Teaching of Linear Programming: Variation Across Disciplines and Countries

Anesa Hosein

Institute of Educational Technology
The Open University

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Supervisors:
Dr. James C. Aczel
Dr. Doug J. Clow
Prof. John T.E. Richardson

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Lastly, I will like thank Almighty God with whom nothing is impossible.
Abstract

An online questionnaire was used to investigate how linear programming is taught across disciplines countries. The questionnaire was sent to 311 lecturers in Australia, New Zealand, UK and USA. Lecturers also completed an “approaches to teaching” questionnaire and some of their students completed an “approaches to studying” inventory.

The study found that mathematically intensive topics such as interior-point method and revised simplex method were taught primarily in USA. Also, lecturers in “pure” disciplines such as mathematics tended to use less software than lecturers in more applied disciplines but taught more solution methods. The sensitivity analysis topic featured more strongly in applied disciplines such as business and engineering. Whilst there appeared to be no differences in “approaches to teaching” between the disciplines, students in the “soft” disciplines such as business appeared to have a more strategic approach than students in the “hard” disciplines such as mathematics and engineering. The study suggests using qualitative methods for further research to collect richer data.
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Chapter 1. Aims and Objectives

1.1 Introduction and Background

This research explores the teaching and learning of a mathematics-based topic called linear programming (LP). LP is employed for determining the best ways to maximize or minimize the use of resources by solving a system of linear inequalities (Winston, 1994). This topic spans various university disciplines and is commonly found within business, engineering and mathematics courses entitled operations research, management science, quantitative methods and optimisation. These courses are taught at both the postgraduate and undergraduate level.

Research into linear programming education exists predominantly in studies covering management science/operations research (MS/OR) courses in US business programmes (e.g. Albritton, McMullen and Gardiner, 2003; Gallagher, 1991; Gunawardane, 1991; Harpell, Lane and Mansour, 1989; Jordan, Lasdon, Lenard, Moore, Powell and Willemain, 1997; Kros and Polito, 2003; Lane, Mansour and Harpell, 1993). From these studies, linear programming was found to be either one of the most important or most covered topic within the MS/OR course. However, there has been limited research into how linear programming is taught at a more detailed level and how its teaching compares across disciplines as well as countries.

1.2 Aims and Objectives

Against this backdrop, this study aims to investigate how the teaching of linear programming varies across disciplines and countries. In particular, the study seeks to
determine if and to what extent specific linear programming sub-topics are covered.

These specific sub-topics include three main aspects of linear programming (see Section 3.2.2, p. 24): the formulation of the problem, the solution of the problem, and the exploration of the solution through a “sensitivity analysis”. For each of the LP topics, the research explores the pedagogical methods employed with respect to using software in teaching and encouraging students’ software interaction.

Further, the investigation attempts to determine if the teaching approaches for linear programming vary across disciplines and whether these patterns, if any, are reflected in the students’ approaches to studying. By examining the pedagogical methods and the studying approaches of linear programming, the research hopes to provide insight and add to the body of knowledge on the teaching and learning of mathematical topics.

1.3 Rationale

Although linear programming has existed in university curricula for more than thirty years, there has been little research into the teaching of its sub-topics until recently (e.g. Albritton et al, 2003). Even though Albritton et al’s research provided some information on the extent that formulation, solution and sensitivity analysis were taught, their work had a decidedly MS/OR focus and did not provide further details into the various types of solutions and sensitivity analysis (see Section 2.2, p. 6). With linear programming being such a prominent part of the MS/OR curriculum, knowing current linear programming teaching practices can perhaps aid lecturers and MS/OR organisations such as the Institution for Operations Research and Management Science
(INFORMS) and the Operation Research Society (ORSOC) in shaping the curriculum to meet their aims as well as the aims of their intended students.

Further, linear programming has not only been a ‘stalwart’ of the classical MS/OR curriculum (Kros and Polito, 2003) but increasingly features in a multitude of other core and optional courses. These courses form part of the curriculum for university students from varying disciplines including agriculture, biology, business studies, computer science, economics, engineering (including civil, environmental, industrial, and mechanical), mathematics, medicine, operations research and statistics.

