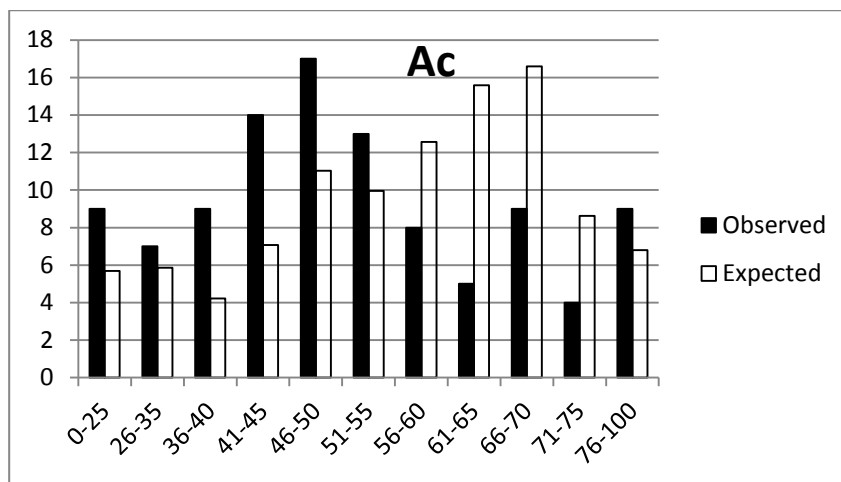
From these results the only two distributions that can be assumed similar are the distributions in the Ab pair. To show where the differences occur the comparison histograms for all the above comparisons are reproduced below in the histograms of Figure 5.3 to Figure 5.14. If the observed and expected values are equal, the two columns in each class should be equal in size.



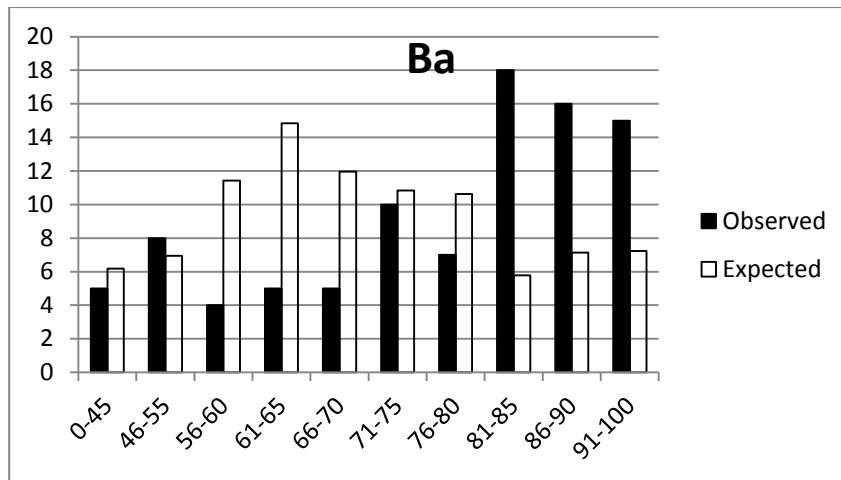
**Figure 5.3 – A1a and A3a histograms**



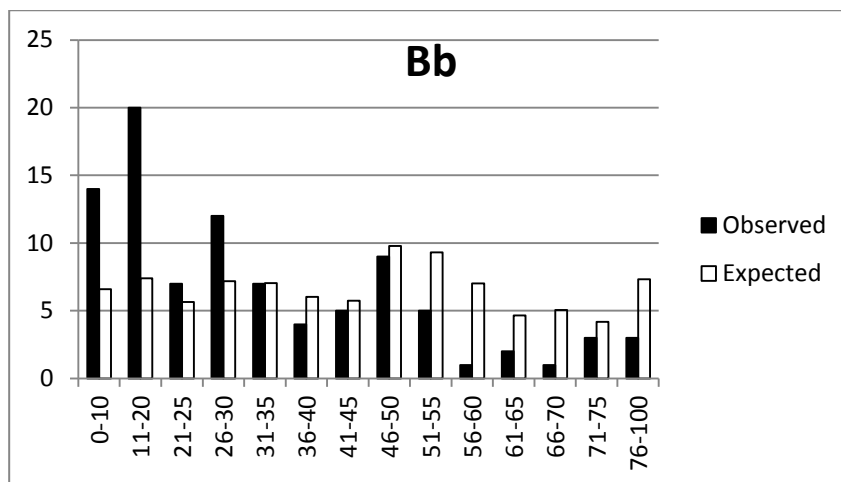
**Figure 5.4 – A1b and A3b histograms**



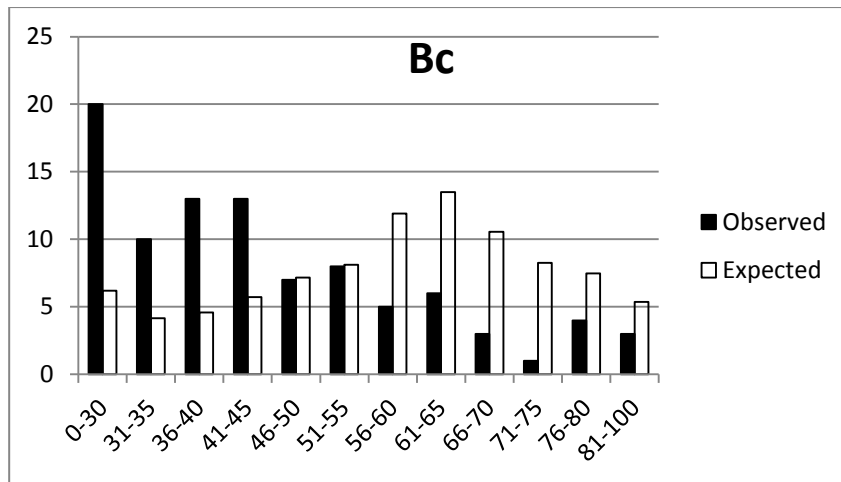
**Figure 5.5 – A1c and A3c histograms**



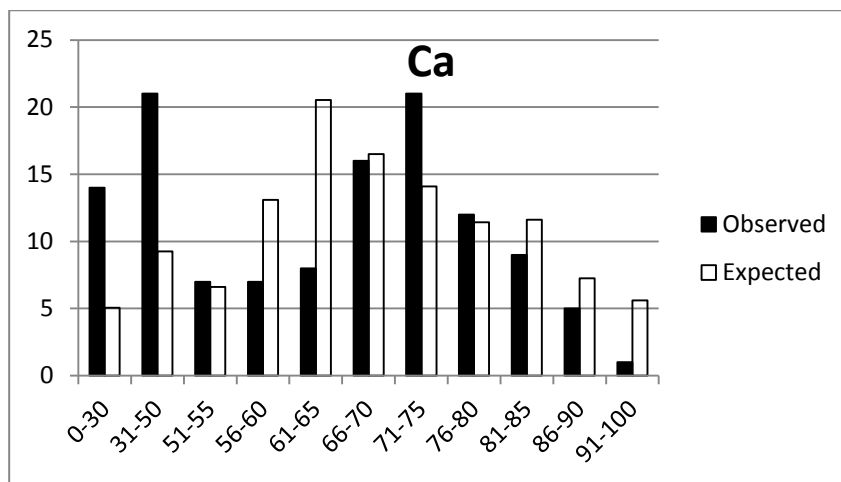
**Figure 5.6 – B1a and B3a histograms**



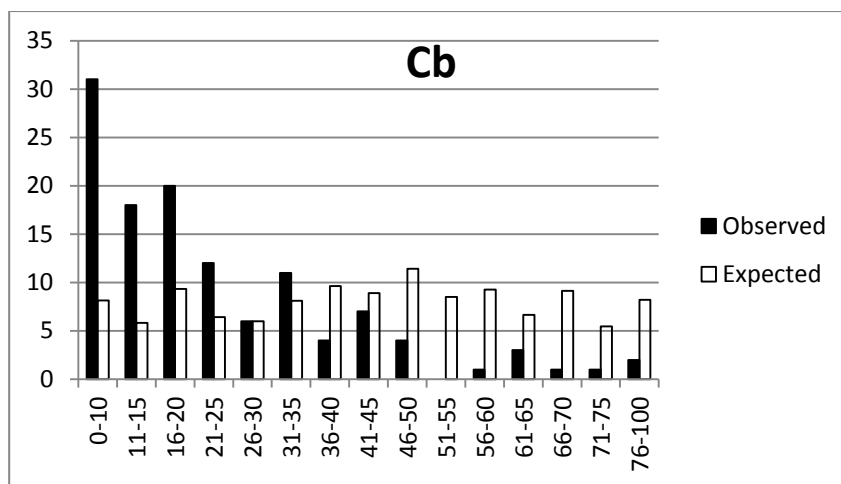
**Figure 5.7 – B1b and B3b histograms**



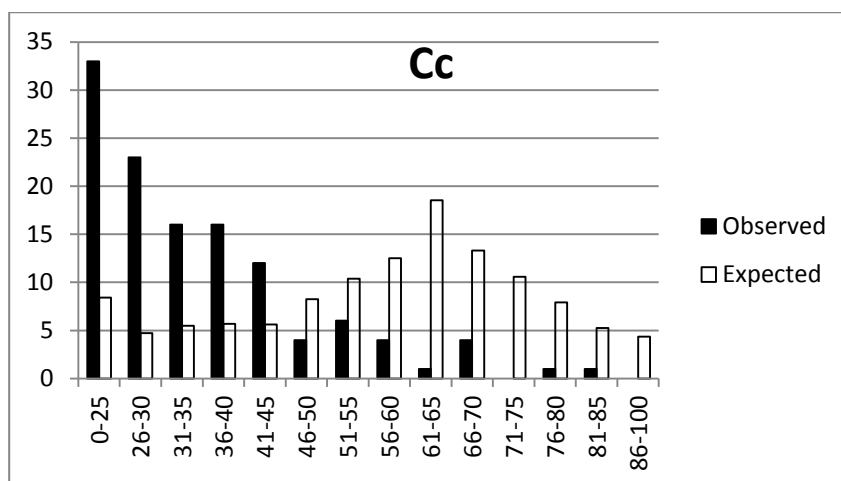
**Figure 5.8 – B1c and B3c histograms**



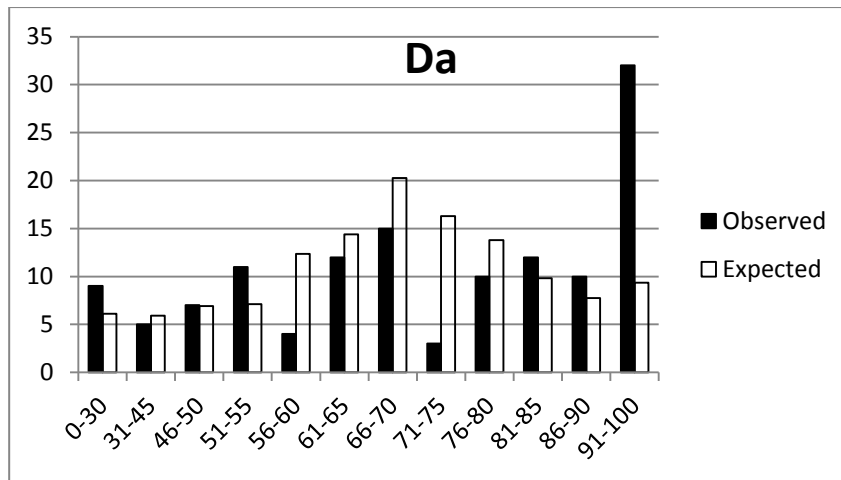
**Figure 5.9 – C1a and C3a histograms**



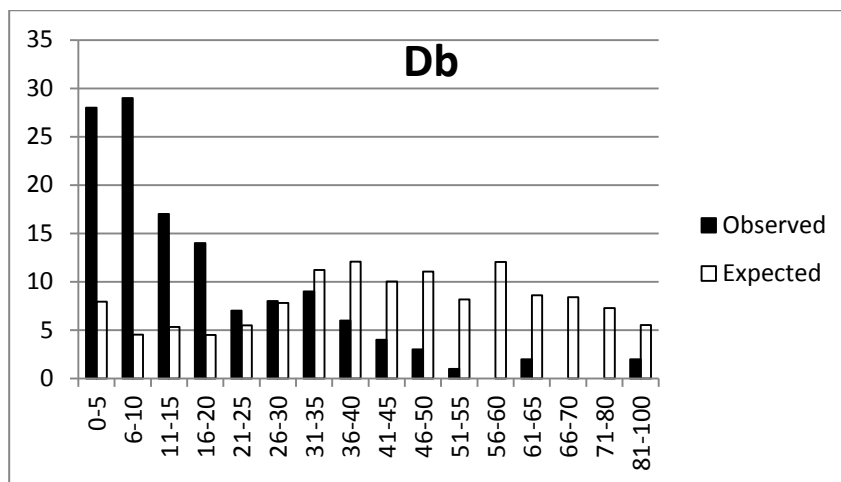
**Figure 5.10 – C1b and C3b histograms**



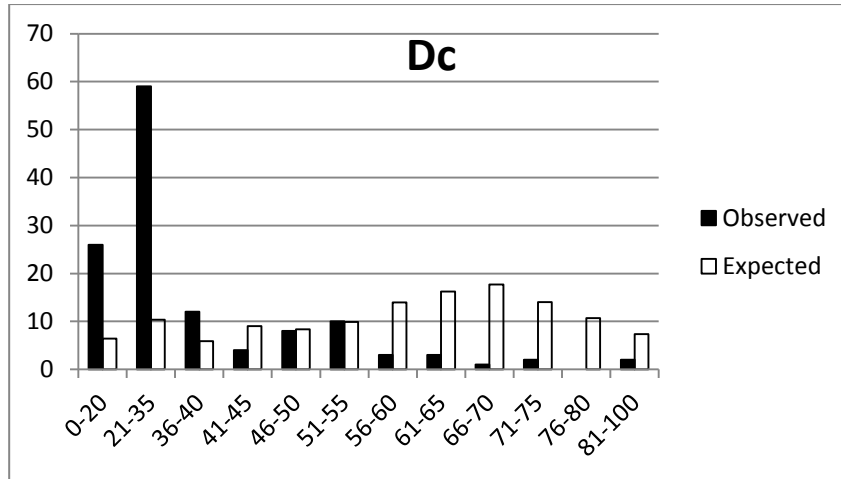
**Figure 5.11 – C1c and C3c histograms**



**Figure 5.12 – D1a and D3a histograms**



**Figure 5.13 – D1b and D3b histograms**



**Figure 5.14 – D1c and D3c histograms**

### 6.3.1.5 Intragroup Comparison

This set of analyses compares a component across all year groups. Previous analysis has shown that parametric analysis is not viable, and so the non-parametric Kruskal-Wallis test is used in place of the ANOVA test. The test statistic  $H'$  is calculated as

$$H' = \frac{H}{1 - \sum_{i=1}^m \frac{T_i}{(N^3 - N)}}$$

where

$$T_i = t_i^3 - t_i$$

and  $H$  is the statistic not adjusted for ties, given by

$$H = \frac{12}{N(N+1)} \sum_{i=1}^k \frac{R_i^2}{n_i} - 3(N+1)$$

where  $R_i$  is the rank sum for group  $i$ . The Kruskal-Wallis test was carried out using SPSS and the results are shown below in Table 5.13.



	1a*	1b*	1c*	2a*	2b*	2c*
Chi-square	46.927	85.480	78.600	8.463	38.661	3.850
Df	3	3	3	3	3	3
Asymp. Sig.	.000	.000	.000	.037	.000	.278

\* Grouping Variable: Group (A, B, C or D)

**Table 5.13 - Non-parametric intragroup results**

From the above results it is clear to see that the only result not significant at the  $p=0.05$  level is 2c, with a significance of  $p=0.278$ . This is a key result, which shows that the average overall mark achieved by students does not vary significantly year to year. The significance value of 0.037 exhibited by 2a shows that the differences between groups in this category will be smaller than the differences in other categories. Further analysis is required in these categories to determine where statistically significant differences lie.

#### **6.3.1.6 Detailed Intragroup Analysis**

This set of analyses compare the same component across all year groups. The previous analysis has shown that there are significant differences between them, and this set of analyses compare the components across the year groups in a pairwise manner to highlight where those differences lie. The appropriate test is the Mann-Whitney test, a non-parametric test for independent variables. The Mann-Whitney U statistic is calculated as

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - S_1$$

where  $n_1$  and  $n_2$  are the group sizes and  $S_1$  is the rank sum for the group. If  $U > n_1 n_2 / 2$  the statistic displayed in the tables, and used in the calculation of Z in place of U is

$$U' = n_1 n_2 - U$$

The Z statistic is calculated as

$$Z = \frac{(U - \frac{n_1 n_2}{2})}{\sqrt{\frac{n_1 n_2}{N(N-1)} (\frac{N^3 - N}{12} - \sum_i T_i)}}$$

where N is the total number of ranks ( $n_1 + n_2$ ) and

$$\sum_i T_i = \sum_i \frac{t^3 - t}{12}$$

where  $t$  is the number of observations tied for each rank  $i$ . The Z distribution is approximately normal, and a 2 tailed significance value is printed based on the normal distribution. The Wilcoxon statistic is also calculated by SPSS as  $W=S_1$  if  $U > n_1 n_2 / 2$ , and as  $W=S_2$  otherwise.

Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym.Sig (2-tailed)
1a A	104	98.45	10238.50	4778.500	10238.500	-.144	.886
B	93	99.62	9264.50				
Total	197						
1b A	104	110.89	11533.00	3599.000	7970.000	-3.097	.002
B	93	85.70	7970.00				
Total	197						
1c A	104	109.66	11404.50	3727.500	8098.500	-2.776	.006
B	93	87.08	8098.50				
Total	197						
2a A	125	108.97	13621.50	5746.500	13621.500	-2.481	.013
B	113	131.15	14819.50				
Total	238						
2b A	125	120.77	15096.50	6903.500	13344.500	-.0300	.764
B	113	118.09	13344.50				
Total	238						

**Table 5.14 – AB pairwise comparison**

Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym.Sig (2-tailed)
1a A	104	141.41	14707.00	3337.000	10718.000	-6.071	.000
C	121	88.58	10718.00				
Total	225						
1b A	104	143.70	14944.50	3099.500	10480.500	-6.559	.000
C	121	86.62	10480.50				
Total	225						
1c A	104	146.64	15251.00	2793.000	10174.000	-7.189	.000
C	121	84.08	10174.00				
Total	225						
2a A	125	138.85	17356.00	9394.000	20870.000	-.066	.947
C	151	138.21	20870.00				
Total	276						
2b A	125	142.94	17868.00	8882.000	20358.000	-.842	.400
C	151	134.82	20358.00				
Total	276						

**Table 5.15 - AC pairwise comparison**

Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym.Sig (2-tailed)
1a A	104	124.02	12898.00	6082.000	14597.000	-1.318	.188
D	130	112.28	14597.00				
Total	234						
1b A	104	158.36	16469.00	2511.000	11026.000	-8.260	.000
D	130	84.82	11026.00				
Total	234						
1c A	104	153.11	15923.50	3056.500	11571.500	-7.199	.000
D	130	89.01	11571.50				
Total	234						
2a A	125	146.44	18305.50	9819.500	23022.500	-.4380	.661
D	162	142.11	23022.50				
Total	287						
2b A	125	176.71	22088.50	6036.500	19239.500	-5.865	.000
D	162	118.76	19239.50				
Total	287						

**Table 5.16 - AD pairwise comparison**

Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym.Sig (2-tailed)
1a B	93	137.06	12746.50	2877.500	10258.500	-6.124	.000
C	121	84.78	10258.50				
Total	214						
1b B	93	123.89	11521.50	4102.500	11483.500	-3.395	.001
C	121	94.90	11483.50				
Total	214						
1c B	93	129.66	12058.00	3566.000	10947.000	-4.590	.000
C	121	90.47	10947.00				
Total	214						
2a B	113	145.45	16436.00	7068.000	18544.000	-2.384	.017
C	151	122.81	18544.00				
Total	264						
2b B	113	135.00	15255.00	8249.000	19725.000	-.460	.645
C	151	130.63	19725.00				
Total	264						

**Table 5.17 – BC pairwise comparison**

Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym.Sig (2-tailed)
1a B	93	118.40	11011.50	5449.500	13964.500	-1.254	.210
D	130	107.42	13964.50				
Total	223						
1b B	93	139.81	13002.00	3459.000	11974.000	-5.445	.000
D	130	92.11	11974.00				
Total	223						
1c B	93	137.09	12749.50	3711.500	12226.500	-4.913	.000
D	130	94.05	12226.50				
Total	223						
2a B	113	152.01	17177.00	7570.000	20773.000	-2.440	.015
D	162	128.23	20773.00				
Total	275						
2b B	113	164.51	18589.50	6157.500	19360.500	-4.618	.000
D	162	119.51	19360.50				
Total	275						

**Table 5.18 – BD pairwise comparison**

Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	Asym.Sig (2-tailed)
1a C	121	106.91	12936.50	5555.500	12936.500	-4.019	.000
D	130	143.77	18689.50				
Total	251						
1b C	121	138.33	16738.00	6373.000	14888.000	-.385	.009
D	130	114.52	14888.00				
Total	251						
1c C	121	127.83	15467.00	7644.000	16159.000	-.385	.700
D	130	124.30	16159.00				
Total	251						
2a C	151	158.59	23947.50	11990.500	25193.500	-.301	.764
D	162	155.52	25193.50				
Total	313						
2b C	151	178.99	27027.00	8911.000	22114.000	-4.151	.000
D	162	136.51	22114.00				
Total	313						

**Table 5.19 – CD pairwise comparison**

The null hypothesis tested here is that there is no difference between distributions, which is to say that students performed equally well in a component in both years. A significance value less than 0.05 suggest sufficient evidence to reject that hypothesis, and this is the case in 20 of the 30 tests. The final 10 tests suggest that there is no evidence to counter the hypothesis. Table 5.20 and Table 5.21 summarise these results, showing the p values in the first and a plain English translation in the second.

Comparison	1a	1b	1c	2a	2b
AB	Accept Null p=0.886	Reject Null p=0.002	Reject Null p=0.006	Reject Null p=0.013	Accept Null p=0.764
AC	Reject Null p<0.0005	Reject Null p<0.0005	Reject Null p<0.0005	Accept Null p=0.947	Accept Null p=0.400
AD	Accept Null p=0.188	Reject Null p<0.0005	Reject Null p<0.0005	Accept Null p=0.661	Reject Null p<0.0005
BC	Reject Null p<0.0005	Reject Null p=0.001	Reject Null p<0.0005	Reject Null p=0.017	Accept Null p=0.645
BD	Accept Null p=0.210	Reject Null p<0.0005	Reject Null p<0.0005	Reject Null p=0.015	Reject Null p<0.0005
CD	Reject Null p<0.0005	Reject Null p=0.009	Accept Null p=0.700	Accept Null p=0.764	Reject Null p<.0005

**Table 5.20 – Pairwise comparison summary**

Comparison	1a	1b	1c	2a	2b
AB	Same	Different	Different	Different	Same
AC	Different	Different	Different	Same	Same
AD	Same	Different	Different	Same	Different
BA	Same	Different	Different	Different	Same
BC	Different	Different	Different	Different	Same
BD	Same	Different	Different	Different	Different
CA	Different	Different	Different	Same	Same
CB	Different	Different	Different	Different	Same
CD	Different	Different	Same	Same	Different
DA	Same	Different	Different	Same	Different
DB	Same	Different	Different	Different	Different
DC	Different	Different	Same	Same	Different

**Table 5.21 – Pairwise comparison summary**

The 1a component is only different between the C group and every other. The 1b component is different between every group. The 1c group is different between every

group except C and D. 2a is different between the B group and every other, and the 2b group is different between the D group and every other.