There are few academic topics that are common to such a variety of disciplines, and this perhaps places LP in an extraordinary position for researching cross-disciplinary methods of teaching and studying. For example, recent studies that have investigated teaching and studying methods across disciplines using qualitative and quantitative surveys have compared responses from topics that were discipline-specific (e.g. Ballantyne, Bain and Packer, 1999; Hativa and Birenbaum, 2000; Lindblom-Ylänne, Trigwell, Nevgi and Ashwin, 1999; Lueddeke, 2003; Norton, Richardson, Hartley, Newstead and Mayes, 2005). There is, however, hardly any common basis for comparison of the teaching or studying methods as the results may reflect methods from courses that are discordant with each other. Using a topic, such as linear programming, that is common to several disciplines to form a baseline, can perhaps ensure that like is comparing like and hence truly determine how disciplines differ in their methods of teaching and learning.
1.4 **Research Questions**

Although, there are several studies on the teaching of MS/OR and linear programming as a topic, the decided lack of literature into the detailed teaching of linear programming provides a rationale for investigating how linear programming sub-topics are taught. Further, because of linear programming’s unusual feature of being common to a variety of disciplines, this study is allowed the unique opportunity to investigate how teaching and learning may differ across disciplines. Thus, the study will seek to address the following research question:

*How is linear programming taught at the university level across disciplines and countries?*

The following specific research questions serve to answer the ‘how’ in the main research question:

i. To what extent are each of the linear programming sub-topics taught in the various disciplines and countries?

ii. Do the types of linear programming software employed vary across disciplines?

iii. To what extent is linear programming software used in the teaching process?

iv. Does students’ interaction with linear programming software for finding the solutions vary across disciplines?
v. Do lecturers’ disciplinary teaching patterns influence the studying and teaching of linear programming?

### 1.5 Dissertation Outline

This dissertation has six chapters. This first chapter presented the aims and the rationale for the research, as well as the questions that the research will attempt to answer.

In the next chapter, a literature review is presented with the aim of providing a better picture into the past research work in the teaching and learning of linear programming as well as research into the comparison of teaching in various disciplines. Further, methodological tools such as the approaches to teaching inventory (ATI) and approaches to study inventory (ASI) are discussed.

The third chapter discusses the methods and seeks to justify and explain the research design implemented. Ethical considerations for participants are also explained here. In Chapter 4, the pertinent results and analysis along with justification for coding are presented.

Chapter 5 seeks to discuss, interpret and summarize the data presented in Chapter 4. The concluding chapter, Chapter 6, reflects on the findings and limitations of this study as well as offer recommendations for future research.
Chapter 2. Literature Review

2.1 Introduction

Although there has been limited research into linear programming teaching, there are a few key studies that shaped this study’s objectives, particularly that of Albritton et al (2003). This chapter begins by discussing their findings and other smaller studies. These studies have predominantly been within the business discipline. Further discussions are made on the possibilities of what these findings might imply in other contexts. Also, as the use of linear programming software is contained in three of the research questions (see Section 1.4), the next part of the chapter will elaborate on current linear programming software usage and trends. Following this section, questionnaire inventories for testing teaching and studying patterns are reviewed as well as the results attained across disciplines for various studies.

2.2 Linear Programming Studies

2.2.1 Linear Programming in Business Studies

In 1997, Jordan et al presented to INFORMS their Magnanti report which investigated how influential MS/ OR was in US Master of Business Administration (MBA) programmes. They found that the MS/ OR had a shrunken presence in the MBAs and ascribed this to MS/ OR no longer being a requirement in the Association to Advance Collegiate Schools of Business (AACSB) accredited MBAs. Following this study, Albritton et al (2003) decided to delve further into the AACSB MBAs’ MS/ OR curricula.
Their study constructed a sample by examining AACSB-accredited MBA websites from which they collected 693 email addresses based on the lecturer’s MS/ OR teaching vitae. Using a web survey, they obtained an 18% response rate (126 responses) which was similar to the 14% (306 responses) response rate received by Jordan et al (1997) using their INFORMS membership list. The key aspects that Albritton et al were looking at was the coverage and degree of coverage in the teaching of MS/ OR topics. They explained that ‘coverage’ referred to whether a topic was taught, whilst the degree of coverage indicated to what extent a topic was taught. This was measured using a 7 point Likert scale, where 1 represented ‘no coverage’ and 7 represented ‘extensive coverage’. If the response was 2 and above, the topic was considered as covered. The exact value of the response was referred to the degree of coverage or the intensity that the topic was covered.

A break-down of the linear programming areas (see Table 1), demonstrated that courses were primarily concerned with the formulation of the linear programming model, the interpretation of the sensitivity results and solving linear programming models by the graphical method.

<table>
<thead>
<tr>
<th>Sub-Areas</th>
<th>Percentage of Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulation</td>
<td>91%</td>
</tr>
<tr>
<td>Sensitivity analysis</td>
<td>83%</td>
</tr>
<tr>
<td>Graphical method</td>
<td>79%</td>
</tr>
<tr>
<td>Spreadsheets for modelling</td>
<td>76%</td>
</tr>
<tr>
<td>Commercial software for modelling</td>
<td>34%</td>
</tr>
<tr>
<td>Dual solutions/duality</td>
<td>33%</td>
</tr>
<tr>
<td>Simplex method (manual)</td>
<td>19%</td>
</tr>
<tr>
<td>Parametric programming</td>
<td>18%</td>
</tr>
</tbody>
</table>

Adapted from Albritton et al (2003)
The results suggested that intensive mathematical areas (such as for simplex and parametric algorithms) were not requirements in these linear programming courses. Perhaps the reason for this is the lack of mathematical background of business students (Grossman, 2001). This suggestion is corroborated by the Magnanti report (Jordan et al, 1997) which reported that 77% of the lecturers thought the mathematical background of students was one of the largest problems associated with MS/OR learning. The Magnanti report also indicated that 53% of the lecturers in 1996 were already considering placing more emphasis on modelling and less on algorithms. This, perhaps, can also explain the low coverage of the mathematical topics such as algorithms in Albritton et al (2003) study.

There is evidence that in Britain, some universities, such as Warwick University, have already shifted away from mathematically intensive MBA programmes to ones which emphasize modelling (Robinson, Meadows, Mingers, O'Brien, Shale and Stray, 2003). The current trends in other disciplines such as engineering or mathematics are not available for the UK, USA or any other country. As these are traditionally mathematically intensive disciplines, it will be interesting to know whether they have maintained the mathematical components of linear programming.

Moreover, the extent to which the knowledge of linear programming algorithms will be requirements in engineering and mathematical courses, when computers can easily calculate these values is unknown. In the US MBAs, Albritton et al (2003) found that 88% of the lecturers were using computers during the teaching of linear programming. Perhaps the low coverage of actual mathematics behind the algorithms
may be due to the replacement of the mathematical workings by computers (Table 1, p. 7).

Albritton et al (2003) examined two main types of software used during the teaching of linear programming. Of the two types of software, dedicated linear programming software (34%) was used the least compared to spreadsheet software (76%). Further, they recorded spreadsheet modelling as the area with the highest degree of coverage excepting formulation of the linear programming problem (see Table 2).

<table>
<thead>
<tr>
<th>Sub–Areas</th>
<th>Mean Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulation</td>
<td>5.25</td>
</tr>
<tr>
<td>Spreadsheets for modelling</td>
<td>4.45</td>
</tr>
<tr>
<td>Sensitivity analysis</td>
<td>4.21</td>
</tr>
<tr>
<td>Graphical method</td>
<td>3.21</td>
</tr>
<tr>
<td>Commercial software for modelling</td>
<td>2.42</td>
</tr>
<tr>
<td>Dual solutions/duality</td>
<td>1.84</td>
</tr>
<tr>
<td>Parametric programming</td>
<td>1.45</td>
</tr>
<tr>
<td>Simplex method (manual)</td>
<td>1.44</td>
</tr>
</tbody>
</table>

Adapted from Albritton et al (2003)

The high concentration on spreadsheets is perhaps because some lecturers may have heeded the recommendations made by the Magnanti report to use spreadsheets as a ‘delivery vehicle’ for MS/ OR algorithms. However, to ascertain whether the pattern can be attributed to the Magnanti report, the pattern for the extent of software usage and the current software employed (such as spreadsheets or specialized software) for teaching LP sub-topics should be examined for other disciplines and countries.
2.2.2 Linear Programming in Other Disciplines

In another linear programming study, Kros and Polito (2003) examined 77 MS/OR courses through the internet in the business, science, engineering and independent disciplines. In their study, the science discipline also included mathematics and statistics whilst the independent disciplines were considered as entities that offered the MS/OR independently of a college, school or department. Kros and Polito counted the occurrence of MS/OR topics in the description of the courses. These topics were grouped similarly to a study carried out by Harpell et al (1989) such as statistics, linear programming, optimization, decision theory and so on. Kros and Polito (2003) found that 47% of the courses examined taught linear programming (see Table 3).