This means that something happens to the 1a component for the C group, which causes a change in performance. Whatever causes this change is rectified for the D group, and the performance for the D group in the 1a component is no different to performance in the A and B groups. There is no corresponding change in the 2a group, implying that whatever happened was limited to the module, however, there is a change in the 2a group that does not correspond to a change in 1a. This occurs for group B, implying something happened to significantly change the average coursework marks, but did not specifically affect the module of interest. The histograms of Figure 5.15 and Figure 5.16 show the differences, with the C distribution of 1a dropping to 0 in the 96-100 range where all other years show a marked increase, and the fairly consistent distributions in the 2a category with the B distribution markedly lower than the others in the 61-70 range and markedly higher above 76.

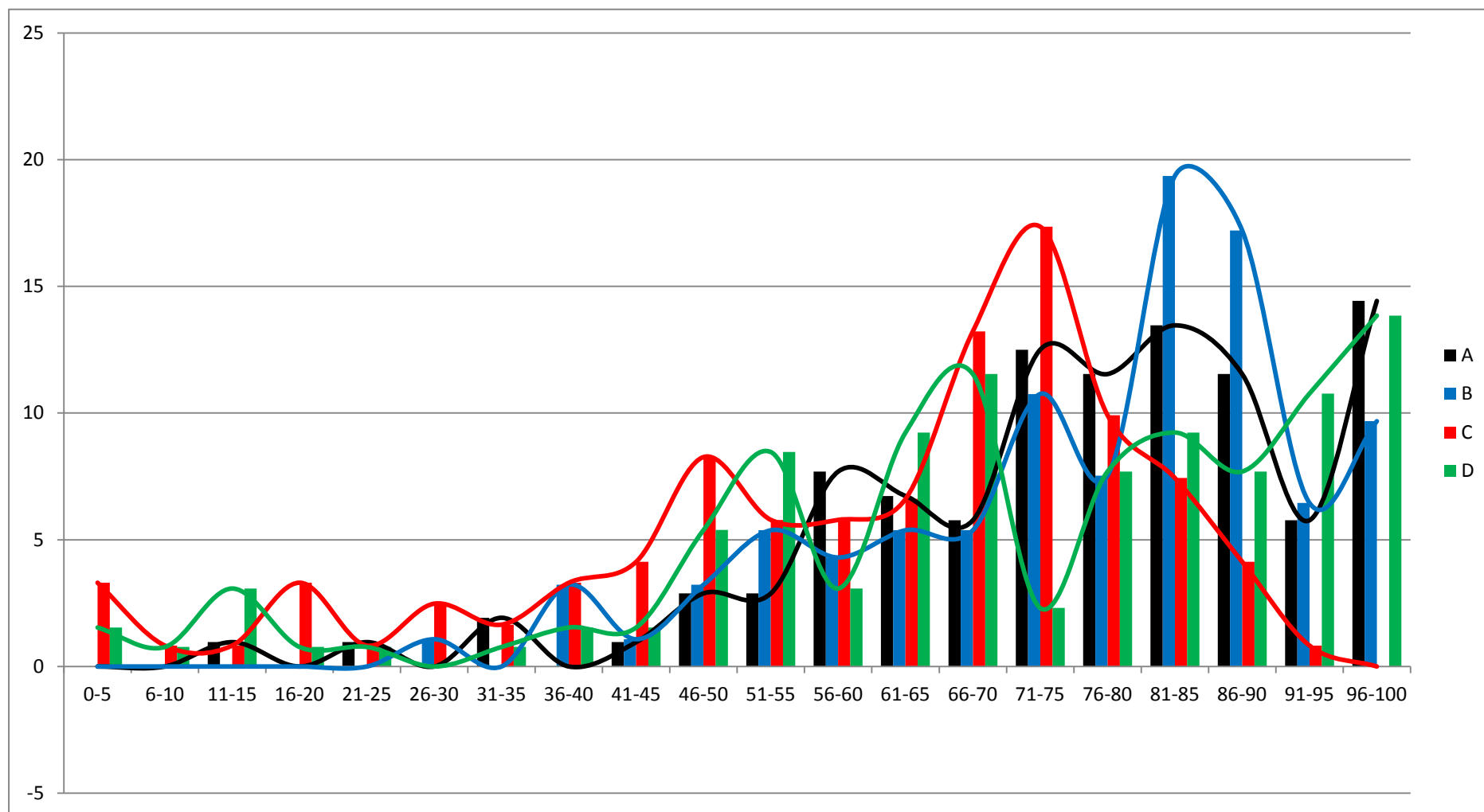
The significant change every year in the 1b component implies that examination marks in the module of interest are changing year to year. The non-parametric tests indicate the sign of the change with the mean rank for each component. Looking at the 1b component for AB, AC and AD the mean rank for group A goes up each time from 110.89 to 143.7 to 158.36 respectively while the mean rank for the partner group (B, C and D) remains relatively constant (85.7, 86.62, and 84.82 respectively). The implication of the increasing difference in mean ranks is that the disparity is getting larger each time, with A having superior performance. The same holds true for group B ranked with C and D and group C ranked with D, indicating that performance is highest in A decreasing year on year to D. This is supported by the histogram Figure 5.17, where clearly higher grades become less frequent with increasing year.

The significant changes all years in the 1c category except C to D, coupled with the mean ranks indicate that the change is negative year to year, that performance in the 1c category drops from group A to a statistical plateau for groups C and D. The histogram of Figure 5.19 shows the differences (and similarities) between the distributions of the 1c group.

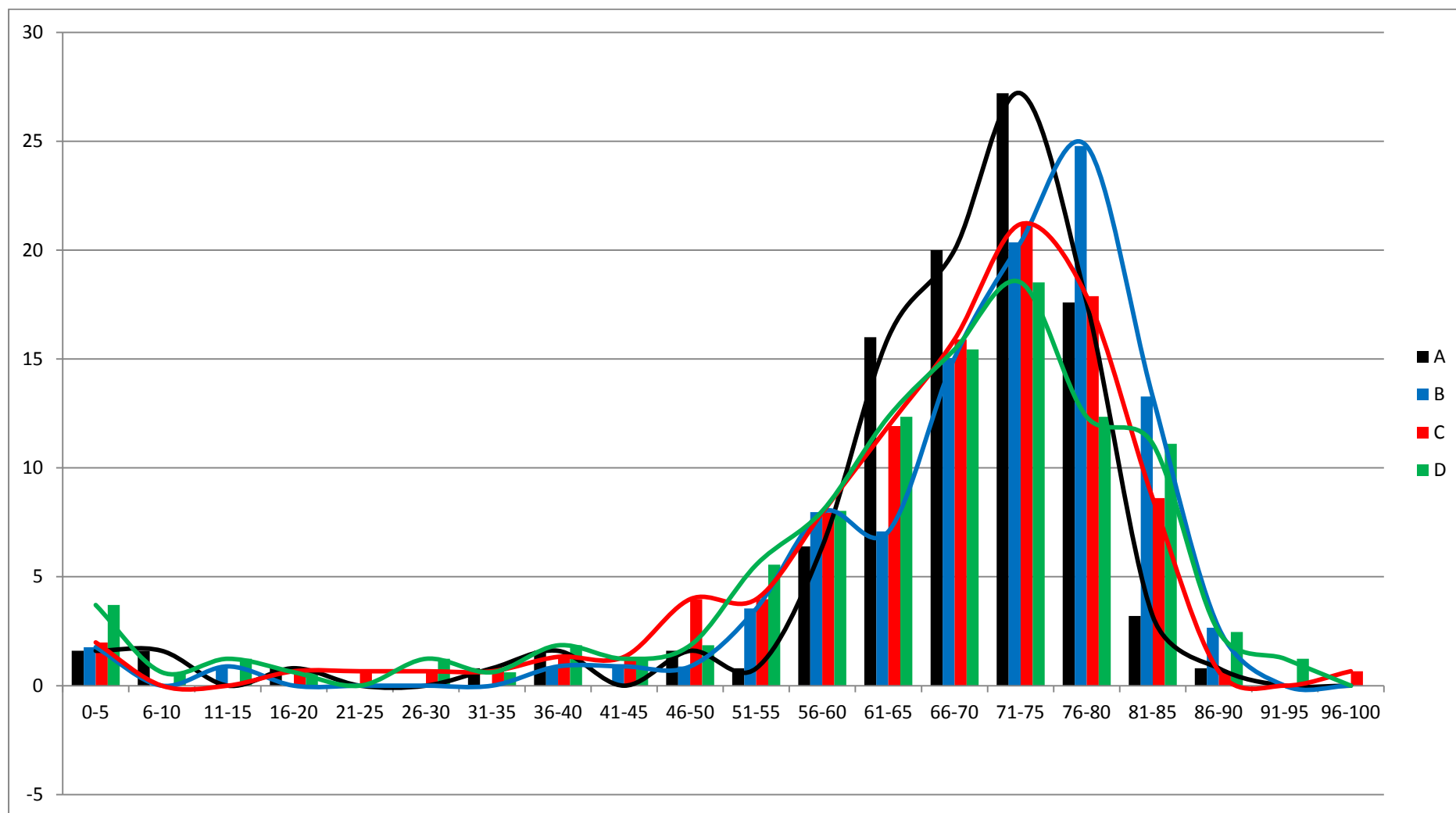
The significant results in the 2a and 2b categories indicate that there are changes in the B and D year groups respectively. The mean ranks indicate that the B group is above the others in the 2a category and that the D group performance is below the others in the 2b category. The sum of ranks in the BD (2b) pairing are inverted, with group D having a higher sum than group B despite being the worse performing module. This is caused by the sizes of the two groups; D has a sample size of 162 compared to Bs 113.

The 2c pairing is not included in this analysis because from Table 5.13 there was no significant difference in that category, and the similarities, especially between B, C and D are shown clearly in the histogram of Figure 5.20.

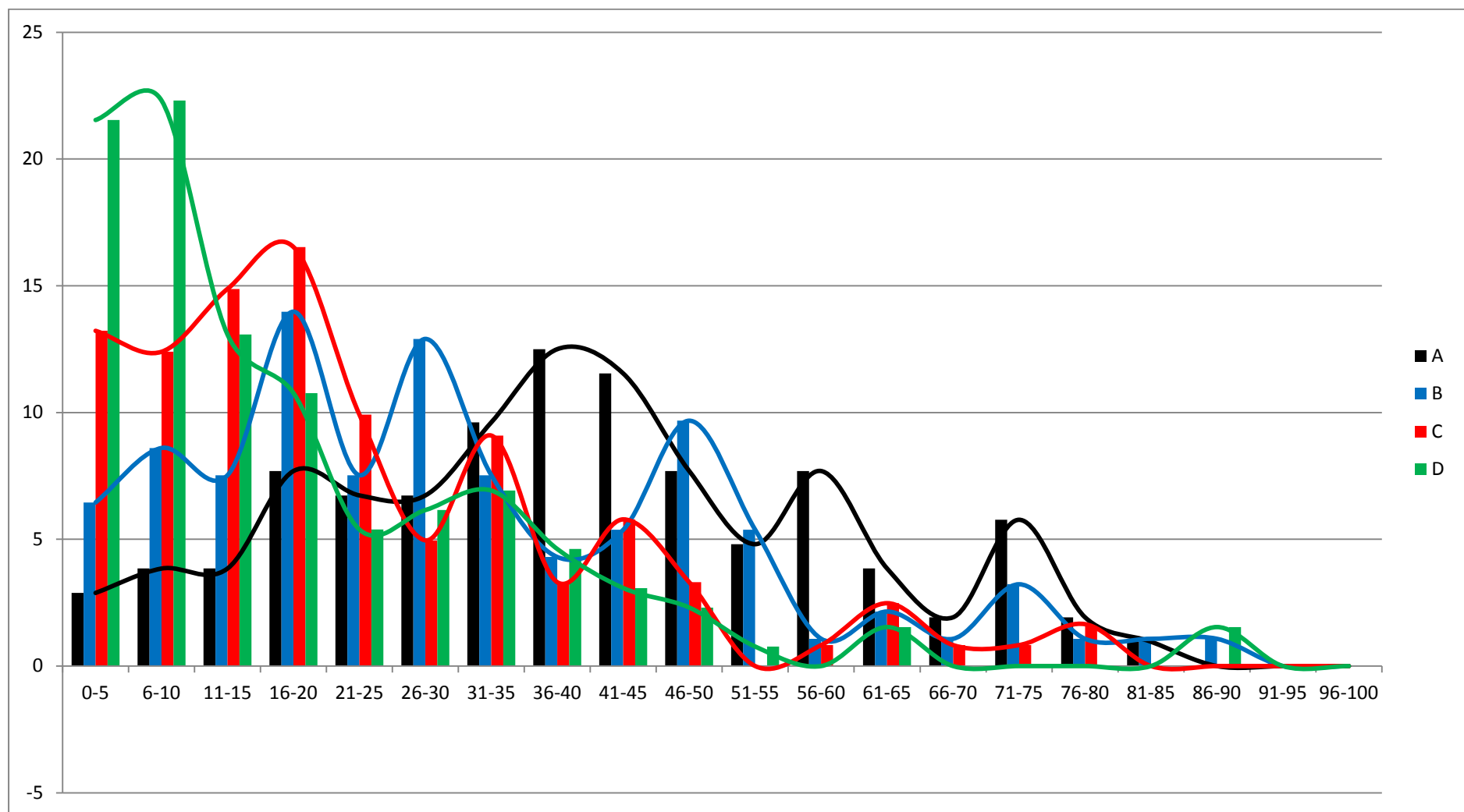




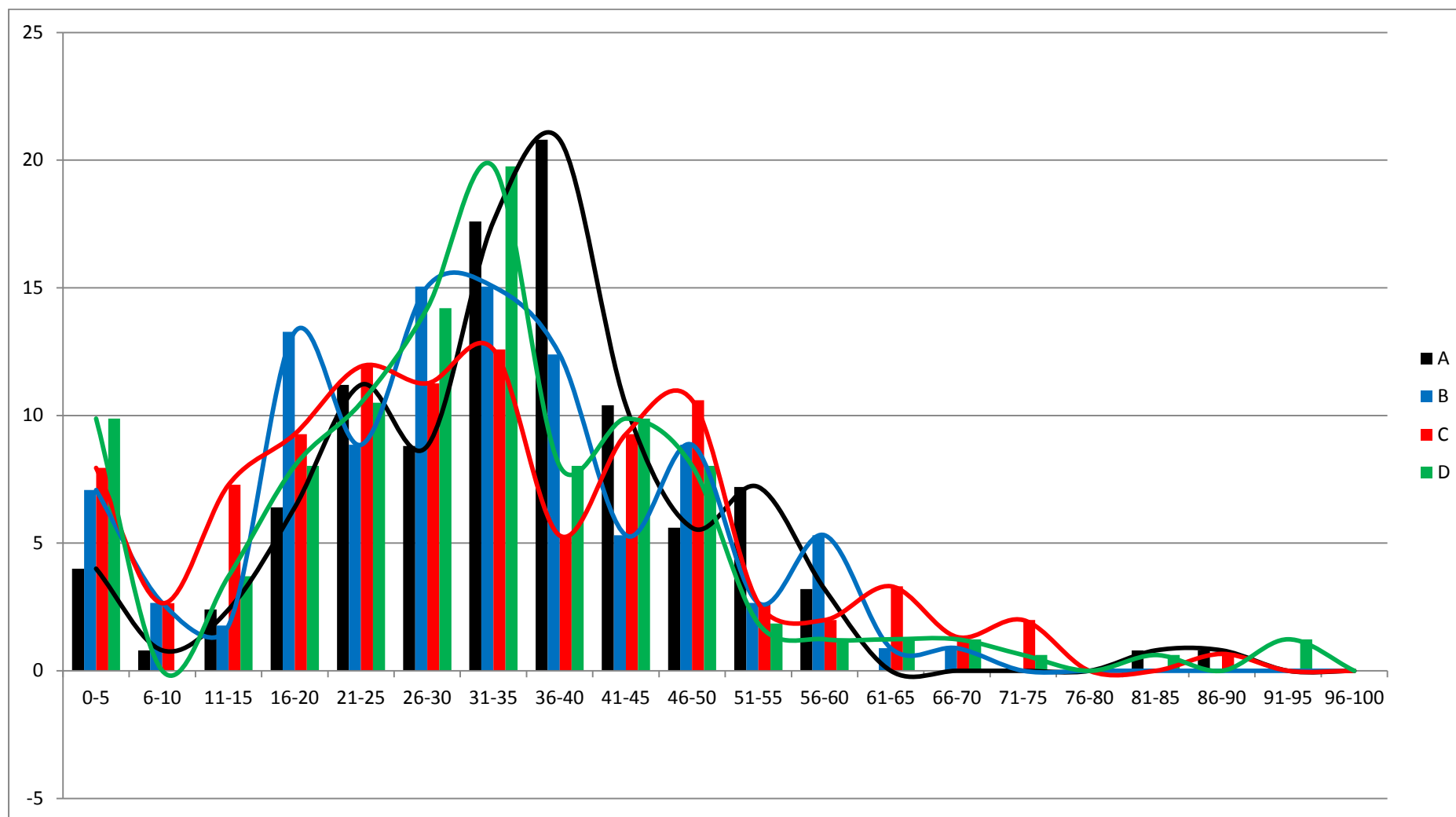
**Figure 5.15 – Histograms of achieved coursework marks by year (ELB046)**



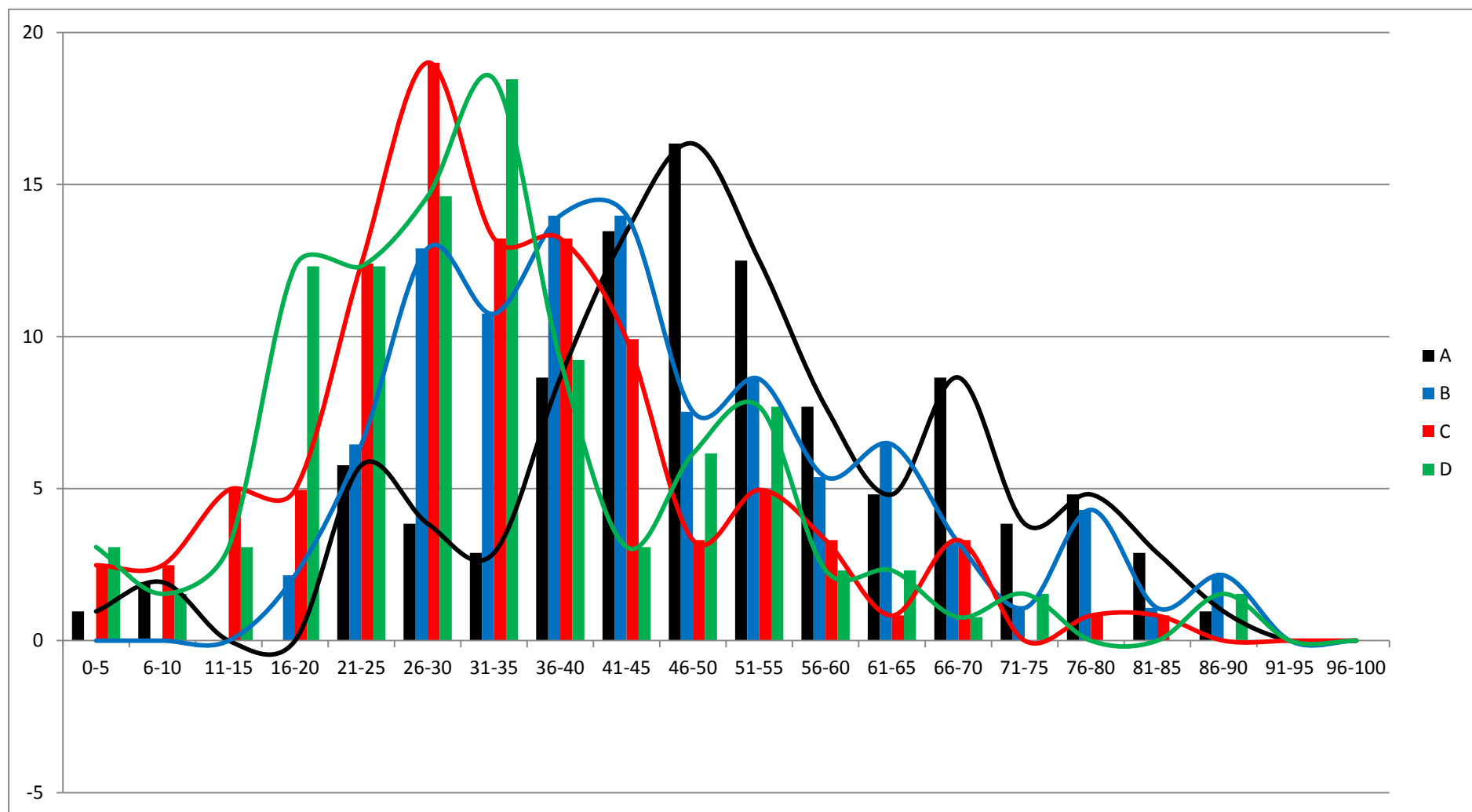
**Figure 5.16 – Histogram of average coursework marks by year**



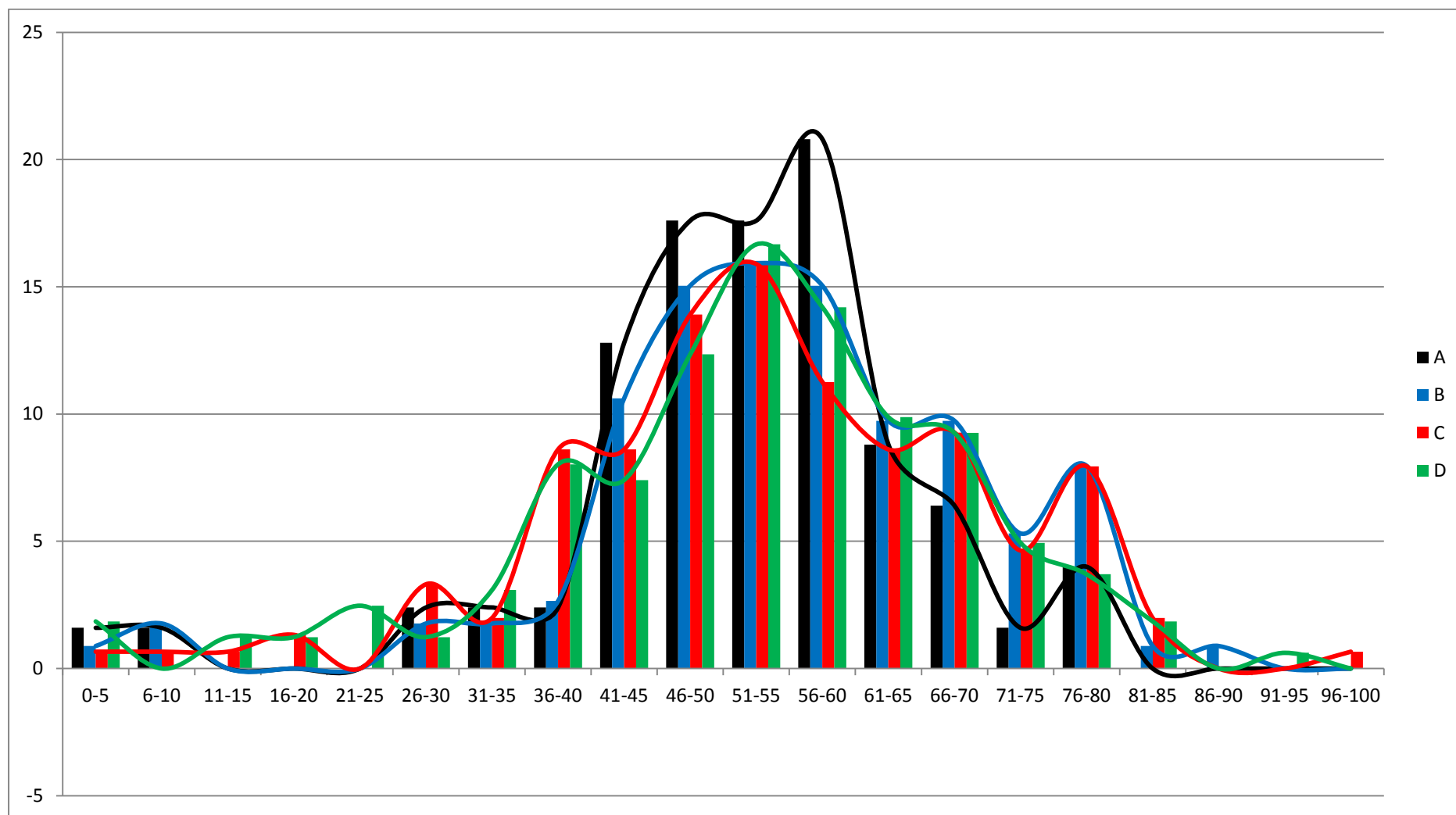
**Figure 5.17 – Histogram of achieved examination marks by year (ELB046)**



**Figure 5.18 - Histogram of average examination marks by year**



**Figure 5.19 – Histogram of achieved module marks by year (ELB046)**



**Figure 5.20 – Histogram of average module marks by year**

Comparing this module in the same way as the ELB046 module was compared, i.e. to student averages and to the generic module of that year using the appropriate techniques allows one to say that the distribution of the coursework marks is not different to the distribution of the average coursework marks. The significant results in the other two pairings indicate there are statistical differences in the two distributions, and as they are normal and the parametric test has been used to compare them, there is a confidence interval available for the difference. This shows that the exam mark is above that which would be expected from the student's average, while the overall mark was below their average.