<table>
<thead>
<tr>
<th>Academic Category</th>
<th>No. of courses</th>
<th>% of courses teaching LP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All MS/OR</td>
<td>Teaching LP</td>
</tr>
<tr>
<td>Schools of Business</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>Schools of Engineering</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Colleges of Science</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Independents</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>77</td>
<td>36</td>
</tr>
</tbody>
</table>

Adapted from Kros and Polito (2003)

They found that only 48% of the business courses contained linear programming which is almost half that found by Albritton et al (2003). Possibly, this is because Albritton et al (2003) considered only AACSB accredited MBA courses. In an earlier survey, Gallagher (1991) found that 86% of the MBA’s MS/OR courses covered linear programming. Of these MBA courses, 81% were AACSB accredited and it is likely that most AACSB MBA MS/OR courses include linear programming.
An interesting finding from Kros and Polito (2003) is that there was a better likelihood of finding linear programming in the MS/ OR courses from colleges of science (63%) and independent schools (63%) than the business (37%) and engineering (48%) schools. These values may have been influenced by the small number of courses found containing linear programming in the science and independent schools. However, the results do provide some indication which disciplines will have more courses teaching linear programming in other countries.

Interestingly, Kros and Polito (2003) found that 34% of the MS/ OR courses covered optimisation which were mainly within the science and engineering schools. Linear programming is often classified as a sub-topic of optimisation. Further, in the Harpell et al (1989)’s classification scheme used by Kros and Polito, Harpell et al explained that their groupings of the MS/ OR topics were based on what lecturers called the topics and hence the groupings were not mutually exclusive. Since Kros and Polito (2003) used an online examination of courses, it is likely that courses did not state explicitly that they taught linear programming. Instead, linear programming may have been incorporated into a larger heading such as optimisation. Hence, there is a possibility that the percentage of courses teaching linear programming might be higher than recorded if the courses teaching optimisation did in fact have a linear programming component.

2.2.3 Teaching with Linear Programming Software

There are a number of software packages that is used during the coverage of linear programming. In fact, software packages used in teaching mathematics have been around since the 1980s which have often been in the form of computer algebra systems
or CAS (Mitic and Thomas, 1994). Recent studies have focussed into how students learn using CAS (e.g. Dana-Picard and Steiner, 2004; Heid and Edwards, 2001; Pierce and Stacey, 2001; 2002; 2004; Whiteman and Nygren, 2000). There are a number of advantages and disadvantages in using these mathematical software packages for teaching and learning. Table 4 illustrates the advantages and disadvantages of CAS as summarized by Whiteman and Nygren (2000).

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reduce arduous computations</td>
<td>1. Black-box effect – accepting what is given</td>
</tr>
<tr>
<td>2. Allows analysis of complex problems with realistic values – enhances relevancy and motivation for learning</td>
<td>2. Solving problems through trial and error – focus should be on the fundamentals rather than software technique</td>
</tr>
<tr>
<td>3. Encourages validation i.e. verification and sanity checks</td>
<td>3. Require additional time and resources to learn software</td>
</tr>
<tr>
<td>4. Encourages thinking and writing in symbols</td>
<td>4. Boring the student with laborious computer demonstrations/ presentations</td>
</tr>
<tr>
<td>5. Allows more time for problem analysis and definition</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Whiteman and Nygren (2000)

One of the disadvantages of CAS as seen by Whiteman and Nygren is that it employs the black-box approach. The black-box approach, using a linear programming example, will mean that students after formulating the problem can enter the coefficient values into the software which then generates the answer. The opposite of this teaching approach is sometimes called white-box (Kutzler, 1996). One of the contentions surrounding software using the black-box approach is that it does not allow the student to understand the phenomena on how the solution is generated. Hence the fear is that students who are subjected to the black-box software packages may work towards getting the final answer through trial and error and may result in overlooking the theory (Whiteman and Nygren, 2000) and also in diminishing the students’ mathematical skills (Hornaes and Royrvik, 2000).
Depending on the aims and objectives of a discipline or a course this behaviour may prove detrimental or useful. For example, in the engineering and business disciplines, where the emphasis is on application, the removal of repetition and drudgery of calculations may allow students to focus on more important aspects of their studies. Therefore, these students may then have more time to concentrate on understanding and applying concepts to more complex and realistic problems (Adams and Fernand, 1995; Hornaes and Royrvik, 2000; Whiteman and Nygren, 2000). However, in the mathematical disciplines where the emphasis is on theory which is needed for higher level courses, software usage without enlightenment of the theory as in a white-box approach may leave the student at a disadvantage.