	Statistic	df	Sig.
E1a-E2a	.977	131	.024
E1b-E2b	.986	131	.197
E1c-E2c	.993	131	.808

**Table 5.22 – Group E normality**

	Paired Differences					Test Statistic T	df	Sig. (2- tail)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
E1b - E2b	3.487	10.888	.951	1.605	5.369	3.665	130	.000
E1c - E2c	-5.356	7.558	.660	-6.663	-4.050	-8.111	130	.000

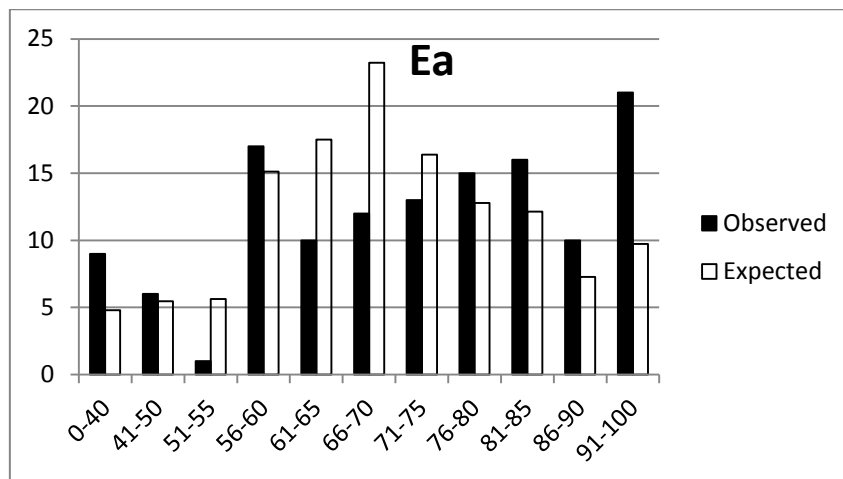
**Table 5.23 – Parametric intergroup results**

		N	Mean Rank	Sum of Ranks	Test Statistic Z	Asymp. Sig. (2-tailed)
E2a - E1a	Negative Ranks	71 <sup>a</sup>	61.97	4400.00	-1.140 <sup>d</sup>	.254
	Positive Ranks	54 <sup>b</sup>	64.35	3475.00		
	Ties	6 <sup>c</sup>				
	Total	131				

a. E2a < E1a; b. E2a > E1a; c. E2a = E1a d. Based on positive ranks

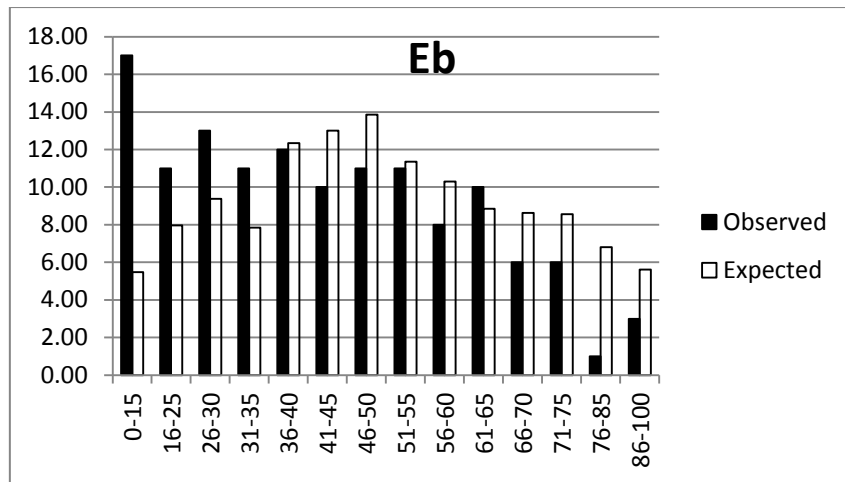
**Table 5.24 – Non-parametric intergroup results**

Comparison to the generic module shows a significant deviation in every component, and by consulting the histograms we can see where the differences between the generic and the observed values lie.

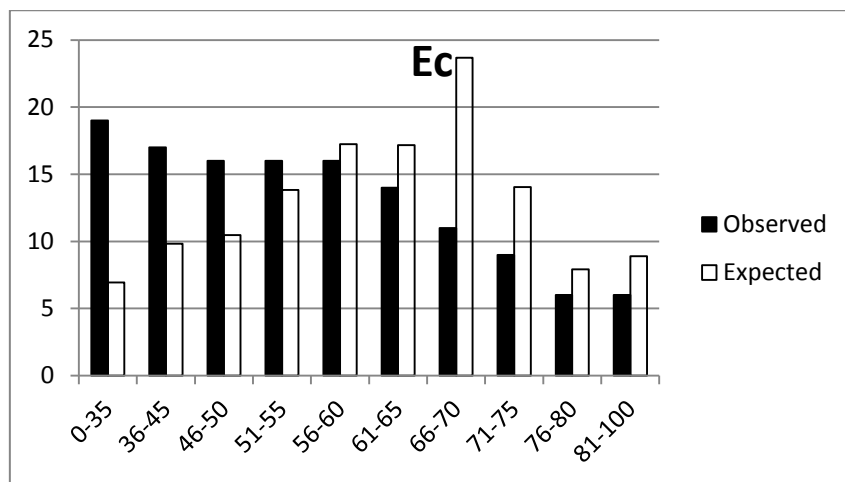


**Figure 5.21 – E1a and E3a histograms**





**Figure 5.22 – E1b and E3b histograms**



**Figure 5.23 – E1c and E3c histograms**

The pairwise comparison (Table 5.25) of the E year group marks and the marks of the other years show that there are significant differences between the marks achieved in the replacement module ELB003 and the original module in all but one of the components, the overall component (1c) of the A year group. This is interesting as this was the highest scoring year for which data had been analysed. Mean ranks show that in the coursework (1a) component the performance in the E year group is below the performance as would be expected on any of the ELB046 modules, whereas in the examination component (1b) the performance is better in the replacement module. The overall component (1c) shows a higher mean rank for the E group in all combinations, but the difference is not significant for the AE group.

The average coursework component (2a) is significantly different between the E year group and all others except B; however, the previous analysis showed that the B year group was anomalous (higher scoring) in that component. For the comparisons that return significant results, the E group should be considered better. For the average examination marks (the 2b component) the only significant difference is between the D and E groups, however, again the D year group was shown to have been anomalous (lower scoring) in this component. If one were to replace the anomalous component in these two years (ie B2a and D2b) with a non-anomalous version, then the results of pairwise comparison with the E group would have been that the 2a component was different (E higher) in every year, and the 2b component would have been comparable every year. The mean ranks for the 2c component indicate that on the three pairings where a significant result was generated it was in favour of the replacement module.

Comparison	1a	1b	1c	2a	2b	2c
AE	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Accept Null $p=0.099$	Reject Null $p=0.013$	Accept Null $p=0.055$	Reject Null $p<0.0005$
BE	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Accept Null $p=0.971$	Accept Null $p=0.222$	Accept Null $p=0.107$
CE	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Reject Null $p=0.016$	Accept Null $p=0.532$	Reject Null $p=0.006$
DE	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Reject Null $p<0.0005$	Reject Null $p=0.010$	Reject Null $p<0.0005$	Reject Null $p=0.002$

**Table 5.25 – Pairwise comparison year E**

### 6.3.2 Discussion – Summary of key findings

This section provides details of the key findings arising from desk research undertaken to identify the sources of student misunderstanding in the ELB046 module.

### **6.3.2.1 Summary of key findings**

The analysis detailed in §5 showed that over half of the intergroup analyses could be achieved using parametric methods, even given the relatively loose significance level of  $p=0.1$ . Using the more stringent level of  $p=0.05$  three quarters are viable for parametric analysis; however, none of the intragroup analyses conform with assumptions required for parametric analysis.

The intergroup analysis for the student-centric model show that there are significant results in most of the pairings, meaning that in most of the pairings there is a significant deviation between the student's average component mark and that achieved in the module of interest. This deviation presents in different ways for each component, with the coursework component being the only one for which the module was (generally) higher scoring than the average. The total component mark pairings are all valid for comparison via parametric methods, which yields, as part of the results, the mean difference between the pairs of samples. This increases from 2% in the A year group to approximately 18% in the C and D years, which indicates overall performance on the module is dropping.

For the module-centric model only one pairing (A1b and A3b) can be assumed similar. This means that only in one case is there a correlation between the distribution of observed marks and the distribution of the generic module, and this mirrors the observations in the student-centric model (A1b and A2b). Information about where the differences lie can only be obtained from the histograms.

The intragroup analysis showed that there was a significant change in every component of assessment, both on the module of interest and the averages throughout the years of interest except the average overall marks. This means that students have not in general got worse over the years but instead respond to assessment measures in different ways.

The detailed analysis showed that for the module of interest the difference in coursework can be narrowed down to a single year group performing abnormally, relative to the consistent level shown in the other year groups while for the other two components it was a general declining trend. This is particularly noticeable for the examination marks, the 1b component (Figure 5.17). For the average exam and coursework components the significant deviations

can be narrowed to a single year group's abnormal behaviour, although a different year group is responsible for each component (group D for the examination, B for the coursework).

The intragroup analyses which show a significant deviation within the four year period that can be narrowed down to a single abnormal year provide us with little information other than that year was abnormal in that component. There are many potential reasons for this variation that cannot be effectively explored here, however, the components where the significant changes occur between multiple years can be considered.

### **6.3.3 Limitations**

A well-known limitation of desk research is the accuracy of the data whereby there is potential for error at the data input stage. It would not be possible to confirm the accuracy during secondary analysis. However the desk research undertaken in this study was performed in a higher education context whereby the data represented real student achievement. Errors are identified and corrected as a matter of course due to the highly sensitive nature of the data.

It is rare for any secondary data set to exactly meet the needs of the researcher. However, in this case the data set met the research requirements specifically. In order for the data to be anonymised personally identifiable data was removed from the data set.

### **6.3.4 Conclusions**

This research has highlighted that coursework marks on ELB046 were routinely higher than average coursework marks, and stable across the four years. This may be explained by students use of readily available support materials, and the hands on laboratory assessments which routinely score highly.

Overall performance in the module shows a declining trend despite the stable performance on coursework and this trend is related to the more marked decline in exam performance over the same period.

Overall average marks do not change significantly across the four years, but the individual component marks do. This indicates that the students' performance is not declining but that they are changing the way in which they use the assessments in order to obtain their grades.

The analysis of year E data shows that the replacement module ELB003 is an improvement upon the ELB046 module that it replaces, and produces as an end product a better student for progression to the ELC040 module. The difference between the coursework marks achieved and the average coursework mark is reduced, and the examination performance is improved to a level approximating the student's average examination performance.

Overall this research has demonstrated that the roots of the student misunderstanding of Electrical Machine Theory seen in the Electrical Machines and Systems module lay in the pre-requisite module Electrical Power B. Students routinely failed to achieve high levels of understanding in this module and as a result were unable to successfully build upon it in the third year module. This has been resolved, at least partially, by what is effectively a rebranding of the second year module.

Having identified the second year module ELB046 as the root cause of student misunderstanding, and identified the trends of assessment in that module, further research is required to identify why these trends are exhibited.

## **7 Interview Studies**

### **7.1 Outline of research presented in this chapter.**

This chapter describes the findings from an interview study undertaken with Part B and Part C students. Semi-structured interviews were undertaken with Part C students who were undertaking the ELC040 – Electrical Machines and Systems module. Structured interviews were administered with the Part B students. The interviews aimed to establish the study practices adopted by students across both years. In total 9 face to face semi-structured interviews were undertaken and 62 structured interviews. Topics discussed during these interviews included study habits employed by students, impressions of the ELC040 and ELB046 modules and teaching methods employed.

### **7.2 Aims and Objectives**

The aim of this study was to collect information on the study practices of Part B and Part C students to identify why assessment appeared to be in decline in the Part B module. The specific objectives were to:

1. Explore student behaviours with regards to studying throughout the year
2. Establish if study practices change in preparation for assessment
3. Identify student attitudes toward the modules

### **7.3 Methods**

This study utilised both structured and semi-structured interviews. Semi-structured interviews were chosen as the primary data collection method as they allow the interviewer freedom to adapt questioning to follow up interesting responses from the interviewee, and given the informal style promoted expansive answers. Structured interviews were chosen as a supplementary method of data collection as it was a convenient method for collecting large volumes of qualitative data in a short time frame.

#### **7.3.1 Semi-structured interviews - Procedure**

A semi-structured interview schedule was developed based upon the findings from the previous two studies. Probes were used to explore interesting responses given by the students. The interview schedule is shown in Table 6.1.

Personal details	<ul style="list-style-type: none"> <li>• How long have you been at uni for?</li> <li>• Which degree program are you enrolled on?</li> <li>• Gender</li> <li>• Age</li> <li>• Industrial experience? Where?</li> </ul>
ELB046	<ul style="list-style-type: none"> <li>• How did you find it?</li> <li>• Do you think everybody found it the same as you?</li> <li>• Identify topics you found especially difficult or easy</li> <li>• Explain why</li> <li>• Can you think of a way the difficult topics could be made easier?</li> </ul>
Study practices	<ul style="list-style-type: none"> <li>• How do you study? How does that change for exam periods? How do you know when you know something?</li> <li>• Is that the same for all modules?</li> <li>• Is that how you have always learned? If not when did you change and why?</li> </ul>
Teaching and learning	<ul style="list-style-type: none"> <li>• How are you finding this module?</li> <li>• What's been the hardest thing you've done so far? Anything that you've understood significantly quicker than your peers? Vice versa?</li> <li>• Can you think of anything to make these topics easier?</li> <li>• Are you worried about any aspect of assessment?</li> <li>• Anything you'd change about the lecturers on the module?</li> </ul>

**Table 6.1 – Interview schedule**

### **7.3.2 Semi-structured interviews – Sampling**

Participants were recruited from the Part C cohort during the academic year 2008/9. An email providing details of the study and inviting interested students to contact the researcher was sent to all students registered on the Part C module (29 students). The email explained that the study wished to explore student study practices and attitudes towards modules, and that responses would be treated with confidence and reported anonymously.

In total 9 students from Part C participated in the semi-structured interviews giving a response rate of 31%. The interviews were recorded using a digital voice recorder with the knowledge and consent of the participants, and transcribed verbatim with any personal

references being removed. Each interview was undertaken by the same researcher who had been trained in interview techniques, and lasted between 15 minutes and an hour.

### **7.3.3 Semi-structured interviews – Analysis**

The transcribed interviews were analysed using thematic analysis as described by Braun and Clarke [23]. They describe six phases to thematic analysis listed below.

1. Familiarising yourself with your data: Transcribing data (if necessary), reading and rereading the data, noting down initial ideas.
2. Generating initial codes: Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes: Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes: Checking in the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic “map” of the analysis.
5. Defining and naming themes: Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing the report: The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

### **7.3.4 Structured interviews – Procedure**

In order to explore the experiences of those students registered for Part B of the program a structured interview study was undertaken. An interview schedule was developed based on the findings of the previous studies. The interviews were conducted during a scheduled lecture period for students registered on ELB046 – Electrical Power B and written student responses were collated once completed. The interview schedule is shown below in Table 6.2.



- How long have you been at university for?
  - Do you have any industrial experience?
  - Which programme are you currently registered on?
  - Age Gender
- The results for the circuits module you took in part A were, on average, lower than would be expected. The following questions relate to that fact.
1. How did you find the module?
  2. How do you think others found it?
  3. Can you think of anything you found difficult but your friends and peers seemed to find easy?
  4. Do you think the teaching/assessment needs changing in any way?
  5. How did you go about studying for the module, and how did you know when you'd learnt something?
  6. Do you think you will change the way you study as a result of your experiences?
  7. Can you give some examples of teaching styles that you think would be suited to the module?
  8. Compare the teaching style of Keith to other lecturers you have had. How does it compare? What are the good and bad points?
  9. Finally, how are you finding this module, Electrical Power?

**Table 6.2 – Structured interview schedule**

### 7.3.5 Structured interviews – Sampling

Participants were recruited from the Part B cohort of the 2008/9 academic year. The questions were printed on paper, and distributed to a class during a scheduled lecture slot. The aims and intentions of the research were made clear at the start and students were informed that participation was voluntary and the confidentiality and anonymity of the responses assured.

In total 62 of the 154 students registered on the module agreed to participate giving a response rate of 40%.

### 7.3.6 Structured interviews – Analysis

The data from the structured interviews were collected together and subjected to a relational content analysis [115]. Interpretation of data is at the core of qualitative research, and Content Analysis can be used to determine the presence of certain concepts within a given data set. Coding units can include words, themes, items, characters and concepts.

Predetermined concepts were explored which directly mapped onto the interview questions. This approach was considered suitable due to the large amount of data gathered in this phase of the study.

## **7.4 Thematic analysis results**

### **7.4.1 ELC040 – Electrical Machines and Systems**

When questioned about how they were finding the Machines and Systems module the students were generally positive. The responses can be classified into two basic categories, the simple or the revealing. The simple responses answer the question without expansion, with phrases such as “*fine, yeah*” (student 5), “*It’s one of the more difficult modules I’d say*” (student 6) or “*Not too bad, I’m understanding more than I did last year, which is good*”.

The revealing responses give insight into other factors affecting the way in which the students approach the module. There is evidence that students approach the module with expectations about how difficult the module is, and evidence that the students are already acting reflectively by linking their work in part C to previous years.

The data providing evidence of the expectations of difficulty include one student whose response about how they were finding the Machines and Systems module was “*quite well actually*” (student 3), in which the surprise was clearly audible, and one student who went further still by identifying from where the expectations are generated with “*I spoke to some people that had just come out of part C and they’ve said it’s a ridiculously hard one to do*” (student 2).

These expectations of difficulty can have either a positive (motivational) or negative (demoralising) effect. Both examples here show a demoralising effect, but certainly in the case of the first it seems that the expectations has been countered by the course of instruction (up to that point at least) and it is hoped that as a result there is no self-fulfilling prophecy at play [116, p. 423].

The data that provide evidence of reflection refer to the part B module, with comments such as “*Technically difficult again. About the same level as last year*” (student 9). This response is evidence of reflection about the degree program as a whole and the related modules in terms of their difficulty, rather than in terms of their content, however other students reflect more

upon the content of the various modules. One student remarked “*it’s just an advancement of last year so it’s alright at the moment*” (student 4) and a second takes an opposing viewpoint with “*The stuff we do in machines and systems I still don’t fully grasp from my previous years either*”(student 2). This is clear evidence that some students realise that their continued education is based upon the concepts and material introduced to them in their earlier years of study. This is a sentiment echoed by other students who, when questioned about the part B module and its relationship to the part A module ELA001, respond that it builds upon the previous module “*a lot*” (student 1). It follows that students who perform better in their earlier years are more likely to achieve higher in later years, however one student quantifies this observation by responding to the question “Presumably with that sort of grade [45-50% overall in ELB046] you can identify areas where you weren’t as strong as maybe you should’ve been, or would’ve liked to have been. Are they hampering you this year?” with “*Not as far as I can see*” (student 9).

#### **7.4.2 ELB046 – Electrical Power B**

When questioned about the part B module ELB046 the general consensus was that it was enjoyable but difficult for the majority of students. One student who found the module “*challenging*” but understood that “*you have to work at it to try and understand what’s being taught*” suggests that this apparent difficulty may be a result of complacency saying

*“maybe they thought it was easier than it was, so when they came to the exam they were like ‘oh, actually it’s really difficult’ because from tutorials and things you do in lectures, maybe people sort of underestimated it a bit”* (student 6).

This is backed up by a further student saying

*“throughout it I thought this is not too bad, and I did alright, and did well on the coursework and then it came to the exam...and I remember going through the paper going ‘no...no...no...oh I can do that bit...no...no...I’ll have a guess at that’, and I came out of the exam knowing fairly comprehensively that I’d not done that well”* (student 7).

A third student offers an explanation for this complacency, and states that the exam

*“was worded completely differently to all the past papers and questions we’d done and just because the wording was so different it confused me on some parts”*(student 3).

### **7.4.3 Lecturer styles**

When questioned about the lecturers style, and invited to suggest potential improvements, students responded positively, often making statements such as *“they’re probably the two best lecturers I’ve had”*(student 4) and saying that they were happy with the style employed on the module. Note the two lecturers referred to are Dr Keith Gregory and Mr Gordon Kettleborough, the lecturer part responsible for ELB046 and primary responsibility for the closely related module Electrical Machines and Drives. The only negative comments about Dr Gregory are that during tutorial sessions when doing calculations he sometimes has a tendency to *“skip some points when he thinks you should know it”* (student 2), which causes the student to be thrown off and spend the rest of the lecture *“copying it down not understanding”*. The student later admitted that he went home after such instances, and worked it through again to gain the understanding he’d missed and bring himself back up to speed, however there is no suggestion that a less conscientious student would behave in a similar manner. A consistent theme is that choosing to do the module is affected by knowing who the lecturer will be, despite the expectations of difficulty which are generated at least in part by the same information. In the case of this module the effect is favourable, as illustrated by statements such as *“I picked their modules because I like the way they teach”*(student 3).

It is interesting to note that students reported that Dr Gregory has a reputation for setting particularly difficult examinations, as acknowledged by one student saying *“The exam is bound to be hard as it’s my final year and Keith’s setting it so....it’s bound to be hard”* (student 4) and another saying that when the module was taught, and the exam set by two lecturers he would pay less attention to the sections set by Dr. Gregory than those set by Mr. Kettleborough. Despite this reputation students acknowledge that Dr. Gregory is not a harsh marker, saying instead that *“he’s actually lenient”* (student 8).

### **7.4.4 Study habits**

The students interviewed described a wide range of study habits, with several of them stating that they would do at least some of the given tutorial questions. Given the supposedly difficult nature of the module a surprising number admit to doing only the smallest amount of

work with statements such as “*throughout the year, unless there’s something triggered in the lectures, I generally won’t do anything*” (student 7) and “*I attend all the lectures, or do my best to, but I don’t tend to do much outside the lecture until it comes to coursework*”(student 4), which isn’t done “*until I’ve got a deadline like the next day*”. This would suggest the student enjoys working under pressure.