However, Macintyre (2000) explains that teachers may combine using black-box software with a white-box teaching approach. If the black-box software is used firstly then through trial and error, students may be able to get a feel for how the black-box might be operating, which can then be followed up by the white-box teaching approach to confirm students’ speculations. In this way the software is being used as an explorative tool (Macintyre, 2000). Conversely when the white-box teaching approach is used first, students acquire an understanding of the theory and then when using the black-box software can understand the reasoning behind the results. Another method he indicated is that teachers may use software that shows the solving of the solution step by step. Heid and Edwards (2001) takes this to mean an intermediate strategy between using black-box software and white-box teaching approach. However, García, García, Galiano, Prieto, Domínguez and Cielos (2005) refers to software of this type as white-box software.
Of which of the three methods that are used in linear programming education is not certain. In 1998, Mitchell advocated that linear programming software should be used as a tool for checking homework problems, illustrating more realistic and complex problems and engaging students in their own exploration and discovery. These reasons are similar to CAS in other mathematical topics (e.g. Dana-Picard and Steiner, 2004; Hornaes and Royrvik, 2004). These proposals seem to reflect a combination of using the black-box software with white-box teaching approaches. However, Mitchell (1998) goes on to say that linear programming software should also be interactive, allow rational arithmetic and permit the student to decide how to complete the simplex algorithm as well as have the opportunity to perform the elementary row operations. This certainly appears to be a recommendation for white-box software.

Software packages for solving linear programming have come in three main forms: spreadsheets, dedicated linear programming software, and CAS/ or mathematical software (Powell, 1997; Winston, 1996). Spreadsheets appear to be a black-box software package and can provide some amount of interaction and exploration. The spreadsheets do not, for example, allow the student to decide how to complete the simplex algorithm (the white-box approach); but it does allow the testing of different solutions through the inputting of different numbers.

However, lecturers can choose to mix the black-box approach of the spreadsheets with that of the white-box teaching approach to promote interaction and exploration. Winston (1996) suggests in the case of business students where algorithms are not taught, spreadsheets are sufficient. This means for business students, the white-box software and white-box teaching approach may not be necessary. On the other hand, he
advocates that quantitative students such as in engineering and mathematics should use dedicated linear programming software. This perhaps means that these students will be taught using a white-box approach and maybe with white-box software. If this suggestion is heeded by lecturers in engineering and mathematics, one should expect that in these disciplines the students will have more interaction with the software for learning the linear programming topic than in the business disciplines.

2.3 Approaches to Teaching Across Disciplines

Although, the white-box and black-box approaches were used in reference to the teaching of mathematical topics, Trigwell, Prosser and Waterhouse (1999) have noted five general approaches to teaching that a lecturer may employ (see Table 5).

Table 5: The five general qualitative teaching approaches

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Intention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-focused</td>
<td>Transmitting information to students</td>
</tr>
<tr>
<td>Teacher-focused</td>
<td>Students acquire the concepts of the discipline</td>
</tr>
<tr>
<td>Teacher/student interaction</td>
<td>Students acquire the concepts of the discipline</td>
</tr>
<tr>
<td>Student-focused</td>
<td>Students developing their conceptions</td>
</tr>
<tr>
<td>Student-focused</td>
<td>Students changing their conceptions</td>
</tr>
</tbody>
</table>

From Trigwell et al (1999)

Trigwell et al (1999) explains that in these teaching approaches there exists a continuum in which a teacher can occupy two extremes from either being more teacher oriented/ focused to being more student oriented/ focused. Prosser and Trigwell (1999) noted that a teacher’s approach is dependent on their conception of teaching. They indicated that there were two types of conceptions: a) information transmission which is related to being teacher-oriented and b) conceptual change related to being student-oriented. From using these conceptions and orientations, Prosser and Trigwell (1999)
were able to develop the approaches to teaching inventory (ATI). By answering the ATI, a teacher will receive a score on their tendency of being student-focussed and teacher-focussed.

However, a number of criticisms have been levelled at the ATI, most recently from Meyer and Eley (2005). They explain that the ATI has had the default status of the instrument for measuring approaches to teaching without any independent scrutiny. Indeed, Meyer and Eley may have sufficient cause for this statement as they went on to state their scepticism of Prosser and Trigwell’s ability to find a number of approaches and conceptions from 24 interview transcripts. Meyer and Eley hinted that perhaps the categories were developed too early and were possibly susceptible to the ‘pre-ordaining’ effect that Kember (1997) eluded to. Further, there have been some ambiguity in the definition and use of terms such as approaches and conceptions in the literature (Kember, 1997). This perhaps has led Meyer and Eley (2005) to speculate whether Prosser and Trigwell’s two entities of conception and teaching are truly different since Meyer and Eley considered them so “semantically similar” and possibly “just different labels for the same thing”.