One student openly admitted that

*“for the first year I didn’t [study]. I did absolutely nothing. I just blagged coursework off other people, did the occasional piece and gave it to other people. I didn’t make many of the lectures either”* (student 3),

however the same student then goes on to say that “*last year I made a conscious decision to make a lot more of the lectures*” and began revising at Easter. It apparently had little effect on his grades, and when reflecting upon his time in the third year says he has “*done a lot more this year*” and explains this by saying “*I think it’s kind of hit me that being my final year I’ve got to do some work*”. The work he describes doing outside of lectures was the tutorial questions, paying particular attention to the ones that were used in class. Another student who reported making good use of the provided tutorial questions stated

*“I do look through my notes every so often, but that’s only if I don’t understand something. I won’t look over them if I understand...and whenever we get tutorials I’ll do a bunch [about half] of them, and go through any done in class again.”* (student 5)

When it comes to revision for examinations, the theme is largely the same. Reading through the provided lecture notes, attempting tutorial questions and seeking assistance if struggling to complete them (the numeric answers without working are given with the problems, and samples of the questions will be completed in class by the lecturer providing a worked solution which can be adapted to similar questions) and finally past papers are attempted. One student claimed he was unable to “*remember more than one [subject] at once*” (student 7) so was forced to revise for just one subject at a time. This poses a problem in a crowded examination timetable when exams may not be separated by any significant time, and as the student himself confesses “*For me that made a big impact on my next exam as well, because I felt crap after [ELB046] exam, it put more pressure onto it*”.

Whether this revision is done individually or as a group, any understanding generated in this period is a secondary outcome. The primary purpose of revision in this manner was reported to maximise retention of answering techniques, in the hope that in the examination the same methods can be used. The examination causes the focus of the student to shift from trying to develop understanding to developing temporary long term memory, that is remembering the techniques until the examination is over, at which point the techniques (and associated knowledge) will be forgotten. One student confirms he worries about “*Being able to sit in an exam and then regurgitate the knowledge*” (student 9) and it is common among undergraduates to struggle to remember information taught in previous years when they failed to reach deep understanding, as evidenced by students making comments such as “*I can’t remember the module that well*”(student 9) and

*“If you gave me even now a first year exam I still wouldn’t know half the stuff on it. There’s things that now, like I look at tutorials from this year and think like this is similar to some of the first year questions and still have no idea.”* (student 2)

One student commented that when he goes through past papers he will

*“look for trends, how the questions are going to look and the certain subjects that are going to come up then revise specifically on those to get me the marks, so that if I can answer two questions 100% complete then it doesn’t really matter about the other ones.”* (student 2)

When challenged regarding this only being a valid technique until the exam paper is “a curveball” the student replied “*Yeah, exactly, which is apparently what Dr Gregory does decide to do*”. The irony of this comment was not explored further: the student still felt it a good idea to revise in a manner that may prove detrimental should the exam contain an unexpected question. This is again a textbook example of surface learning techniques, but it seems only applied in the very late stages of the module, in a bid to maximise marks achieved in the examination. The author rather suspects that in the event that the exam is not in the form expected that this effort to maximise marks might actually back fire on the learner and cause a reduction in the marks achieved. Dr Gregory insists the exams are not “curveballs” in their entirety, instead one question can be considered to be out of the ordinary whilst the rest remain similar to both previous examination questions and tutorial questions given

throughout the year. He anticipates that any student who had done the tutorial questions would be able to answer the examination paper to an acceptable standard.

#### **7.4.5 Knowing you know**

To support the assertion that not all students are employing a surface learning approach by attempting to rote learn the methods required to answer questions the students were asked to explain when they felt they knew something. Several responses were indicative of deep approaches to learning, with participants stating that they felt they knew something when they can explain or teach it to someone else, however a significant number of responses could be interpreted as exhibiting a surface approach, with comments such as *“it’s just repetition really I find would be the way to [learn]...until you know something”*(student 2) and

*“I think if you do tutorials or exam questions and get them wrong, go back, try them again and then once you get to the stage where you’re getting most things right, then you’ve basically got it I think”*(student 6).

Deeper probing allowed the motivations behind the responses to this question to be included in the classification of approaches, and the student who earlier claimed the examination was worded completely differently stated that because of the way the module was taught he *“knew how you should be answering”* (student 3) and that he *“learnt the theory by knowing what did what with it in the questions”*. This, and the final comment above, is evidence of an approach, which discounting motivations, would ordinarily be regarded in literature as a surface approach, however there may be more to it than that, and this would be classified by Case and Marshall [106] as a procedural deep approach, somewhere between the widely acknowledged surface and deep approaches. Other authors, in particular Biggs [117], would attach the label “Achieving” to this approach

One of the most interesting comments received in response to this question is a student who responded that he knew something when he could *“go through a few questions and get the right answer”* (student 4). His initial response to the question was

*“I don’t know. If I get the answer very quickly and easily, I generally assume it’s wrong because it’s not very often I go straight in and know the answer...assuming it’s a maths type of question.”* (student 4)

This indicates a low level of confidence in the student's own abilities, and a very high level of self-doubt, which can lead to a self-fulfilling prophecy [116, p. 423].

#### **7.4.6 Semi-structured interviews – Summary of findings**

Consistent with the aims of this study, this research has identified that students enrolled on the Part C module reported that they expected the module to be difficult but they felt they were progressing well. In reflecting on their progress, many of the students showed evidence of metacognitive reflection.

The students in this study reported that Electrical Power Theory is notoriously difficult within the field of electrical engineering, but also reported that they felt that lecturer styles are suited to the module.

Students reported using standard revision techniques in advance of assessment and did not demonstrate the use of advanced study skills. There was no evidence to suggest innovative learning techniques were employed by those participating in this study.

### **7.5 Content Analysis - Results**

#### **7.5.1 ELA001 – Circuits**

Of the 62 respondents to the paper interview, some 45% of them responded that they found the module hard. Almost a quarter (23%) contradicted this view claiming it was easy. This disparity is presumably down to the level of education received in similar topics at a secondary level, and indeed some of the students cite their previous education as a reason for the module being easy with comments such as “*I found it a revision of what I’ve learnt at school previously*”. Resolving this is one of the goals of the first year of any tertiary education course.

Over half (60%) responded that other students in the class found the module either the same or similar to themselves. Some of the responses showed no definitive comment such as “*Some found it easy, quite a lot found it hard*” and imply that the emphasis of the split is perceived to be on the hard side, and this is supported by the self-assessment question.



### 7.5.2 Teaching and assessment

The students were asked whether they thought the teaching or assessment needed changing in any way. A high number of categories were identified because of the variety of responses received. The responses simply categorised (ie Yes/No) are correlated with the answers to the first question about how hard the ELA001 module was. The four people that answered “yes” all found the module hard, while 10 of the 16 answering “no” found the module easy.

Nine people thought that the assessment needed changing with two of them asking for the exam to be split according to the lecturer responsible, three asking for a higher weighting for coursework. It is notable that two of the students claim the exam needs to be easier, and that it was dissimilar to previous years.

22 respondents want the teaching to be changed, eight of which asked for more use of the LEARN server (the locally hosted virtual learning environment at Loughborough University) and seven asking for more tutorials. There are no correlations with these students answers to the first question. The remaining seven are split between generic comments (“less notes”, “more teaching styles” etc.) and wanting more revision lectures.

### 7.5.3 Studying and Knowing you Know

Student responses to the question “How did you study for the module and how did you know when you’d learnt something?” showed that it seemed to be interpreted as being about revision techniques. A large number (37%) profess to using their notes in some manner, but only about a fifth report rewriting them. The majority of them simply read through them.

23% reported using questions of some variety, either the tutorials given out in the notes (and the worked solutions provided as a part of the lecture series) or past examination papers. 25% of students did not mention their study practices explicitly, however, when they reply with statements like “*I then continue to do tutorial qu’s to ensure I could still do the work*” study practices (as opposed to revision practices) can be inferred. Responses like this are categorised as “no mention” because inference is not comparable to a definitive response.

The few responses that do provide insight into study habits essentially echo the part C interview answers, in that people didn’t study hard and left things to the last minute. One

student reflects that it shows and he “*got a last minute mark in his exam*” and learnt only that which he had needed for the coursework.

Responses given by students about how they judge their level of understanding were varied, and often focus on the student’s ability to answer questions. Few students responded that they quantified their understanding on a higher level, for example when they were able to “*explain to another*”. Given the propensity for judging levels of understanding via question answers it is surprising that here, as in ELC040, the examination is often not what they were expecting.

One incredibly interesting response is provided by a student in answer to the question about study methods and quantification of understanding with “*Past papers. And this I beileive is the problem. The understanding is by-past as long as you can learn a method to answer a given question. If you know to multiply X with Y you get the marks and pass, but to understand the question, topic and understanding is something very different all together [sic]*”.

#### **7.5.4 ELB046 – Electrical Power B**

The final question of the interview asked how the student was finding the ELB046 module upon which they were at the time enrolled, and the results were categorised according to how the students rated the relative difficulty of this and the previous module. Some 65% of respondents said that the module was the same as or harder than the Part A module, however, some of those responses are inferred from comments such as “*I’m concerned that I won’t do as well in this module as it’s similar to circuit theory and I’m expecting a hard paper.*”

Discounting the inferred responses, only 40% of students thought the module was as hard or harder.

Only 13% thought it was easier than the Part A module, and some 20% gave responses from which it was impossible to infer the relative level of difficulty such as “*OK*” or “*The module is as expected*”, or simply failing to provide a response at all. Two of the students answer that it is too soon to comment on how they are finding the module, a comment which reveals that for those students at least the level of difficulty is defined towards the end of the module, possibly even after results have been published.

### 7.5.5 Other interesting comments

Some students demonstrated evidence of reflection, and metacognition (the awareness of one's own learning) with one student responding that as a result of his experiences in the part A module he will “*definitely*” change the way he studies, by demonstrating “*more thinking, less learning*”. This is an almost textbook example of the metacognitive epiphany required to change from a dependent learner to an independent learner. This is however contradicted by other students suggesting that aspects of the course should be taught more in keeping with the styles employed by secondary level teachers – “*I think some of the maths might be better taught in a school maths type way with the teacher walking around and helping students do questions.*”

The students consistently reported positively about the lecturer (lecturer A) with comments such as “*He is a good lecturer*”, “*I enjoy his lectures and his oral explanations*” and “*Possibly one of the best lecturers on campus*”. When answering the question about whether or not different teaching styles would be more appropriate, students reply that the module and the teaching styles are a good match.

Past exam papers were reported as being difficult with some of the last topics studied in the module as it seemed to develop on past theory learnt and being able to ‘think’. You are taught to learn by rote from a young age, and the time this changed was in A-level physics, however, did not realise until coming to university that you cannot always just put numbers into an equation and get a result. ‘Thinking’ needs to be developed from A levels onwards at least, and lectures at university need to place an emphasis from the first year in all modules.

### 7.5.6 Summary of findings

The structured interviews show that students found the ELA001 module difficult, and the majority believe that most other students felt the same way as they did. A small minority reported the opposing viewpoint, and claimed to find the module easy. As this is a first year module, one explanation for this disparity is the differing levels of secondary education; a common problem within tertiary education which the first year of any undergraduate degree course is designed to address.

Some students expressed a preference for the assessment to be changed. The students who expressed a desire to see the assessment changed in some form were largely students who

found the module as a whole troublesome. Alternative assessments that were suggested by the students were to have the examination split into two, each part reflecting the content delivered by each of the two lecturers. The other preference expressed by students was to have the weighting of the examination reduced, making coursework assessment worth a greater percentage. The first of these preferences is indicative of the students' failure to combine the content in the module into a cohesive understanding, seeing the content delivered by the two lecturers as two independent units rather than two facets of a single unit.

The desire for more use of the interactive learning environment (LEARN), more tutorial and more revision lectures reported suggests that the students enrolled in the second year module have (or at least had) not made the transition between dependent and independent learner.

Students provided evidence of poor study techniques, by reporting last minute sessions to complete coursework and last minute revision for exams. The responses about "how you know" suggest that students have not acquired and do not appreciate the need to acquire higher level cognitive skills such as recombining elements to yield new knowledge at this stage in their development. Instead, according to Bloom's taxonomy, they have only acquired basic skills enabling the comprehension and application of knowledge.

## **7.6 Interview Study Conclusions**

Interviews provided evidence that students in the third year had begun to think reflectively about their work, and rather than viewing their course as a series of distinct and independent modules had begun to view it as a single cohesive whole relating together their current modules and those taught in previous years. Their view of modules is however clouded by expectations of difficulty, and it is possible that such expectations affect student attainment in a self-fulfilling prophecy. It is equally possible of course, that the expectations could have an opposite effect and motivate the students to put in extra effort turning it into a suicidal prophecy (one that causes a reaction to ensure the prophecy turns out false rather than ensure it comes true), however there is no empirical evidence to support this.

When questioned about the part B module the students overwhelmingly reported that it was difficult. The examination was reported to be exceptionally hard and not in keeping with what the students had prepared for. There are dual implications of these statements the first is that students have an expectation of what the examination will be like, to the extent that they

are effectively preparing for something entirely alien. The second implication is that students do not attempt to understand the material (if they understood the material fully the examination format would make little difference) and that there is a level of complacency generated within the student body. This is related to the demonstrable inability of students to answer questions of an unfamiliar format despite having sufficient knowledge and arguably expertise to do so, and could be as a result of exposure to a limited selection of “tutorial” questions of a very restricted format. This limited exposure makes comments about unexpected examinations all the more surprising.

The part B module had developed a reputation as being difficult, especially in terms of examination. Despite this many students admitted to poor study practices e.g. surface and strategic learning approaches. Reputations such as this propagate as students acquire attitudes about the difficulty from more senior students, and it can be argued that the more socially active students (and therefore the ones most likely to be approached for their impressions of the modules) are also the ones least likely to be the best performers as they simply do not devote as much time to their studies.

Revision techniques tend to focus essentially upon the development of algorithms and stratagems for the answering of questions that the student expects to be on the paper. This is based largely upon the prevalence of questions on previous examination papers, and the identification of trends as to their probability of recurrence. Given this, and the similarity of both the examination papers to others from previous years, and the individual questions to the tutorials, it is a surprise that higher marks are not recorded in the examination. It is also surprising that examinations are perceived to be in an unusual and unexpected format.

## **7.7 Semi-structured interviews – Limitations**

In the semi-structured interview study, the participants were self – selecting. This could have resulted in a sample of students that held particularly strong views about the module(s) in question. It was difficult to recruit students, in total only nine interviews were conducted. The study asked for students to discuss current learning strategies in the middle of the academic semester and it may have been the case that some students had high workloads which precluded them from volunteering for this study. However, the data gained was detailed and provided the basis for the structured interview study.

The findings from this study are based on self-report data obtained during retrospective interviews. It is therefore possible that information has been missed due to the limitations of memory recall.

The structured interviews provided far less rich data but the structured nature of the interview schedule meant that the responses from the students were focused and were suitable for a relational content analysis.

A consequence of the interview process is the active promotion of reflective thought in the learner, caused by asking the learner to think back to the way he has studied in the past and identify the troublesome areas in their knowledge. The effects of this enforced reflective activity are unknown, but given that reflective thinking is known to enhance understanding, it can be assumed to have a net positive effect.

## 8 Software

### 8.1 Introduction

This chapter describes the development and implementation of software and hardware to support the teaching on the machines and systems module. The software was developed as a teaching aid which displayed real-time data. In other words, the software permitted live demonstrations to entire classes on machine behaviour. Previous chapters have identified that electrical engineering students demonstrate a lack of understanding of key concepts in electrical machine theory. The studies presented have also identified that the roots of the misunderstanding lie in the second year module whereby students demonstrate strategic learning behaviour which results in poor understanding. Pedagogic literature shows that students have varied learning styles and in particular students reading engineering topics struggle with abstract concepts. By combining real-time data presentation, smaller class sizes, and greater depth of study it may be possible to address these misunderstandings in an active teaching environment. This would allow the student the opportunity to explore their misunderstandings and, through presentation of concrete evidence, correct them. Software was subsequently developed to facilitate the presentation of real-time data.

The software developed for this project was written using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench). This is proprietary to National Instruments and uses a graphical, general purpose programming language known as G. A brief overview of graphical programming language is provided below.

The software was designed as an interactive teaching aid, to be used by the lecturer throughout the course of instruction on the module Electrical Machines and Systems. Interactive teaching aids have been sought for many years [118], but have recently become more viable for applications requiring the capture and manipulation of large volumes of data. The software reported here utilises real-time data rather than simulated and allows a high level of adaptability by the lecturer.

It was designed to allow the student to observe experiments as they were demonstrated by the lecturer. This facilitated the opportunity for students to ask questions and obtain answers that codify their observations into a more complete cognitive structure. It is reminiscent of, but

developed separately from, the Microcomputer Based Laboratory (MBL) tools used during Interactive Lecture Demonstrations (ILD) [81] [119] [120].

## 8.2 Overview

LabVIEW programs are written in G and then compiled into machine code; much the same as a program would be constructed using one of the more familiar text based programming languages such as C. The key difference is that instead of commands such as the conditional statement IF, the loop statement WHILE, or even the mathematical expression  $I=J+K$ , these functions are represented and constructed using icons that are wired together by the software author to form a block diagram of the program. Any function (icon) is executed as soon as all input nodes have valid data, implying that parallel processing is not only possible, but actively exploited, where in a standard text based language execution is determined not by the availability of data, but by the order in which statements are written leading to sequential processing. Each programming unit in LabVIEW capable of executing in its own right is known as a VI (Virtual Instrument). When these VIs are nested, i.e. one is used as a subroutine in another, then the lower level subroutine VI is known as a subVI. The parallel processing inherent to LabVIEW applies equally to levels as it does to processes in the same level. That is to say that a subVI can be executed at the same time as processes in the calling VI.

Another key advantage of the LabVIEW platform is the ease of developing a graphical user interface (GUI). This is done automatically, as each VI consists of a “Front Panel” and a “Block Diagram”, and indeed it is through the front panels of the VIs that they can be connected in both hierarchical and linear manners. Variables and inputs are represented on the front panel as a variety of intuitive controls, such as buttons and switches (for Boolean variables) or dials and sliding controls (for numeric variables). Similarly, outputs are represented as indicators, either as graphical devices such as colour changing “LEDs” for Boolean outputs or gauges for numeric variables. Other output options are available for other data types, for example an output array can be displayed numerically as a series of cells in a traditional grid or by plotting one variable against another to show the same information graphically.



### 8.3 Development

LabVIEW was chosen because, as well as the benefits outlined above, the manufacturers of the data acquisition device, Data Translation, provide a package called the LV-Link. This is a collection of VIs that function as device controllers, allowing the developer of the software using those VIs to concentrate on the high level programming without being unduly concerned with the low level demands of the hardware. The LV-Link package also provides example VIs for things such as simple data acquisition and display, which can be used as both examples of use, and as foundation launching points from which custom code can be produced.

The software was developed over a period of time, with a number of variants tested. Many of these variants involve only small changes to certain parameters as sections were developed to a “completed” state independently. The development followed an iterative process, testing usability and functionality of the software itself. The software was designed to be used with very little time required on the part of the lecturer to make changes to the display, so that it could be used fluidly in teaching scenarios, but still be highly adaptable to address a wide range of potential student questions. One such example of this was the trigger function for the oscilloscope style waveform viewer visible on the meters page of the software, which was initially designed to be at a user definable level on a user definable channel, but after successive attempts failed to yield consistent results, this was changed to a rising edge zero crossing on a user defined channel.

### 8.4 General Operation

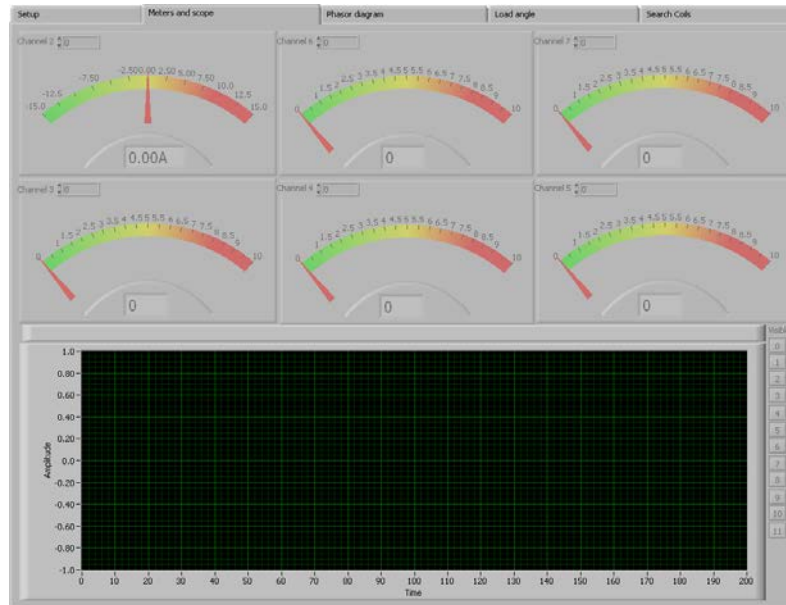
The software written consists of four VIs of varying complexity; *Main*, *Linespu*, *Processpowerpu*, and *deltathing*. The last three are subVIs, called from and returning to *Main*, and are each responsible for creating different aspects of the finished product. The end user (lecturer and student) see the GUI or front panel of *Main.vi*, which is divided into 5 panes; *Setup*, *Meters and scope*, *Phasor diagram*, *Load angle* and *Search Coils*. The subVI *processpowerpu* is responsible for all the calculations and data manipulation for the Meters and scope pane, the phasor diagram output is generated by the subVI *linespu*, and the load angle pane output comes from the *deltathing* subVI. The output for the search coils pane is generated by a collaboration of the *processpowerpu* and *linespu* subVIs and the calling VI.

Input to the subVIs for things such as channel selection which is used to determine which manipulation is required are generated by the calling VI and passed to the subVI.

The *Setup* page contains controls which are used to initialize the hardware and begin the data acquisition. Also included on this page are controls that define which channels must be sampled, and certain display options, namely which channel is to be used as the trigger for the oscilloscope operation and how many meters are required to for display.

By default the software is set to sample all 12 possible channels, trigger off channel 0 and enable no meters for display. As a consequence of the defaults the only controls the user need check and change for the meters and trigger channel, which enables and illuminates the required number of meters and their associated controls, and the channel that the trigger acts on for the second pane of the software.

The *Meters and scope* page shows the number of meters required by the user as illuminated and active, while the meters not required are “greyed out” and disabled (please see Figure 7.1). If the meter is enabled, the channel control in the top left of the meter is enabled, and this allows the user to select which channel is displayed on this meter. Selecting the channel will change the meter scale to mimic the meter on the laboratory machine set, and the software includes a digital display, complete with units, of the value under the needle. Underneath the meter display there is a waveform display which has 12 buttons down the right hand side. These buttons correspond to channels that can be displayed. If the user selects that channel be sampled, then the button is active and the waveform seen on that channel can be displayed. If the user has not selected the channel be sampled, the button is greyed out and the waveform cannot be displayed (because it does not exist).



**Figure 8.1 – Meters and scopes page**

The third page, the *Phasor diagram* page, is only really valid for a machine operating in synchronous conditions: Asynchronous machines have an induced field current which is difficult to measure. The machine state and three channel selection boxes need to be set for the field and armature phase currents and armature phase voltage, and from these values the phasors diagram is constructed in real-time. Changing the machine operating condition changes the position and relative size of the phasors, which are drawn using the voltage as reference with 230V being 1 per unit.

The load angle page shows a view of the power/load angle characteristic, and includes a cursor, with two indicators giving the value of  $\delta$  and P at that point.

The final page shows an exact reproduction of the phasor diagram previously described, but cuts off a portion of the lower half, so the current phasor for a synchronous motor cannot be seen in its entirety. In place of the bottom half of the phasor diagram is a waveform display set up to show the output from the search coils on a per unit scale.

## 8.5 Detailed Operation

### 8.5.1 Main VI

The *Main* VI does very little in terms of processing, it is instead responsible for handling the PC communication with the data acquisition hardware, collating inputs and passing them to the appropriate subVIs so that the analysis required is carried out, and finally, when they have executed, removing the returned data from arrays and clusters where necessary, and passing them to the output indicators.

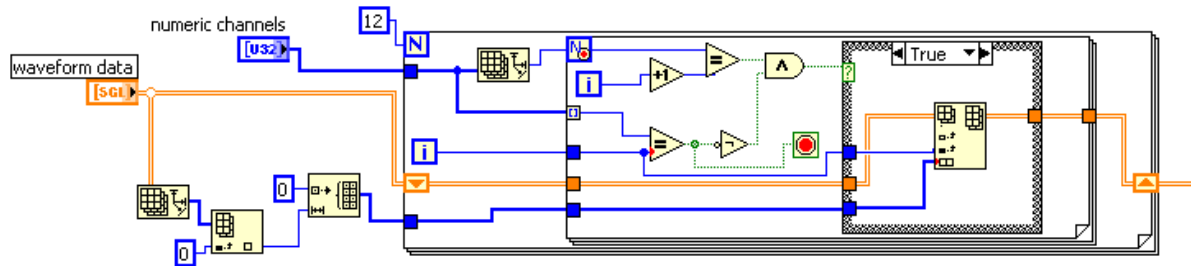
The entire VI is contained within a DO WHILE conditional structure to allow continuous operation. The conditional to which this is linked is controlled by a button on the first set up panel of the GUI, and allows the acquisition of data to be ceased without exiting the entire application. Within this is one large IF conditional which is executed only on the first iteration. It is responsible for transferring pertinent data to subVIs which control the hardware and initiate acquisition and for setting the enabled/disabled state of 12 buttons which control whether or not waveforms are displayed on the oscilloscope. These states are set based upon whether or not the channel appears in the channel list. On subsequent iterations this loop is skipped. Also within the main DO WHILE structure is all the controls that can be used while the software is in operation, along with all the indicators which the user will see. This results in what looks like quite a busy VI with many icons and connections, but is actually relatively simple.

### 8.5.2 Processpowerpu VI

The first subVI in the chain is *processpowerpu*. This has seven input nodes, and five output nodes, however one of those is left over as a legacy from a troubleshooting stage. The input nodes are: an array of raw data, samples per cycle, a bundle of seven numeric inputs, a cluster of 24 references, an array containing the channel list, a cluster of another 12 references and a bundle of two numeric controls. The output nodes are: a bundle of six numeric values, a padded array of raw data, a padded array of data which contains only an integer number of cycles, an array of data processed for display on the oscilloscope function, and a cluster of numeric values, and the previously mentioned legacy cluster of troubleshooting data.

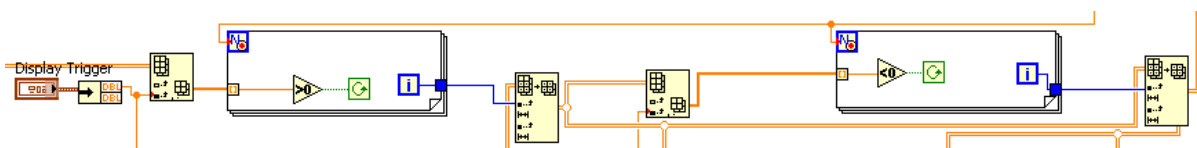
This VI takes the raw data input, labelled “waveform data”, which is an array of  $n$  by  $m$ , where  $n$  is the number of samples, and  $m$  is the number of channels, and passes it through a

nested structure of for loops to pad the array with columns of zeros and ensure it is an array of 12 (the maximum possible number of sampled channels) columns. This does not just add the required number of columns onto the back of the array, but instead inserts them into the array according to the channel list so that each channel is in the right place as if all 12 had been sampled. The output from this stage is an array of size  $n$  by 12. This stage is shown in close detail in Figure 7.2.



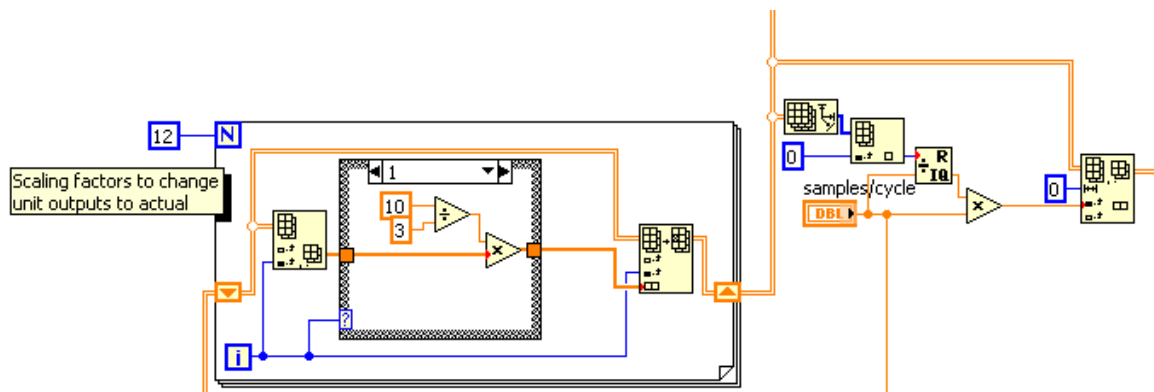
**Figure 8.2 – Code to pad array to 12 columns**

After this the padded array then passes to the trigger code, where the correct channel (column) is selected from the array as defined by the user on the set up page of the GUI, and passed through a conditional for loop. The condition for execution is if the sample value is greater than 0. When this condition fails to be true the loop stops executing, and the iteration number ( $i$ ) is passed out. This is then used to remove the rows for which the condition was true from the array, leaving an array of  $n-i$  rows and 12 columns. This array is passed into a second conditional for loop, to do the same again except this time with the condition of execution that the sample be less than 0. Again, when this loop ceases to execute, the iteration number of this loop ( $i_2$ ) is used to remove the samples for which the condition is true, leaving an array of  $n-i-i_2$  rows by 12 columns. The effect of these two loops is to discard all samples prior to the first rising edge zero crossing. This section is shown in close detail in Figure 7.3.



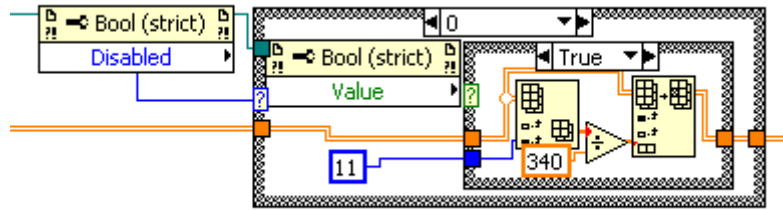
**Figure 8.3 – Code to find first rising zero crossing**

Data is then passed to a FOR structure that multiplies every value in each column by one of two predetermined values to compensate for the voltage and current transducers. This does not change the size of the array, but simply modifies the values so that they are now the actual values on the channels sampled. At this point the array is split, with one copy being used for providing data to the oscilloscope display, and the other copy having the tail removed to ensure that the array from that point forward only contains an integer number of cycles. This is used to provide data for the meters and is also one of the outputs from the subVI labelled “int cycles”.



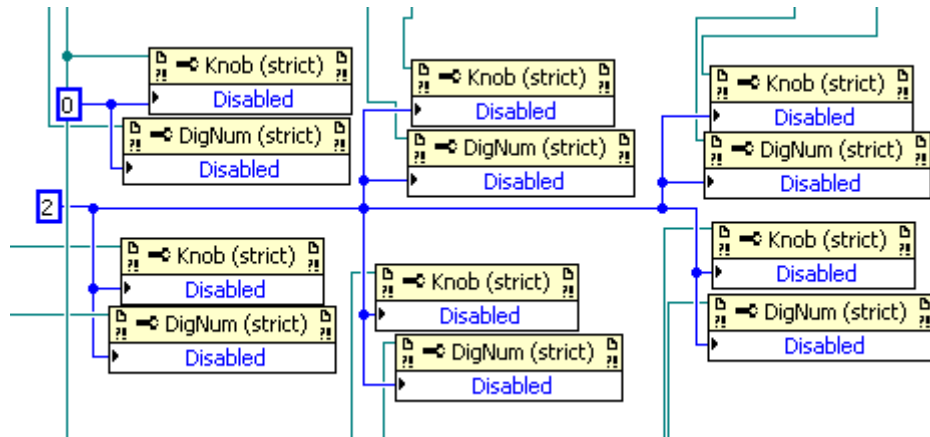
**Figure 8.4 – Code to convert sampled values to real, and to produce “int cycles”**

The oscilloscope display data is generated by taking the padded array and passing it through a series of IF structures. These IF structures go through the channels in reverse order, i.e. 11 to 0, to assess whether or not the channel has been sampled and, assuming it has, whether the user has selected to view that channel on the oscilloscope (Figure 7.5). If both are true the real values are converted to per unit, however if either of these conditions is false, the column is removed from the array. The result of these operations is that the output “*Display data*” returned to the calling VI is an array of size  $n-i-i2$  rows by  $b$  columns, where  $b$  is the number of channels selected for display.

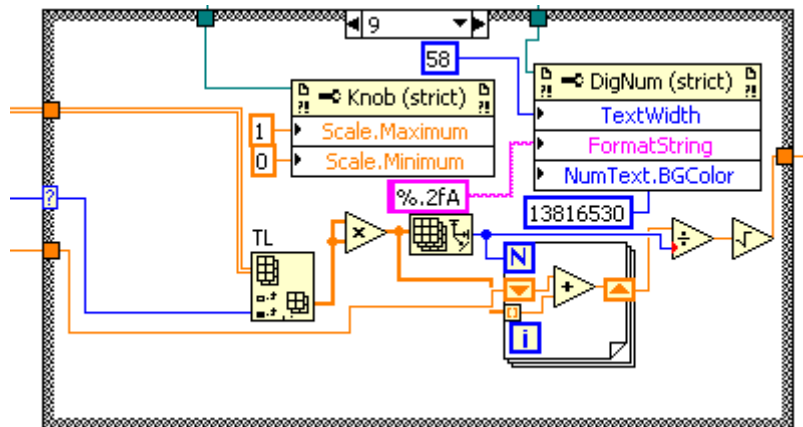


**Figure 8.5 – Example code to create per unit oscilloscope display**

The *int cycles* array is processed to provide output for the meters on the front panel which is done with a nested CASE structure. At the outside level this enables the requisite number of meters and associated controls and disables the remainder (Figure 7.6). Inside this structure there are up to 6 more, depending upon how many meters were enabled. These second level structures are controlled by the channel selected for display on each meter. Setting the control generates multiple changes for the display, not just changing which channel the value is presented for, but also the scale shown and the unit appended to the digital readout. All of the second level structures contain maths to calculate RMS values from the array, and therefore the output is a single value rather than an array (Figure 7.7). For channels 4-7, the mathematics is slightly more complicated, as these channels correspond to the two wattmeters of the machine set. In these cases the software selects the partner channel and performs instantaneous multiplication to determine power. The unit is appended to the digital display as usual, but the background colour of that display is changed to indicate direction, where on the machine set there is a reversing switch on the meter itself. If the meters are not enabled then 0 is passed out of the structure and returned to the calling VI.



**Figure 8.6 – Code to enable or disable meters. In this case only one meter is to be enabled.**



**Figure 8.7 – Example code to display channel 9 on a meter**

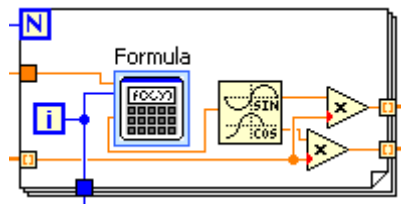
### 8.5.3 Linespu VI

This VI, responsible for the construction of the phasor diagram, has seven input and six output nodes. The inputs are: voltage, field and armature current variables, int cycles, a cluster of six boolean switch states, sample period and speed. The output nodes are: a bundle of seven numeric values, the phasor diagram picture, and four separate numeric values:  $V$ ,  $E_f$ ,  $\delta$  and  $X_s$ .

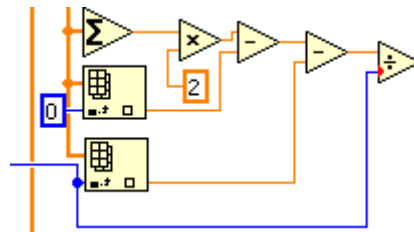
The construction of the phasor diagram requires knowledge of which of the sampled channels correspond to the armature phase voltage and currents, and the field winding current. The field current is nominally DC, so the samples are simply summed and divided by the number of samples to provide a DC average. This is then used with a lookup table to



determine the value of  $E_f$  which is interpolated from a table of experimental data. The armature phase voltage and currents are assumed sinusoidal and often out of phase, and must be resolved into their relative RMS magnitudes and the phase relationship determined prior to the construction of the diagram. The process is the same for both voltage and current waveforms, and this is: resolving the waveforms into orthogonal components (Figure 7.8), then performing a numerical integration of these orthogonal components (Figure 7.9). Pythagoras' theorem is then used to calculate magnitude, and the RMS value of the waveform is found by dividing that magnitude by  $\sqrt{2}$  as the waveform is sinusoidal. The arctangent of the two components is also calculated to determine the argument of the phasor.



**Figure 8.8 – Code to resolve orthogonal components**



**Figure 8.9 – Numerical integration code**

From the argument and the magnitude of the voltage and current phasors, the power factor can be calculated as the cosine of the difference of the two arguments (to take into account irregularities in the trigger). The magnitude of the  $IR$  phasor is calculated with a simple scalar multiplication using tested values for resistance of the windings, in both conventional and inverted arrangements, and the magnitude of the  $IX_s$  phasor is calculated as

$$|IX_s| = \sqrt{E_f^2 - (Vx + IR)^2 - Vy}$$

where  $V_x$  and  $V_y$  are the components of RMS voltage resolved to be in phase, and in phase quadrature with the current phasor (that is  $V_x = V \cos \varphi$  and  $V_y = \sqrt{V_{RMS}^2 - V_x^2}$  respectively). The magnitude of  $I X_s$  is then multiplied by the power factor to get the horizontal component  $I X_{sx}$  (phase quadrature with voltage), and the vertical component is calculated from  $I X_{sy} = E_f \cos(\delta) - V - I R_y$ , where  $I R_y$  is the vertical component (in phase with  $V$ ) of the  $I R$  drop and  $\delta$  is given by  $\delta = \sin^{-1} \left( \frac{I R + I X_s}{E_f} \right)$ .

Any of the phasors can be hidden at any time using the buttons to the right of the display without affecting the drawing of the diagram, with the exception of the  $I R$  phasor, which shifts the position of the root of the  $I X_s$  phasor. Each phasor button has a pair of associated indicators, one showing the magnitude of the phasor in real units, and the other showing the colour of that phasor on the diagram. The load angle and power factor indicators are constantly visible, and update in real-time. The machine state button changes both the resistance value of the field windings and the open circuit characteristics of the machine, so the machine can be run as either a conventional stator fed machine or an inverted rotor fed machine and the software will still display the correct phasor diagram. In addition to the phasor diagram, the locus of the  $E_f$  phasor is displayed. This is a useful addition as it shows very clearly the value of  $E_f$  doesn't change (assuming field current is constant) when the machine is operating under various loads, despite the load angle and  $I X_s$  phasor changing.

With all the necessary values computed, the phasors can be drawn according to which of them the user has selected to be visible. They are produced by drawing from the centre of the picture area out for the current phasor, then again from the centre drawing vertically for the voltage phasor. The  $I R$  phasor is then drawn if required, followed by the  $I X_s$  phasor. From the end of the  $I X_s$  phasor the  $E_f$  phasor is drawn back to the centre of the picture. All of the magnitudes, and other values of interest are passed out to be displayed alongside the buttons controlling the display. If any phasors are omitted from the diagram then the colour indicator is also removed from the display.

#### 8.5.4 Deltathing VI

This VI has four input nodes:  $V$ ,  $E_f$ ,  $\delta$  and  $X_s$ , all calculated from the previous VI, and a single output node: *waveform data*. The VI generates a sine wave of  $P$  against  $\delta$ , using the equation  $P = \frac{3VE_f}{X_s} \sin \delta$ . A cursor is included tracking along the curve with a digital readout of  $\delta$  and  $P$ , allowing the user to see clearly the link between load angle and power, specifically how the load angle is different for the same power for a machine operating with a leading power factor compared to a machine operating with a lagging power factor.

### 8.6 Software Implementation

Once the software had been developed it was implemented in two revision lectures on the module Electrical Machines and Systems. The revision lectures were given at the end of academic year in 2010 and again in 2011. The software was used by the lecturer in a presentation on electrical machines. At the end of each lecture an evaluation was undertaken with each group of students. This evaluation consisted of obtaining feedback from the students by way of questionnaire.

### 8.7 Software Evaluation

#### 8.7.1 Introduction

The software was designed as an interactive teaching aid, to be used by the lecturer throughout the course of instruction on the module Electrical Machines and Systems. Interactive teaching aids have been sought for many years [118], but have recently become more viable for applications requiring the capture and manipulation of large volumes of data. The software reported here utilises real-time data rather than simulated and allows a high level of adaptability by the lecturer.

Previous chapters have detailed studies which indicate that understanding of electrical machine theory is difficult to develop, and provided evidence of dropping attainment in electrical power resulting in a lower level of understanding at entry to the part C module. Students from the part C module, when interviewed, expressed favourable opinions of demonstrations to link abstract information to concrete example *“he could show you it happens? I suppose that would be quite a good idea being able to actually see it”*.

It was designed to allow the student to observe experiments as they were demonstrated by the lecturer. This facilitated the opportunity for students to ask questions and obtain answers that codify their observations into a more complete cognitive structure. It is reminiscent of, but developed separately from, the Microcomputer Based Laboratory (MBL) tools used during Interactive Lecture Demonstrations (ILD) [81] [119] [120].

MBL and ILD instruction has been shown to be more effective in aiding the learning of force and motion concepts in physics than traditional lecture based instruction [120] [79] [80]. Newtonian motion is a frequently cited example of conceptually difficult knowledge, and such an approach can be used to create an inherently active environment [81], and it is expected that similar benefits will be seen from the real-time teaching aid in electrical machine theory.

### **8.7.2 Procedure**

In order to explore the experiences of students and help determine the efficacy of the software a questionnaire was developed which consisted of 3 questions to which closed (Yes/No) responses were anticipated, and 2 questions to which open responses were anticipated. This questionnaire is shown in Table 7.1

The presentation (as a whole)	<ul style="list-style-type: none"> <li>• Reinforced my understanding</li> <li>• Changed my understanding</li> <li>• Clarified my understanding</li> <li>• Confused my understanding</li> <li>• Other</li> </ul>
The use of real machines (as opposed to simulations)	<ul style="list-style-type: none"> <li>• Made the presentation more interesting/meaningful</li> <li>• Confused me because of the unstable and distorted waveforms</li> <li>• Made me realise theory is idealised</li> <li>• Made me realise that electrical machine behaviour is complex</li> <li>• Other</li> </ul>
The real-time presentation (i.e. the software)	<ul style="list-style-type: none"> <li>• Is a useful teaching aid</li> <li>• Worth further development</li> <li>• Other</li> </ul>
Which other modules would benefit from this approach?	Open question
What aesthetic changes should be made (to the software)	Open question

**Table 7.1 – Interview schedule for software efficacy**

### **8.7.3 Study sampling**

Students enrolled on the ELC040 module in two year groups (2009/10 and 2010/11) were invited to evaluate the software at the end of their module revision lectures. This was an optional session which was in addition to taught material. The students, upon arriving at the lecture were told the aims of the lecture (namely to use and provide feedback on the experimental software) and a further opportunity to decline to provide feedback. In total 33 students participated, 8 from the first year group (2010) and 25 from the second (2011).

### **8.7.4 Study analysis**

The data from the completed and returned questionnaires was combined and coded by the researcher. Frequencies were calculated for the closed questions and a thematic analysis conducted on any open responses obtained.

### 8.7.5 Study results

The first closed question concerns the development in student's understanding as a result of the presentation using the software. The response options cover a range of potential changes in understanding. The Response were grouped into four categories: reinforcing, changing, clarifying and confusing. These categories are defined by both the initial conditions of the student, and the changes experienced, as illustrated in the Table 7.2, and the differences were explained to the students prior to completion of the questionnaire.

Category	Initial understanding	Change in understanding
Reinforcing	Good understanding, with very little confusion	Small changes, confirming ideas and theories already held
Changing	The student understands his concepts well, and can form reasoned arguments in support of his understanding.	The student switches his concepts for different concepts, with similar levels of conviction and ability to reason in support.
Clarifying	Poor understanding of concepts. The student knows the salient points, but has no cohesive mental structure relating them.	The student's understanding is not contradicted by the presentation, allowing him to form greater understanding.
Confusing	Any level of understanding, but most likely poor.	The student's understanding is contradicted by the presentation, but not to an extent allowing them to form any kind of clear understanding.

**Table 7.2 – Categories of change**

Response	Yes	No	No answer
Reinforcing	5	1	2
Changing	1	4	3
Clarifying	4	1	3
Confusing	0	4	4

**Table 7.3 – Results for question about changing understanding, group 1**

Response	Yes	No	No answer
Reinforcing	23	2	0
Changing	9	14	2
Clarifying	22	1	2
Confusing	2	21	2

**Table 7.4 – Results for question about changing understanding, group 2**

Response	Yes	No	No answer
More interesting/meaningful	5	1	2
Confusing	0	4	4
Idealised theory	7	0	1
Complex behaviour	5	1	2

**Table 7.5 – Results for question about use of real machines, group 1**

Response	Yes	No	No answer
More interesting/meaningful	25	0	0
Confusing	0	23	2
Idealised theory	21	2	2
Complex behaviour	20	3	2

**Table 7.6 – Results for question about use of real machines, group 2**

## 8.8 Study discussion

Of the 8 students in the first group, five respondents claimed that the presentation had reinforced their understanding, several of those also saying that their understanding had been also been clarified by the presentation. This indicates that the student takes the information presented and incorporates it into his/her mental structures to create a more detailed mental model, which is enhanced to varying degrees in different conceptual areas. The very low frequencies of “changed” or a “confused” understanding is indicative of the presentation being a positive experience for the students. The frequency count of “changed” understandings is indicative that the concepts the student develops during the course of instruction are either correct, or the presentation is insufficient to change them. The low

frequency of students confused by the presentation is encouraging and suggests the huge potential of the software in having few or no negative effects.

Some students used the space provided to leave feedback on the changes the presentation had caused in their understanding. The feedback given is all positive, but also revealing, with comments such as *“This presentation actually proved the behaviour of synchronous machines”* tallying closely with *“This session has gone a long way in enabling me to understand the mechanics of synchronous machines. It helped me much better than the class notes, because I was able to see and identify how the machine works unlike the class notes which is quite a lot of theory and can be overwhelming. The lab summarised the notes perfectly well”*. Two comments were sufficient to cause some concern. These comments were *“It was more interesting than the lecture and it has given me ideas on the way in which a synchronous machine behaves. I had no previous understanding”*. Whilst highly supportive of the software, the qualifier at the end is alarming as the evaluation was delivered at the end of the academic year, shortly before the assessment period. The second statement to cause concern was *“It expanded my understanding of a synchronous machine with regards to slotting and the fact that if you reduce or increase the load too much, it could become an induction machine”*. Again, it is encouraging in the first instance, but the final part of the statement is worrying, equating a synchronous machine undergoing pole slip to an induction machine. This belief may be rooted in the way the synchronous machine was started in this instance; rather than using a separate machine as a pony motor to bring the machine up to speed, it was started as an induction motor with the field winding short circuited before being brought into synchronisation by the application of a field current.

During the evaluation at the end of 2011, 25 of 26 registered students completed the questionnaire; however, the interaction of the second group was noticeably lower than in the previous year. Some students failed to provide an answer for the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> statements of this questionnaire and also failed to provide complete answers to the other two closed questions, and two more students gave an affirmative response to all four statements despite the 4<sup>th</sup> clearly being contradictory to the previous three. The data from the second year's evaluation supports the conclusions drawn from the first years data but the only feedback applicable to this first set of questions is *“Overall this lecture was very informative and useful”*.



The question about how useful the use of real machine data is, as opposed to simulated and simplified data again received positive feedback. The 0 count for causing confusion is obviously the desired response. Just over a half of the students suggest that the presentation was more interesting and meaningful as a result of the real-time data, however there is no way to determine whether or not the students would make a similar statement about the use of idealised data. The statement in the group that the use of this data made the students realise that the theory presented is often idealised allies closely with the statement about realising that electrical machine behaviour is complex, and is an important point for future development of the students. It might be that students were aware of the idealised nature of the theory presented in the course of instruction, and that the behaviour of machines is more complex than they are exposed to in the course of lectures. However, the responses given by the students show that this presentation contrasts with the theory presented in the notes and lectures, draws attention to the differences (and the differences were also explicitly picked out and explained by the lecturer). It also gives the students an appreciation of where approximations and idealisations are made, why, and most importantly what impact they have.

Students who added comments to the open questions were positive about the use of real machine data saying things like *“It helped me better visualise/realise pole slipping and how slot gaps affect waveforms”* and *“already understood that real machines were not ideal, but interesting to see it on graphs”*. The most encouraging comment was *“I personally found the theory of synchronous machines too overwhelming and complex, but this lab has simplified the theory for me. I feel more confident in this subject area”*

At the end of 2011, the group provided even stronger evidence in support of the use of real machine data as a way of making the presentation more meaningful and interesting. Open ended feedback from the second cohort was again limited, but echoed the statements from the first group, *“Realising sine waves are not smooth due to the stator slots is useful”* and *“The use of real machines showed that the theory is an approximation but does not vary much from what actually happens”*.

The students overwhelmingly felt the real-time presentation was a useful teaching aid. Only two of the first group failed to respond to that statement, while the rest of the group agreed. Seven of the group agreed that it was worth further development, which presumably means

that one of the group thought it was not a useful teaching aid in its current state but could be with more development. Written feedback was also overwhelmingly positive, with students feeling it is “*an essential way of demonstrating and should be used as much as possible*” and that it “*always helps understanding to see how taught theory applies in practice in the lab on real machines*”. Two students praised the session as “*very interactive*” which is a very favourable approach to teaching and learning much encouraged in literature. One of those two students further expands his point saying “*it would be awesome if the theory and the practical sessions like today could go [sic] both be used in teaching as it ensures an alternative form of teaching i.e. If you don’t like or understand the theory, then maybe the practical session could help you understand it better which it did for me.*” An interesting thing to note from this comment is the apparent distinction between practical and theoretical sessions, made as if the two were incongruous rather than two sides of the same coin, and this view is repeated by a second student who declared the software “*a useful teaching aid but, the theory must be discussed first in the lecture in order to avoid confusion*”. Resolving this apparent disparity was one of the driving motivational factors for the design of the software, and it is hoped that in future the software can be used to bring the practical and theory sessions together into a single cohesive session.

The second administering of the evaluation questionnaire confirmed these conclusions with 23 students declaring the software a worthwhile teaching aid (the remaining 2 failed to provide any response to the statement). Two students were at odds with the others, both from the same cohort and the first, declaring the software unworthy of further development. The limited feedback provided again echoed the earlier group with “*would be beneficial if immediately after learning the theory, the demonstration is shown*” [emphasis by underlining original] and “*it would be great if these presentations were shown after each lab as a means for further understanding*”. The best piece of feedback says “*the theory can be quite dull and daunting. Practical demonstrations certainly aid the theory and make it more interesting and understandable*”.

Unique to the second cohort were comments suggesting that the content of the presentation should be made available beforehand, and that possibly a hand out containing things such as the circuit diagram might be useful.

The first of the open questions asked the students to suggest which areas of the machines curriculum would benefit from the same approach. Some students provided specific examples of the areas that would benefit “*induction motors and 3 phase transformers*”, while others were far more general “*This type of approach would be beneficial in all modules which deal with this type of machinery*” and “*The entire electrical machines topics [sic] should adopt this method*”. One student stated that “*it would be more useful for all the machines labs as often when completing labs by ourselves we do not follow what is actually happening*”, implying that he felt this session was intended as a replacement for the hands on laboratory time the students are exposed to during their studies. It should be made clear at this juncture that this was never an intention of the software, indeed the hands on lab time to which the students are exposed is a part of the assessment and an important component to the course. The same student goes on to say that it “*makes lectures more interesting as we can see what is happening in the real world*” which is a positive thing in that it counters the feedback received during the interview study about the theory being too abstract and difficult to relate to the real world. This enhanced interaction leads to greater understanding, and this is recognised by other students “*It’s faster as I can see what happens and it improves my understanding*” and “*this software is brilliant. After every Keith’s lecture he should demonstrate it, to the class so that they can get a deep understand [sic] to this module*”

The second cohort offered a similar spread of comments about which other modules to apply the software to, with general comments along the lines of “*most bits that it can be done with*”, “*any that can be demonstrated*” and “*apply the same demonstration with the other sections of the curriculum*”. Three specific comments were left, one for the part A Circuits module, and two for induction motors. However, one of these claims it would have been helpful “*to visualise how the squirrel cage works*” however it is hugely impractical to measure squirrel cage currents (the only possible way would involve embedded current transducers and some way of getting the signal out of the machine) so real-time data display is not a viable option for this: It is proposed that some form of animation would prove more useful here.

The second open question simply asked the students for feedback on the aesthetics of the projection, and suggestions for improvements. There were two areas highlighted by the students, the first being the phasor diagrams which one student wanted labelling more clearly as he didn’t remember what one of the phasors represented. This is a problem that is already addressed in the software: Next to the phasor diagram there is a colour coded legend

showing which phasors are represented, their colours and their numeric values. Maybe the way to solve this perceived problem is to highlight it to the students, so that if it should slip their mind what the phasors represent they can easily remind themselves. A student from the second cohort suggests that the legend is hard to decipher, however, without other comments to the same effect there's little evidence to suggest the display is deficient in that manner.

The second aesthetic problem raised by students, and the associated solution proposed was for the meters. Students found the labelling abstract, and struggled to associate the label "channel 0" with "phase voltage". They suggested that labelling the meters directly with the text description of the measured parameter would be a dramatic improvement; however doing so with fixed labels would hugely limit the adaptability of the software. It may be possible, in future revisions, to add a text box into which the lecturer could type a label for the meter, but this may lead to a cluttered appearance, and it is unclear whether this solution is viable in terms of preparation time. It may also lead to confusion if the lecturer were to change the meter to measure a different quantity but forget to change the label. The second cohort echo concerns about the meter labelling, and it occurs that if labels were to be introduced to the meters it may be possible to update them and incorporate doing so into the presentation by saying for example "This meter is a copy of the ammeter on the machine set here which is connected to show the armature current of the machine, so we can label it  $I_a$ ". This approach would not impact on the preparation time and may make things even better for the student observers.

## **8.9 Conclusions**

An interactive electronic teaching aid was designed and developed to support the instruction of Part B students on the module 'ELC040', Electrical Machines and Systems. The teaching aid aimed to enhance student learning by utilising real time data to provide concrete illustrations to support abstract theory. Student evaluation of this teaching aid was positive, with the majority of students reporting a desire for widespread implantation.

## **9 Discussion, Implications and Recommendations**

### **9.1 Introduction**

This thesis is concerned with student understanding of key concepts within electrical engineering, in particular the theory of electrical power and electrical machine theory. Through a programme of research which utilised mixed methods studies this research aimed to establish the primary factors influencing student cognition

Chapters 4, 5, 6 and 7 report studies which aimed to establish the root causes of student misunderstanding in the field of electrical machine theory. This theory is a specialised branch of electrical power theory, and it is this field in which the misunderstandings are rooted.

Chapter 2 explores the literature which underpins the development of student understanding, covering models and approaches to memory, and cognitive development theories, the combination of which result in the individual learners. Chapter 3 explores the teaching and learning literature, which is concerned with the development of a learner (in this case a freshman undergraduate) into a highly educated individual (a new graduate).

Higher education is currently facing huge changes: the introduction of higher fees may be seen as creating the ‘student as consumer’. As such, it is of utmost importance that institutions meet student needs in relation to teaching and learning. This work has highlighted the importance of addressing a range of implicit factors which underpin student understanding.

### **9.2 Overview of Literature**

Pedagogical literature has suggested that the traditional teaching paradigm involving students in passive lecture scenarios is inferior to more contemporary approaches involving learners in an active manner. The traditional approaches effectively reduce the learner to a passive recipient of knowledge, and given this, it is hardly surprising that levels of understanding have been found to be low. The student tends towards study practices which emphasise the reproduction of knowledge rather than the application of it or the development of understanding. This results in difficulty understanding and applying abstract concepts and is especially acute among learners of STEM subjects where module content is comparatively high.

It is widely accepted that students have a spectrum of learning styles; an approach ideal for one will not be ideal for all. Active teaching approaches are inherently equipped to deal with these differences and can support the embedding of new concepts into existing mental structures. However, the very fact that they require activity on the behalf of the learner can make the learner resistant to engage with them as they lack confidence, are resistant to change, and have failed to make the transition between dependent and independent learner.

### **9.3 Overview of Research Findings**

Research in this thesis is aimed essentially at understanding why students fail to develop a high level of understanding in a particular module, where the roots of any misunderstandings lay and what the study habits of the students were. A summary of the research findings from each of the studies undertaken is described below.

#### **9.3.1 Identifying Student Understanding**

A questionnaire study was undertaken with third year engineering students enrolled on the Electrical Machines and Systems module at Loughborough University, UK. The study aimed to identify the understanding exhibited by students in relation to three core theoretical concepts, namely

1. Magneto-Motive Force
2. Inductive Reactance, and
3. Phasors

This study showed that participants demonstrated a low level of understanding in relation to the key concepts required to fully comprehend Electrical Machine Theory. In addition students demonstrated consensus as to how mmf should be defined but this consensus was inherently incorrect. Participants also demonstrated consensus in how phasors were defined but again this was incorrect. As a result of these findings it was apparent that the course of instruction appeared to be ineffective in addressing this low level of understanding.

Overall the findings of this study suggest that the origins of student misunderstanding lie elsewhere, and are already established by the time they read for this module.

### **9.3.2 Desk Data to Explore the Sources of Student Misunderstanding**

Having identified that the source of student misunderstanding in Electrical Machine and Systems lay elsewhere than in that module, desk research was undertaken to analyse secondary data on student performance in the pre-requisite Part B module in order to identify where the roots of student misunderstanding lay.

The results of this study highlighted that coursework marks were comparable across the four years of the investigation, and were routinely higher on the ELB046 module than the students' average coursework mark. Examination performance shows a declining trend across the same period, and this results in a declining trend on the module overall. This is a key finding and the implications of this are discussed in more depth below.

### **9.3.3 Interview Studies**

Building on the findings of the previous chapters the aim of this study was to collect information on the study practices of Part B and Part C students to identify the cause of the decline in performance on the Part B module. A qualitative approach was used to explore the study practices as described by students.

The study showed that a majority of Part B students found Electrical Power theory a difficult field of study. Some students had failed to make the transition from dependent to independent learner and reported poor study techniques leading to a low level of understanding (but sufficient knowledge is acquired to pass assessment).

Part C students showed more evidence of metacognitive thinking, reflective behaviour and cohesive study. The study practices reported however were still poor and provide concrete evidence of strategic study behaviours, including forfeiting one module which is perceived as difficult and using other “easier” modules to improve the average mark for the year.

### **9.3.4 Software**

Having identified the roots of student misunderstanding as lying in the second year of undergraduate study, an interactive electronic teaching aid was developed to support the teaching and learning on the Electrical Machines and Systems module. This was designed to allow the students to observe demonstrations using real-time data. This has advantages over other interactive display methods, whereby there is scope for the students to ask probing

questions and for the demonstrations to be adapted to provide answers to those questions. Furthermore, the use of real-time data emphasises the idealised nature of theory as it is taught, and provides the learners with concrete evidence to back up the abstract theories.

Evaluation identified that students reported favourably about the software, and were keen to see it implemented on a wider scale. It was viewed as a helpful addition to the course.

#### **9.4 Strategic learning**

Roots of student misunderstanding in Electrical Machines and Systems were identified as lying in the Part B module, and investigating the performance records of four year groups in that Part B module made it apparent that there is a downward trend in student achievement. This trend is caused by declining examination performance and it is a matter for discussion as to why this trend is evident. Desk research identified a declining trend in examination performance on the part B module which led to a declining trend in the overall performance, however, this trend showed evidence of coming to a plateau, whereby a large proportion of students were getting a mark in the 30%-40% region. The interview based research has identified a number of behavioural responses on behalf of students in relation to the Part B module, for example, students report adopting strategic study practices whereby the approach to each module on the student's curriculum is not equal.

In this case the approach to the module of interest (ELB046) was essentially to gain enough marks to avoid reassessment. Achieving module credit (defined as a mark in excess of 40%) is viewed by some students as a bonus, while the approach of doing as well as possible is limited (and indicated by the students scoring well on the exam). This approach is enabled by the university policy with regards to modules taught in both semesters, which dictates that a minimum level of assessment must be carried out in the first semester and feedback given. This allows the student to (in this case) work out how many marks are required in the examination to achieve the desired mark (30% - 40%), and neglect studying for understanding or to gain the highest mark possible. Taking this approach reduces the amount of time required for this notoriously "hard" module and allows the student to focus his attention on other modules to ensure he gains credit in them, and has a sufficiently high average to acquire a good degree classification at his graduation.

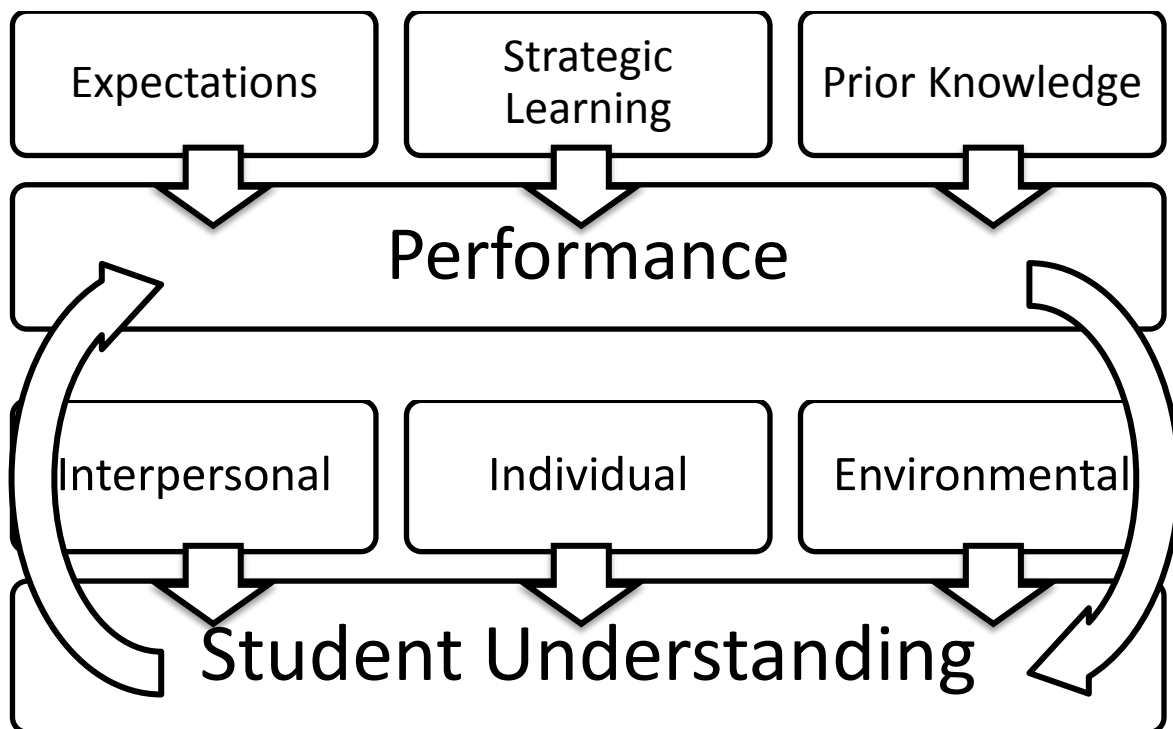


An extreme example of this strategic study practice for which up until now, there is only anecdotal evidence, is strategic failure, where the student will gain a high mark in the coursework component of the assessment, but deliberately fail the examination in a manner that forces them to sit it again. This effectively reduces the student examination load by one, and drastically increases the amount of time available to him to study for his other examinations (as a harder module is generally allocated more study time than an easier one). The deliberately failed examination is then retaken by the student in the Special Assessment Period at the end of the summer break, which provides the student with ample study time for the module. The drawback to this approach is that second attempt examination marks are capped at 40%. However, if the amount of work required to achieve 40%, or even a passing grade (30%) at the first attempt would lead to either a real or perceived decrease in performance on other modules then it may be deemed a justifiable approach.

It is evident from the interview responses that the examination changes the focus of any studying practices employed, from attempting to generate understanding to generating temporary long term knowledge, whereby the student merely attempts to remember techniques and formulae until the examination is over. Once the examination is over, these techniques and formulae are discarded.

## **9.5 The new model**

This research has identified a number of interactions that arise as a result of the teaching of critical concepts. The model shows the influences that affect student engagement with the material delivered and ultimately lead to performance as quantified by assessment within the University. Furthermore separate factors which have an impact upon the development of understanding are illustrated, and the reciprocal nature of the interaction between performance and understanding highlighted. The model is displayed below as Figure 8.1.



**Figure 9.1 – Model of influences on student performance and understanding**

## **9.6 Contribution to knowledge**

As evident in this thesis student understanding of key concepts within electrical engineering is challenging to achieve. This research has identified a number of potential influences which if addressed appropriately can facilitate understanding. These are shown in Figure 8.1. The major contribution to knowledge offered by this thesis is the understanding of these influences and how they impact upon student learning. This model, although developed at a single institution, has profound power and is widely adaptable, both to other institutions offering similar courses and to other fields of study. It is essential that institutions recognise these influences and how they affect students and design their teaching and learning to account for and exploit these influences so that students have the opportunity to fulfil their potential.

A further innovative contribution to knowledge is the generic module method of comparison. This creates a hypothetical average module based upon the average mark distributions of all other modules undertaken in that academic year. It allows the direct comparison of modules even when cohort sizes are different.

## 9.7 Final Conclusions

This research set out to achieve four distinct objectives, and utilised a number methods in order to achieve them:

1. *Establish common factors underpinning students' inability to grasp the concepts of Electrical Machine Theory*
2. *Identify students' learning strategies whilst undertaking the Machines and Systems module and how these learning strategies have developed over time*
3. *Establish temporal trends in attainment levels of students undertaking the assessment components of a pre-requisite module "Electrical Power B"*
4. *Develop a teaching and learning tool to support students' understanding of Electrical Machine Theory specifically related to synchronous machines*

Objective 1 was achieved using a combination of interview and questionnaire data. Analysis of the questionnaires highlighted that the preconceptions carried into the third year module were persistent and difficult to change by instruction alone. This finding is backed up by interview data where respondents confirmed that understanding in previous years influenced the understanding they were able to generate in later years with statements such as *"it's just an advancement of last year"*.

Objective 2 was achieved with a combination of secondary analysis of performance data which identified a decreasing trend in overall performance which stabilised at the pass level. The individual components however showed different trends, with coursework remaining very highly graded throughout and examination performance showing a marked drop. It was possible that this might be the result of specific strategies (strategically learning just enough to gain passing marks while concentrating time and effort on 'easier' modules) The presence of these strategies were confirmed in interviews by responses that there were *"other, more important things...timeline wise"* and *"It's not worth putting yourself through the pressure and scrambling your brain trying to work it out"*.

Objective 3 was achieved through secondary analysis of performance data over several years which showed that in the module of interest coursework attainment was high, and exam performance had a decreasing trend. This is in contrast to student average marks, indicating the trend was isolated to the module of interest, and not symptomatic of a general trend

towards decreasing attainment. This work included the development of a novel comparison technique, designed to compare modules rather than student cohorts.

Real time data acquisition hardware was installed in a machine set and software written in LabVIEW for real time data processing which was linked to a data projector to display information to students in a laboratory environment. This addressed objective 4, and facilitates an active learning environment and the generation of concrete examples to counter misunderstandings and improve the acquisition of abstract concepts. In addition, the flexibility to demonstrate phenomena in a variety of ways and categorically answer a students' "what if?" question promotes engagement with the curriculum

## **9.8 Proposed further work**

It is suggested that the software constructed in this thesis is implemented in the manner it was designed for; a teaching aid for use throughout the year, not just a one-off session. Students enrolled on the course should be invited to participate in a longitudinal study to monitor the development of understanding. Furthermore, the identification of the strategic study practices (sacrificing one module of study for the advancement of others) is worthy of further and more detailed pedagogic research. It is an interesting question as to whether these practices are common in undergraduate education, and if so, whether they are restricted to electrical engineering, STEM subjects or prevalent across higher education. It is also of interest to discover what motivates students to consider such strategies, and whether they continue given the changing landscape of higher education given the changes in fee structure.

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## Appendix A – Module Specifications

### 10ELC040 - Electrical Machines and Systems

<b>Principally taught by</b>	Electronic & Electrical Engineering
<b>Modular weight</b>	15
<b>ECTS Credit</b>	7.5
<b>Credit Level</b>	6
<b>Exam weighting</b>	80
<b>SAP Restriction</b>	Some elements of assessment cannot be reassessed in SAP (Re-assessment involving laboratory work is not available during the Special Assessment Period.)
<b>Prerequisite modules</b>	ELB046 (E)
<b>Availability</b>	Module is available to any student meeting pre-requisites, but numbers will be restricted and priority will be given to students for whom the module is listed in their Programme Regulations.
<b>Responsible Examiner</b>	Dr K Gregory
<b>Delivery Period</b>	Semester 1 and Semester 2

#### Aims:

This module aims:

- to introduce the fundamentals of synchronous machine performance under steady-state conditions.
- to apply transformer equivalent circuit concepts to three-phase systems.
- to allow students to further develop their understanding of the way in which electrical machine and transformer behaviour can be modelled.

#### Intended Learning Outcomes:

(1) Knowledge and Understanding

On completion of the module students should have:

- developed their understanding of the principles and operational characteristics of synchronous machines well enough to be able to make general steady-state performance predictions.
- applied the knowledge of transformers gained in Part B to three-phase devices.
- developed an initial understanding of the way in which synchronous machines interact with powers systems under steady-state conditions.

#### Skills and Attributes

(i) Intellectual/cognitive skills

On completion of the module students should have:

- analysed mathematically the operation of three-phase transformers and synchronous

machines at a level sufficient to make steady-state performance predictions.  
- extended their understanding of how the theoretical basis of circuit theory and electromagnetism can be applied to practical situations.

#### (ii) Practical skills

On completion of the module students should have:

- undertaken the laboratory measurement of pertinent operating characteristics of a round-rotor synchronous motor.
- demonstrated their ability to analyse and evaluate experimental data.
- developed the ability to construct round-rotor synchronous machine operating charts.

#### Key/transferable skills

On completion of the module students should have:

- solved subject specific numerical and conceptual problems alone and in groups.
- undertaken experimental work in small groups.
- developed their information retrieval skills from sources such as the Internet and the library.

#### **Content:**

Introduction to per-unit systems. Three-phase transformers: equivalent circuits, construction, ratings, connections, groups, voltage regulation, efficiency, all-day efficiency. Three-phase synchronous machines: equivalent circuits, ratings, armature winding construction, winding factors, mechanisms of torque production, synchronous reactance, dq model, round-rotor and salient-pole phasor diagrams. Synchronous machines on infinite bus-bars: real and apparent power, power factor and power flow, motor and generator operation, power/load angle curves, synchronising power, operating charts, steady-state stability. Parallel operation of two synchronous generators.

#### **Method of Teaching, Learning and Assessment:**

**Total student effort for the module:** 150 hours on average over two semesters.

**Teaching & Learning:** Lectures-tutorials 2/week for 20 weeks, 3 hours of laboratory exercises and the remaining time for coursework, self-directed reading, problem solving and revision. Module delivery is normally suspended during the semester 1 examination period (weeks 12 to 15).

**Assessment:** One three-hour written examination (80%), one coursework exercise (15%) and one laboratory exercise (5%) completed in semester 1. The execution of the laboratory exercise is assessed in the laboratory. Laboratory work is supervised but self-directed. The laboratory exercise may form part of the examination.

#### **Method of Feedback:**

##### **1. Feedback given to students in response to assessed work**

Individual written feedback on coursework;  
Individual feedback on request

##### **2. Developmental feedback generated through teaching activities**

Interaction with staff in the laboratory;  
Dialogue between students and staff in tutorials

## **09ELB046 - Electrical Power**

<b>Principally taught by</b>	Electronic & Electrical Engineering
<b>Modular weight</b>	15
<b>ECTS Credit</b>	7.5
<b>Credit Level</b>	5
<b>Exam weighting</b>	70
<b>SAP Restriction</b>	Some elements of assessment cannot be reassessed in SAP (Re-assessment involving laboratory work is not available during the Special Assessment Period.)
<b>Prerequisite modules</b>	ELA001 (E) and ELA005 (E) or equivalent
<b>Other prereq modules</b>	A knowledge of basic circuit theory and electromagnetism will be expected
<b>Availability</b>	Module is available to any student meeting pre-requisites, but numbers will be restricted and priority will be given to students for whom the module is listed in their Programme Regulations.
<b>Responsible Examiner</b>	Dr K Gregory
<b>Delivery Period</b>	Semester 1 and Semester 2

### **Aims:**

The aims of this module are to:

- use relevant equivalent circuit concepts to illustrate the behaviour of transformers and induction machines.
- allow students to develop their understanding of the way in which ferromagnetic material behaviour influences machine operation.

### **Intended Learning Outcomes:**

Knowledge and Understanding

On completion of the module students should have:

- a basic knowledge of the characteristics of the common ferromagnetic materials
- a basic knowledge of the operational characteristics of transformers and induction machines
- a basic understanding of how ferromagnetic material behaviour affects the operation of transformers and induction machines
- an understanding of the principles and operational characteristics of transformers and induction machines sufficient to be able to make general performance predictions

Subject-specific Skills

(i) Intellectual/cognitive Skills

On completion of the module students should be able to:

- analyse mathematically the operation of transformers and induction machines at a level sufficient to make general performance predictions
- apply elements of circuit theory to relevant practical problems

(ii) Practical/subject specific Skills

On completion of the module students should be able to:

- undertake the laboratory measurement of the equivalent circuit parameters of transformers and induction machines and test these measurements experimentally
- demonstrate their ability to analyse and present experimental data
- use relevant laboratory equipment effectively

Key/Transferable Skills

On completion of the module students should have:

- solved subject specific numerical and conceptual problems alone and in groups
- undertaken experimental work in small groups
- applied mathematical techniques introduced in Part A in a new context
- applied practical/laboratory techniques introduced in Part A in a new context

**Content:**

Introduction to magnetic materials, simple magnetic circuits and electrical losses. Production of rotating magnetic fields. Transformers: Equivalent circuits, measurement of equivalent circuit parameters, performance prediction using equivalent circuits, accuracy and limitations of equivalent circuits. Single-phase transformers: ratings, voltage regulation, efficiency. Three-phase transformers: ratings, connections, groups, voltage regulation, efficiency, all-day efficiency. Autotransformers. Induction machines: Equivalent circuits, measurement of equivalent circuit parameters, performance prediction using equivalent circuits, accuracy and limitations of equivalent circuits. Motor/generator/braking modes of operation, speed reversal, speed control (pole changing, rotor resistance, armature voltage, frequency changing and slip-energy recovery).

**Method of Teaching, Learning and Assessment:**

**Total student effort for the module:** 150 hours on average over two semesters.

**Teaching & Learning:** Lectures-tutorials 2/week for 24 weeks, 6 hours of laboratory exercises and the remaining time for coursework, self-directed reading, problem solving and revision. Module delivery is normally continuous during the semester 1 examination period (weeks 12 to 15).

**Assessment:** One two-hour written examination (70%). One assessed individual coursework exercise (10%) and the Single-Phase Transformer laboratory (10%) are completed before the end of semester 1. The Three-Phase Induction Motor laboratory (10%) is completed in semester 2. The execution of the laboratory exercises is assessed in the laboratory and CAA exercises are used to assess calculation accuracy. Laboratory work is supervised but self-directed. Each exercise may form part of the examination and laboratory attendance is mandatory.

**Method of Feedback:**

**1. Feedback given to students in response to assessed work**

Individual written feedback on coursework;  
Individual feedback on request

## **2. Developmental feedback generated through teaching activities**

Interaction with staff in the laboratory;  
Results of Computer Aided Assessment;  
Dialogue between students and staff in tutorials

# Appendix B – Pre-sessional questionnaire

Department of Electronic & Electrical Engineering

**Electrical Machines and Systems, Pre-Sessional Exercise**

Please answer the following questions by ticking the relevant boxes. This exercise is designed to check your understanding of some of the concepts that will be used in Electrical Machines and Systems. The exercise is anonymous and is not part of the assessment, i.e. **there are no marks attached to it**, so be as honest as you can in your replies.

(Q1) Which of the following statements is closest to your understanding of what magneto-motive force (mmf) is?

(a) The force that drives flux around a magnetic circuit. ☐ 14

(b) ☒ An indicator of the ability of a current carrying winding to produce a magnetic field.

(c) ☒ The line integral of magnetizing force H around a closed contour in a magnetic field.

(d) The sum of current enclosed by any closed path in a magnetic field. ☐ 0

Department of Electronic & Electrical Engineering

**Electrical Machines and Systems, Pre-Sessional Exercise**

(Q2) Which of the following statements is closest to your understanding of what inductive reactance is?

(a) The equivalent of resistance in an AC circuit. ☐

(b) ☒ An invented circuit element that represents the effects of the emf induced in a circuit by the magnetic field produced by its own changing current.

(c) ☒ An invented circuit element that represents the effects of the emf induced in a circuit by a magnetic field produced by a changing current in another circuit.

(d) The ratio of the rms voltage to the rms current in an AC circuit. ☐

(e) The ratio of the rms voltage to the in-phase component of the rms current in an AC circuit. ☐

(f) The ratio of the rms voltage to the quadrature component of the rms current in an AC circuit. ☐

Department of Electronic & Electrical Engineering

**Electrical Machines and Systems, Pre-Sessional Exercise**

(Q3) Which of the following statements are closest to your understanding of what a phasor is?

(a) ☒ A pictorial representation of an alternating quantity that has magnitude and phase. tick any

(b) A pictorial representation of a quantity that varies in time. ☐

(c) ☒ A pictorial representation of a quantity that varies sinusoidally in time.

(d) A pictorial representation of a quantity that varies in space. ☐

(e) A pictorial representation of a quantity that varies sinusoidally in space. ☐

Department of Electronic & Electrical Engineering

**Electrical Machines and Systems, Pre-Sessional Exercise**

(Q4) Which of the following statements do you think is true?

(a) MMF is a lumped parameter, i.e. a quantity that can be considered to have a value at one point in a magnetic field. ☐

(b) ☒ MMF is a distributed parameter, i.e. a quantity that has a value at any point in a magnetic field.

(c) ☒ MMF can vary in time.

(d) ☒ MMF can vary in space.

(e) ☒ MMF can be a phasor quantity.

(f) ☒ Inductive reactance and inductance are the same thing.

(g) ☒ Inductive reactance only has meaning under steady-state AC conditions.

(h) ☒ Inductive reactance only has meaning under steady-state sinusoidal AC conditions.

(i) ☒ Phasors and complex numbers are different representations of the same thing.

(j) ☒ Argand diagrams were designed to look like phasor diagrams.

(k) ☒ It is a coincidence that Argand diagrams look like phasor diagrams.

# Appendix C – Mid-session questionnaire

## Electrical Machines and Systems, Mid-Sessional Exercise

Please answer the following questions by ticking the relevant boxes. This exercise is designed to check your understanding of some of the concepts that will be used in Electrical Machines and Systems. The exercise is anonymous and is not part of the assessment, i.e. **there are no marks attached to it**, so be as honest as you can in your replies. Please ensure you answer **all** questions.

(Q1) Which of the following statements is closest to your understanding of what magnetomotive force (mmf) is?

- |  | tick one                            |
|--|-------------------------------------|
| (a) The force that drives flux around a magnetic circuit.                                  | <input checked="" type="checkbox"/> |
| (b) An indicator of the ability of a current carrying winding to produce a magnetic field. | <input type="checkbox"/>            |
| (c) The line integral of magnetizing force H around a closed contour in a magnetic field.  | <input type="checkbox"/>            |
| (d) The sum of current enclosed by any closed path in a magnetic field.                    | <input type="checkbox"/>            |

(Q2) Which of the following statements is closest to your understanding of what inductive reactance is?

- |  | tick one                            |
|--|-------------------------------------|
| (a) The equivalent of resistance in an AC circuit.   | <input type="checkbox"/>            |
| (b) An invented circuit element that represents the effects of the emf induced in a circuit by the magnetic field produced by its own changing current.            | <input checked="" type="checkbox"/> |
| (c) An invented circuit element that represents the effects of the emf induced in a circuit by a magnetic field produced by a changing current in another circuit. | <input type="checkbox"/>            |
| (d) None of these statements are close to my understanding.  | <input type="checkbox"/>            |

(Q3) Which of the following statements are closest to your understanding of what a phasor is?

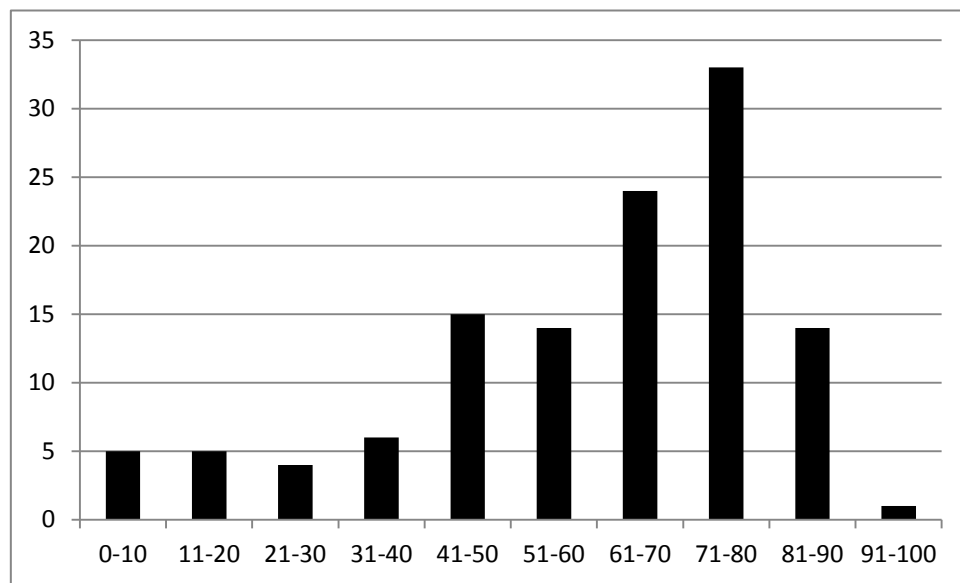
- |   | tick any                            |
|---|-------------------------------------|
| (a) A pictorial representation of an alternating quantity that has magnitude and phase. | <input checked="" type="checkbox"/> |
| (b) A pictorial representation of a quantity that varies in time.                       | <input type="checkbox"/>            |
| (c) A pictorial representation of a quantity that varies sinusoidally in time.          | <input type="checkbox"/>            |
| (d) A pictorial representation of a quantity that varies in space.                      | <input type="checkbox"/>            |
| (e) A pictorial representation of a quantity that varies sinusoidally in space.         | <input type="checkbox"/>            |

(Q4) Which of the following statements do you think is true?

- |   | true                                | false                               |
|---|-------------------------------------|-------------------------------------|
| (a) MMF is a lumped parameter, i.e. a quantity that can be considered to have a value at one point in a magnetic field. | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (b) MMF can vary in time.   | <input checked="" type="checkbox"/> | <input type="checkbox"/>            |
| (c) MMF can vary in space.  | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (d) MMF can be a phasor quantity.   | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (e) Inductive reactance and inductance are the same thing.  | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (f) Inductive reactance only has meaning under steady-state non-sinusoidal AC conditions.                               | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (g) Inductive reactance only has meaning under steady-state sinusoidal AC conditions.                                   | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (h) Phasors and complex numbers are different representations of the same thing.  | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |
| (i) Argand diagrams were designed to look like phasor diagrams.   | <input type="checkbox"/>            | <input checked="" type="checkbox"/> |

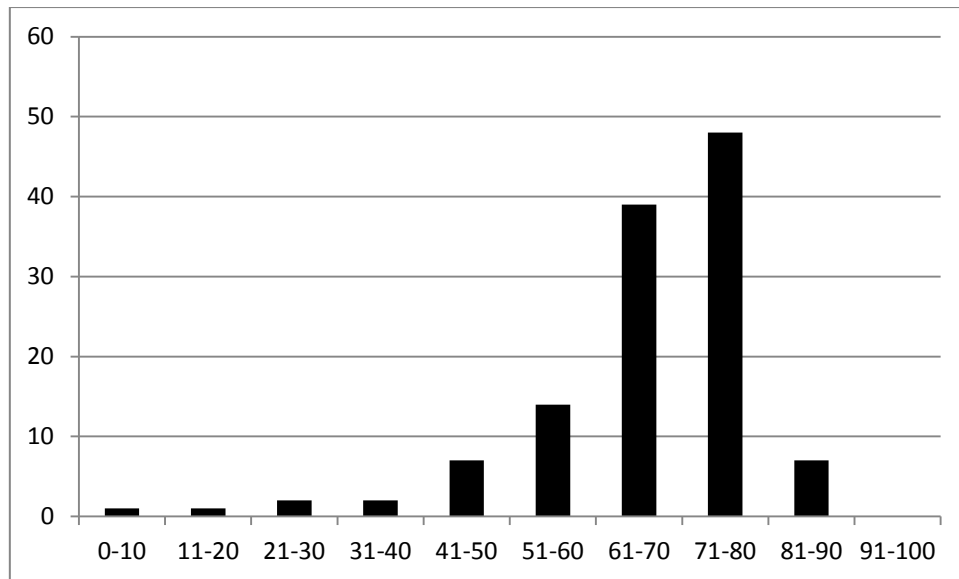


## Appendix D – Normalised histograms and the Generic Module Method

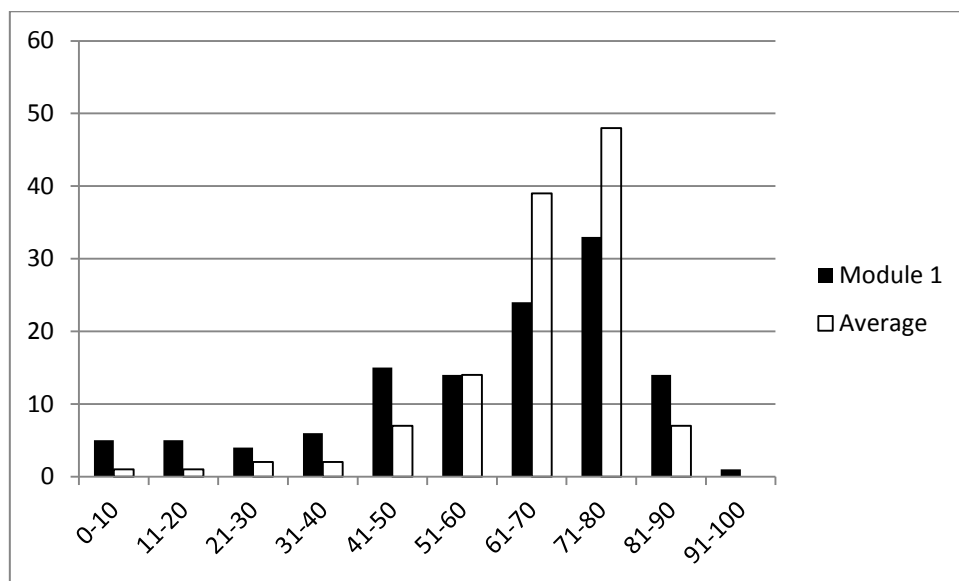


**Figure D.1 – Module 1 distribution histogram**

Remember the histogram of Figure 5.2, reproduced above as Figure D.1, and consider the histogram of Figure D.2 which is the distribution of the average marks for the same component for the same 121 students of Module 1. Clearly the two figures are different, and a visual comparison of the two is relatively simple, especially when combined onto the same axes (Figure D.3), and any differences (e.g. there are fewer marks below 50 for the second distribution) are relevant and valid.



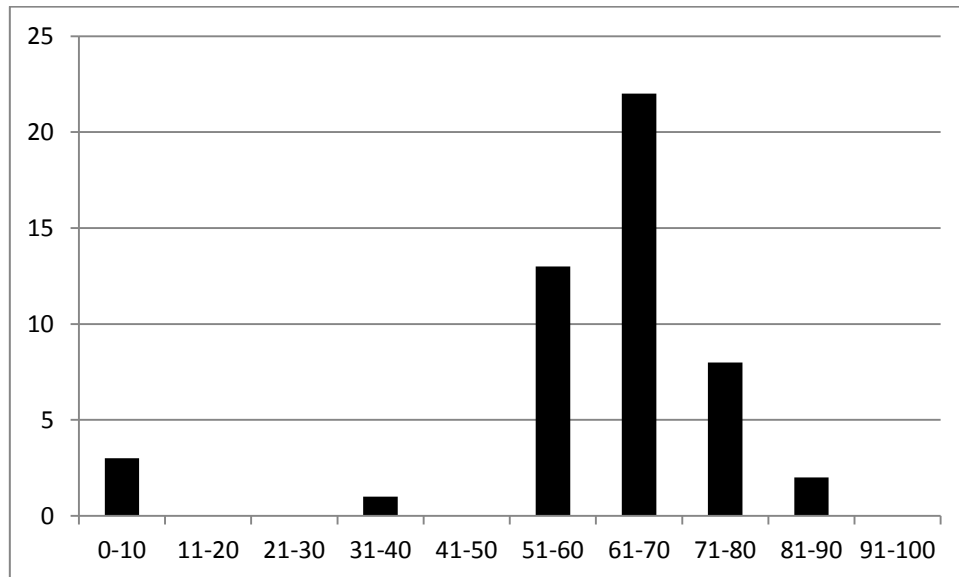
**Figure D.2 – Average distribution histogram**



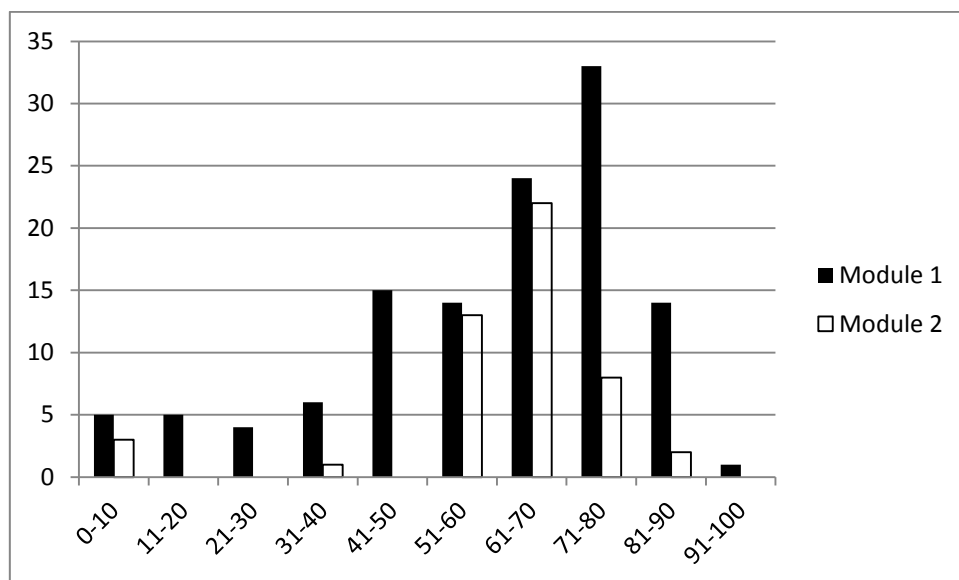
**Figure D.3 - Histogram 2 and 3 on the same axes**

Consider now the histogram of Figure D.4, which shows the distribution of marks in a second module with a class size of just 49, all of whom were also amongst the 121 students registered on module 1. Direct comparison of those 49 students, as discussed previously has emphasis on the specific student group performance, which may not be indicative of the performance on the whole of the 121 students, however, one cannot compare the full cohort of each module directly in the same way as we did with Figure D.3. The resultant histogram of attempting such a thing is obviously flawed (Figure D.5) and any observations made (e.g.

less people scored in the 61-70 bin in the smaller module) whilst correct are invalid and irrelevant, because there are fewer people on the second module overall. Incidentally any attempt to compare the distribution of marks for the subset of 49 with the whole module of 121 would be flawed in the same way.



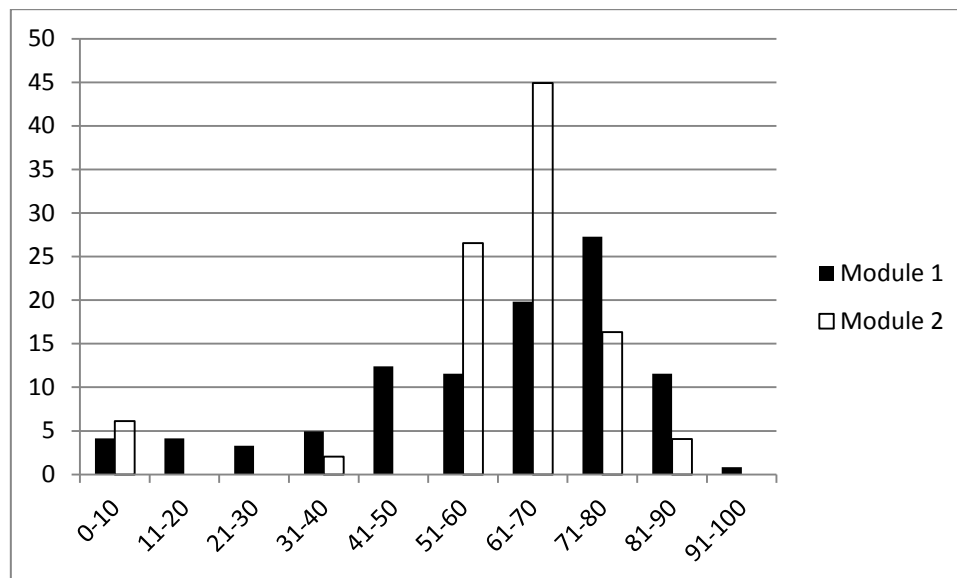
**Figure D.4 – Module 2 histogram**



**Figure D.5 – Comparison of modules 1 and 2**

Normalising the histograms so that instead of showing a frequency count in each bin there is a proportion (in this thesis a percentage) allows the comparison of different modules where

the cohort is not the same in each. This allows relevant and valid observations to be made (e.g. a higher percentage of students score in the 61-70 range on module 2 than module 1).



**Figure D.6 - Normalised histograms for modules 1 and 2**

Having seen the power of the normalised histogram it becomes a simple matter to generate an average module to which a specific module can be compared. This is done by taking the average of the normalised distributions of all the modules in the year.

As an example consider a year group of 25 students, who between them undertake four modules. Two of these are compulsory, and of the remaining two each student must choose at least one. Marks are shown in Table D.1 and the end result is that we wish to compare module A with the generic module created from this year.

Student	Module A	Module B	Module C	Module D
1	62	59		78
2	28	36	9	93
3	1	31	33	53
4	54	12		67
5	65	12	22	
6	58	86	75	36
7	48	73	35	21
8	12	16	56	
9	90	82	89	3
10	98	6		76
11	65	88	87	39
12	18	1		49
13	0	43	62	76
14	70	2		67
15	81	26	10	59
16	8	87		35
17	4	3	1	
18	42	58		27
19	39	41	82	
20	13	43		77
21	77	39		87
22	39	6	31	
23	17	98	46	52
24	74	88	76	94
25	12	51	11	36

**Table D.1**

The marks are grouped into bins and the tally of each bin calculated for each module (Table D.2).

Bin\Module	A	B	C	D
0-10	4	5	3	1
11-20	5	3	1	0
21-30	1	1	1	2
31-40	2	3	3	4
41-50	2	3	1	1
51-60	2	3	1	3
61-70	4	0	1	2
71-80	2	1	2	4
81-90	2	5	3	1
91-100	1	1	0	2
Total	25	25	16	20

**Table D.2**

The frequency counts in each bin are then converted to percentages (Table D.3).

Bin\Module	A	B	C	D
0-10	16	20	18.75	5
11-20	20	12	6.25	0
21-30	4	4	6.25	10
31-40	8	12	18.75	20
41-50	8	12	6.25	5
51-60	8	12	6.25	15
61-70	16	0	6.25	10
71-80	8	4	12.5	20
81-90	8	20	18.75	5
91-100	4	4	0	10
Total	100	100	100	100

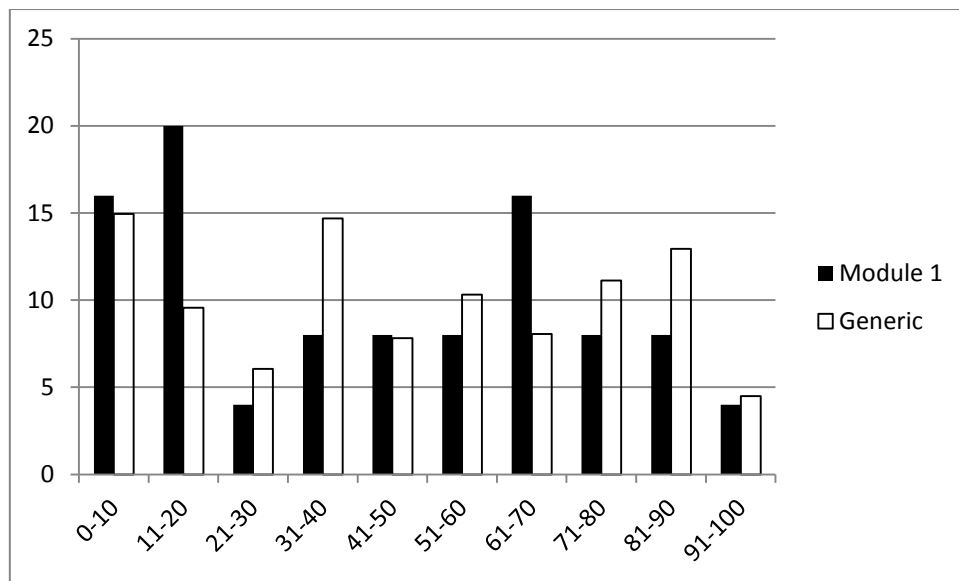
**Table D.3**

And finally the average of each bin across the modules is calculated to create the histogram of the generic module (Table D.4)

Bin	
0-10	14.9375
11-20	9.5625
21-30	6.0625
31-40	14.6875
41-50	7.8125
51-60	10.3125
61-70	8.0625
71-80	11.125
81-90	12.9375
91-100	4.5
Total	100

**Table D.4**

Which allows the comparison of module A with the generic module as shown in Figure D.7.



**Figure D.7 – Module 1 compared with generic module**

## **Appendix E – Interview Transcript – Student 4**

Interviewer: Let's get straight to it shall we? How long you been at uni for?

Student: This is now my fourth year.

I: Does that include a year in industry?

S: No, I did a foundation year at the beginning. Then three straight years.

I: Cool. You've no industrial experience then?

S: No.

I: Gender is male, age?

S: 22

I: Degree program

S: Electrical and Electronic

I: Masters or Bachelors?

S: Bachelors.

I: If at any time you don't understand why I'm asking a question, do ask, and I'll explain it.

First 5 questions relate to electrical power, reason being it's a pre requisite for machines and systems and the average exam mark was poor.

S: Yeah, I spoke to Keith afterwards and he wasn't hugely impressed with the overall mark.

I: First question is how did you find the module?

S: Well, it was very interesting, definitely difficult. A lot of the theory took me a long time to get my head round. Well taught, but personally it just took me a long time to get my head round the theory behind it all. That's probably in part due to me not doing enough work outside of the actual lecture and just relying on what I was taught.

I: Did you do any work outside of lectures?

S: Coursework and the odd tutorial, but nothing substantial no.

I: Do you think everybody found it difficult like you did?

S: Yeah, I think that was the general consensus, certainly among my group of friends who were in the lecture with me, that was the general consensus yeah.

I: Is there anything you can think of that you found especially difficult?

S: Not a particular thing no.

I: Is there anything you struggled to understand but your friends understood straight off the bat?

S: Nothing that springs out particularly, for me it was a general..everything.

I: Was there anything you didn't find difficult?



S: Some of the stuff at the beginning on like magnetising theory and that with Keith, but that was more of a background theory sort of thing.

I: Is that because you had prior knowledge?

S: No. Whether it was the start of the year and there was less going on with other modules as well, that might've helped, I don't know.

I: Did your friend find that that was..

S: Yeah I think everyone sort of eased into it fairly easily like that yeah.

I: You don't know why you found it difficult do you? Because you've said that you didn't do a lot of work outside of lectures.

S: I think for me I tend to learn better if I can see something if that makes sense, whereas a lot of that was just sort of theory behind stuff, until you got into... Even tutorials and that, it's equations and things but you don't actually see why you're doing what you're doing. I very much work better when I can see what's going on. A lot of the stuff you can't do that, it's just not possible, but you know, that's just the way I work.

I: So if I say that you found it too abstract, and couldn't relate the theory to the physical, you'd agree with that statement?

S: Yeah.

I: Do you think if you put in more work outside of lectures, more tutorials and so on, that would help?

S: Yes. Definitely.

I: Did you understand the lectures as they were going on?

S: Yes and no. Parts of it were fine in the lecture, until it came to relating it to the tutorial things.

I: So you struggled to relate the lecture material to the tutorials?

S: Yes.

I: Can you think of a way it would've been made easier for you?

S: Umm. Obviously visual representation would've been a bonus for me personally.

I: Is there anything you particularly would've liked to see visually represented?

S: I can't think back to the specifics of the module now.

I: No problem.

S: I definitely found with Gordon's side of the lectures, he did a lot more on the OHP and taught it, told you what you were writing but he also put diagrams in there, whereas Keith's

he gave you a big wad of notes then sort of read through it. He didn't just read through it, he did it in a good way of reading through it, but I think I related better to Gordon's methods.

I: Was Gordon drawing the diagram then as he's working through the notes, relating back to the diagram?

S: Yes.

I: And that helped you did it?

S: I think so yeah.

I: Can you think of a way the lecturers could've related the tutorial questions to the lecture notes a bit better?

S: I suppose bringing in real examples, if that makes sense. I know the circuits in the tutorials and that we were going through were examples of what actually happens, but if they could then relate it to a - not a physical example but a real life situation that would probably. With it being theory as well, you can't always do that.

I: Would it have helped you if for example Keith went through a section of notes then said tutorial question 4 relates to what we've just gone through?

S: Yes, that probably would've.

I: Next three questions aren't specifically about last year, they're general questions mainly about university, but anything from school you thin is relevant, or even if you don't. The more you give me now that more work I have to do but the better it is. OK. Tell me about how you study throughout the year, if you study throughout the year.

S: I attend all the lectures, or do my best to do so, but I don't tend to do much outside the lecture until it comes to coursework. For me personally I don't tend to have the motivation to do the coursework until I've got a deadline like the next day and it suddenly becomes really important to do it. I always say I'm not going to do it anymore, but always do. That's my biggest downfall, time management. That's been the same all through my learning career.

I: Ok, what about revision periods?

S: I get distracted very easily.

I: Is that because you don't want to be doing the revision?

S: Yeah, probably. I always sit down with the best intentions, but it just never seems to happen. Terribly easily distracted.

I: How do you, when you get set up for revision, what's your plan of attack?

S: Generally I make notes on my notes and then try and go through tutorials and exam papers. But again with my poor time management, I end up taking loads of notes and running out of time to go through tutorials and things.

I: So you end up basically your revision consists of going through your notes?

S: Pretty much yeah. If I managed to do more work outside of lectures in term time, I wouldn't have to do that, and I could go straight in and do past exams and things.

I: So if you were to start doing more work outside of exam time, what work would that be? Rewriting notes?

S: Umm, tutorial questions I think. Doing the actual questions is the best way of learning what you're trying to do, so..

I: When you say you revise using tutorials and past papers, would that be revising to learn the steps of the question, so if a similar question came up in the exam you'd be able to-

S: Yes, to a point it is yeah. Also to get experience doing the work, but yeah I suppose mainly it is to learn the steps through so you can relate it to anything.

I: So if a question on the same subject came up but it was different, would that be a problem for you?

S: Depends how different. Certainly with Keith's exams he tends to chuck in really horrible nasty bits to catch you out and they generally catch me out. And I tend to find if I get to a step I don't know, I really fall down at that point.

I: Say it's a multi part question, 5 parts, you do parts a and b ok, then part c stumps you. Do you then look at d and e?

S: Yes. If it's something if you need to carry something forward, I'll pick a value that I think. Say it's a specific number you need to carry forward to the next part. If I can't do that part, I'll make up a value that seems in the right range then carry on the question to get the marks. You still get the theory marks but you don't get the marks for the right answer.

I: Do you write a little note on the answer paper to let the examiner know what's happening?

S: Yes.

I: OK. Interesting question here, always gives good answers. How do you know when you know something?

S: I don't know. If I get the answer very quickly and easily, I generally assume it's wrong because it's not very often I go straight in and know the answer. Assuming it's a numerical maths type of question. If it's a theory question and I know the answer then I know I've probably got it right. But if it's a case of working something out and it comes really easily

then... You can also relate it to the number of marks awarded to that question as to how easy it should be to get the answer.

I: So you base your knowledge of knowledge on exam questions and whether you can answer them?

S: Yes.

I: So at what point do you stop, if you're revising something, at what point do you decide you know it?

S: Once I can go through a few questions and get the right answer.

I: Is time a factor in that at all?

S: Generally yeah, it does become a factor because I end up working myself into a corner as I say so...

I: What I meant by that was is it as soon as you can answer a few questions a day or within an hour? You know, can you answer the question in an exam sort of time frame?

S: I suppose it is to a point, but it's more a case of being able to get the answer. I tend to find that if I do questions like that I make stupid I might get the theory right, but I'll make stupid mistakes like minus ones like, stupid things like that that end up bringing the final answer out wrong despite having done the theory right.

I: Do you revise and study the same in all modules?

S: Yes, well I try to anyway.

I: Is that how you've always studied or have you changed it after your first or second year, or after foundation maybe?

S: Umm no, that's pretty much how I've always done it.

I: And is that the same as school?

S: Yeah, a definite way of improving that would be to not have to make the notes, and just go straight into questions, so it all comes back down to doing more work throughout the year.

I: Next question, next 5 questions, are not related to anything in particular, they just are general questions, apart from this first one, which relates to this module. Are you doing machines and drives as well?

S: Yes. Both of them yeah.

I: How are you finding machines and systems?

S: So far it's alright. It's just it's an advancement of last years, so it seems alright at the moment.

I: Are you doing more work outside of lectures this year?

S: The majority of my time at the moment is taken up with final year project rather than...

I: What's your final year project?

[Identifiable information removed]

I: Good supervisor?

S: He's alright. Not very quick to respond to emails, hard to find at times.

I: So yeah, you say this module's going alright, and it's an extension of last year. What's the hardest thing you've done so far in machines and systems?

S: Certainly the three phase transformer stuff. That certainly was uhh. I don't know I suppose the only reason I thought about that was because that's what the coursework was based on as well.

I: Is there anything you found straightforward or easy?

S: I find Gordon's stuff a lot more, not easier, but it's making more sense this year.

I: The same as last year?

S: Yeah.

I: Do you reckon it's the same reasoning?

S: Yeah, I suppose so yeah. His one is more, can be more easily related to actual processes.

I: You're talking about his machines and drives?

S: Machines and drives yeah.

I: I had somebody else say that, he said it seemed more logical.

S: That definitely makes sense yeah.

I: Why do you think you found the three phase transformer difficult, or particularly difficult?

S: Umm.

I: Or was it purely that it's stuck in your mind because you've had to look at it for the coursework?

S: I don't know. Umm. I suppose having learnt, or gone through the single phase stuff, to then sort of think I've got my head round it, and then gone to the three phase stuff and you're back at square one almost, it was just a ... Going back to square one was a daunting thing if that makes sense.

I: Do you think everyone found the three phase transformer stuff tricky?

S: Probably not. I'm just trying to think no. Some people I know just find the electrical power side of things really easy and it just makes sense for them, so I know they didn't, but I know some other people who did find it difficult, so a bit of a mix for that one.

I: Anything you can think of that would've made it easier for you to understand?

S: Umm Not off the top of my head. No I think it is just me having to put the work in and do it I think.

I: You say you don't put the work in because you lack the motivation to do it?

S: Yeah, at the moment it is a case of FYP taken over everything, but whether it would be different if I didn't have that there... I like to think it would be, but whether or not I don't know.

I: You're obviously quite a big lad, you play rugby?

S: Yeah

I: First team?

S: I don't play for the uni, I play for the town side. Loughborough Town. I managed to sleep through the trials for the university, so that wasn't a good start. When it got to that point I thought it was probably not worth going down again.

I: Do you think that impacts on your studying?

S: No, if I've got. There's only two training sessions a week and a game on Saturday

I: What about gym time?

S: I go to the gym 3 times a week, but... maybe the gym time does, but...

I: I'm not criticising, just trying to cover the bases so to speak

S: Yeah, that's fine. The rugby is something I've always had worked into my schedule and when it comes to exams and revising, I'll skip the training sessions and just go for the games.

I: Where do you do your revision? Home library?

S: 50/50 between home and library.

I: Do you find you do more when you're at home?

S: More in the library usually. Simply because I haven't got the distractions that I have at home.

I: Is there any aspect of the assessment for machines and systems that you're worried about? Obviously you've done one piece of coursework already.

S: Yeah, the first piece of coursework I think went well, obviously I've not had any marks back for it yet, but I did all the work for it so I think I did alright in that one. The exam is bound to be hard, because obviously A it's my final year and B Keith's setting it so... it's bound to be hard. Umm. There must be another piece of coursework. A lab assessment. That should be alright, it's just the exam I think will be the main worry for me.

I: Are you worried at all about the machines and drive assessment? Same sort of deal?

S: No, it'll probably be the same, the exam that'll be the trickier part.

I: Do you generally struggle with exams?

S: Yeah exams aren't a good part for me. I tend to not get stressed, but when one thing goes wrong, there's always that risk with me that everything will go wrong after that because I just panic a bit and yeah, I'm not particularly good in exam situations.

I: Yeah, that's a fairly consistent theme. I wasn't good in exams. With regards to Keith and Gordon in mainly machines and systems but also machines and drives, is there anything you would change? I suppose it also relates to power and circuits in part A if you can remember that far back.

S: Yeah, umm, what just in terms of lecturing?

I: In terms of lecturing, the way they produce their notes, when they give you the notes, courseworks, anything.

S: No, they're probably the two best lecturers I've had, so I think I relate better to Gordon's methods. But I'm quite good at taking notes in lectures, so in terms of things I'd change I can't think of anything no.

I: I had one bloke earlier on who said the room for machines and systems was diabolical. The one on top of the library.

S: Yeah. That was just a room as far as I can tell, that doesn't really bother me too much.

I: What I said to him in regards to that point was would it be better if you were to have your lecture in the machines lab downstairs. On the desks at the back. Would that work better for you?

S: Unless you're actually using the machines, I don't think it really makes a difference what room you're in. So long as you can see.

I: If, you say you have trouble relating abstract concepts to the physical world, if there was the opportunity for you to be in a lecture in the machines lab downstairs, and Keith to be demonstrating something on the machines downstairs, would that help you?

S: Personally I think it would yeah.

I: The problem with that currently is that you won't be able to see the dials or meters on the machine set. Now obviously for some things he's talking about you'd need to be able to see them, so do you think that it would work in a situation where there's 20 of you down there and you'd all have to go look at the machine set. Is that going to slow things down too much and ruin the flow?

S: Umm, yeah, if you've got to then start individually having a look, it's going to slow things down, but at the same time I think it would be a beneficial thing to have.

I: Right. What about access to notes? I've had a few people saying they would rather have hardcopy and available on Learn. Does that make a difference to you?

S: So long as it's one or the other, it doesn't. I always go to the lectures, so if there's a handout, I've got a copy. I think probably hardcopy would be. I'd prefer hardcopy to having to go find it on learn. Tutorial examples and that, solutions would be handy on learn.

I: Do you get given tutorial answers at all?

S: We get numerical answers, but not the theory to reach it.

I: So you want worked answers?

S: Yes, but it's not a huge thing, as I go and take notes when he does go through tutorials.

I: Are past paper answers available?

S: Last year they were, don't know about this year, haven't looked yet.

I: Anything else you want to comment on, doesn't have to be related.

S: Not that I can think of no.



## Appendix F – Structured Interview Responses

This appendix contains the responses to the paper interview given to part B students. There are a series of numbers written in the top right of the sheet, which correspond to how the questionnaires were grouped into response categories, however such quantification was only possible for questions 1,2,4,5 and 9. Numbers beginning with 1, 2, and 9 are two digits long, and categorise the response to those questions, while numbers beginning 4 or 5 could be two or three digits in length. Categories are tabulated below.

11	Easy	15	Harder at the start, getting easier
12	OK (manageable etc)	16	Coursework easy, exam hard
13	Hard (challenging etc)	17	Lot of content (infer hard)
14	Easy at the beginning, getting harder	18	No comment

21	No definitive comment	23	Same or similar
22	Harder than me	24	Easier than me

41	Yes	45	451	Teaching – More tutorials
42	No		452	Teaching – Use LEARN more
43	Not sure / No comment		453	More revision
	441 Assessment – Exam		454	Generic comments
44	442 Assessment – too harsh	46	Overall generic comments	
	443 Higher coursework weighting			

51	511	Notes – rewriting	53	Lab/coursework	
	512	Notes – generic mention	54	Lectures	
	513	Notes – no rewriting	55	551	Other – internet
52	521	Tutorial questions		552	Other - textbooks
	522	Examination questions	56	No mention	

91	Same or harder, no explicit mention	94	Power easier than circuits
92	Power harder than circuits	95	Too soon to say
93	Same, explicit mention	96	Impossible to infer

17441  
Clear

23 521

Q1

- How long have you been at university for? 1 year 4 months
- Do you have any industrial experience? No
- Which programme are you currently registered on? Systems Engineering MEng
- Age 20 Gender male

The results for the circuits module you took in part A were, on average, lower than would be expected. The following questions relate to that fact.

1. How did you find the module?
2. How do you think others found it?
3. Can you think of anything you found difficult but your friends and peers seemed to find easy?
4. Do you think the teaching/assessment needs changing in any way?
5. How did you go about studying for the module, and how did you know when you'd learnt something?
6. Do you think you will change the way you study as a result of your experiences?
7. Can you give some examples of teaching styles that you think would be suited to the module?
8. Compare the teaching style of Keith to other lecturers you have had. How does it compare? What are the good and bad points?
9. Finally, how are you finding this module, Electrical Power?

1. the module had lots of content to remember, particularly formulas, compared to other modules. ~~questions were~~ ~~seemed not to be~~ questions were asked in a way that made it hard to see the point of the module and equations it related to.

2. most people found relating to the course content in the questions hard.

3. All I remember is the questions in the second half of the paper hard.

4. Exam questions need to be clearer in order to relate to the course content. The teaching is fine.

5. I attend all lectures and do the tutorial questions and relate to the answers. ~~Neener the exam I practice lots of past papers until I know the method.~~

6. No

7. In a lecture there the OHP style of teaching makes best.

8. Keith will go through questions on the OHP at a ~~pace~~ good pace and I feel this suits in quite well.

8. we also get a bit of background knowledge in order to understand clearly.

9. I'm concerned that I won't do as well in this module as it seems similar to circuit theory and I am expecting a hard paper. However, I feel I am more than capable of learning the content which is pitched at the right level - providing I can relate my knowledge to what the questions ask.

# Appendix G – Software Evaluation

## Real-time data presentation as an aid to electrical machines teaching

You have seen a brief presentation of an experimental application that allows electrical machine data to be captured, analysed and displayed to a student group in real-time. As an aid to the development of this software we would value your opinion on its usefulness and your suggestions as to how it should be further developed.

Which of the following are most applicable? The presentation:

- (a) Reinforced my understanding of the way in which a synchronous machine behaves. ☒ [YES] [NO]
- (b) Changed my understanding of the way in which a synchronous machine behaves. ☐ [YES] [NO]
- (c) Clarified my understanding of the way in which a synchronous machine behaves. ☐ [YES] [NO]
- (d) Confused my understanding of the way in which a synchronous machine behaves. ☐ [YES] [NO]
- (e) Other (please expand on this in the space below).

Which of the following are most applicable? The use of real machines:

- (a) Made the presentation more interesting and/or meaningful. ☐ [YES] [NO]
- (b) Confused me because of the unstable and distorted waveforms presented. ☐ [YES] [NO]
- (c) Made me realise that the theory presented is often idealised. ☒ [YES] [NO]
- (d) Made me realise that real electrical machine behaviour is complex. ☒ [YES] [NO]
- (e) Other (please expand on this in the space below).

*It helped me better visualise/realise pole slipping & how slot gaps affect waveforms.*

Which of the following are most applicable? Is the real-time presentation:

- (a) A useful teaching aid. ☐ [YES] [NO]
- (b) Worth further development. ☐ [YES] [NO]
- (c) Other (please expand on this in the space below).

*seems quite useful however don't feel it advanced my knowledge very much past that which I have learnt from static phasor diagrams. It was useful to properly see/hear pole slipping.*

Please turn over the page.

After seeing the prototype software in use have you any suggestions as to which sections of the machines curriculum would benefit from the same approach?

*Better ~~add~~ labels on the computer projected readouts  
i.e. which voltage it represents as opposed to just being channel '0'*