Interestingly, Kember and Gow (1994) also observed two conceptions through interviews of lecturers which appeared to measure the same concepts as proposed by Prosser and Trigwell. These orientations they called knowledge transmission and learning facilitation. The former can be associated with a teacher-oriented approach whilst the latter with a student-oriented approach. Unlike Prosser and Trigwell’s ATI, Kember (1997) pointed out that the category conceptions emerged using a grounded theory approach and hence were not pre-ordained. Using this data, Kember and Gow
(1994) developed a questionnaire to test these conceptions and approaches called the “teaching orientation questionnaire”. Whether this questionnaire can sustain the same independent scrutiny as the ATI is also not known. The teaching orientation questionnaire, however, has the added advantage over the ATI, in that it contained subscales for its two conceptions (see Table 6).

Table 6: Scales for the two orientations of teaching

<table>
<thead>
<tr>
<th>Learning facilitation</th>
<th>Knowledge transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving</td>
<td>Training for specific jobs</td>
</tr>
<tr>
<td>More interactive teaching</td>
<td>Greater use of media</td>
</tr>
<tr>
<td>Facilitative teaching</td>
<td>Imparting information</td>
</tr>
<tr>
<td>Pastoral interest</td>
<td>Knowledge of subject</td>
</tr>
<tr>
<td>Motivator of students</td>
<td></td>
</tr>
</tbody>
</table>

From Norton et al (2005)

Whilst the ATI was targeted at the course level, the teaching orientation questionnaire was developed for use at the departmental level. Norton et al (2005) however modified the teaching orientation question to be representative of the course by changing half of the items on the original questionnaire, so that the questionnaire reflected the approaches to teaching of teachers by looking at their intentions and beliefs which is different to the ATI which sought to represent strategies and intentions of the teachers.

Although, the ATI has found widespread employment in several disciplines including social sciences, sciences, humanities and law (Meyer and Eley, 2005) and countries such as the UK and Finland (e.g. Lindblom-Ylänne et al, 2005; Lueddeke, 2003) there has been limited work into comparing the ‘approaches to teaching’ across disciplines. Considering that Prosser and Trigwell’s original work was conducted by interviewing Australian university lecturers in the sciences, the question rightly arises
whether there has been sufficient evidence to warrant a cross-over not only to different countries but to disciplines as well. Even so, until there is an independent scrutiny that the ATI cannot stand up to, researchers will continue using the ATI in various contexts.

In one of these contexts where ATI research has recently been used is in comparing ATI scores across disciplines such as by Lueddeke (2003). In his research, Lueddeke sought to compare ATI scores across disciplines using Biglan (1973)’s disciplines classification of “soft disciplines” such as the social sciences and “hard disciplines” such as the natural sciences. In Lueddeke (2003)’s ATI survey of 300 teaching staff in business (soft), technology (hard) and social sciences (soft), he found that the hard disciplines had higher teacher-focused (TF) scores than the soft disciplines’ TF score. On the other hand, the soft disciplines’ student-focused (SF) scores were higher than the SF scores for the hard disciplines (see Table 7). These results implied that the hard-disciplines were more likely to employ a teacher-focused strategy whilst the soft disciplines were more likely to employ a student-focused strategy.

<table>
<thead>
<tr>
<th></th>
<th>Business (n=41)</th>
<th>Technology (n=48)</th>
<th>Social Science (n=46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TF</td>
<td>17.5</td>
<td>TF</td>
<td>TF</td>
</tr>
<tr>
<td>SF</td>
<td>82.5</td>
<td>SF</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>43.5</td>
<td></td>
<td>56.5</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td></td>
<td>76</td>
</tr>
</tbody>
</table>

This is similar to results found by Trigwell (2002)’s study that he conducted between design and technology teachers using the ATI. He found that the technology teachers (hard disciplines) had higher teacher focussed scores than the design teachers (soft discipline).
Following Lueddeke (2003)’s study, Lindblom-Ylänne et al (2005) went further into subdividing the disciplines into Biglan (1973)’s four groupings. These four groupings are based on the paradigm of the discipline that is whether it is a hard or soft disciplines and whether the discipline deals with subjects in the pure form such as mathematics or the applied form such as engineering. Thus the four groupings they used were hard-pure, soft-pure, hard-applied and soft-applied disciplines. They found similar results to that of Lueddeke (2003), in that soft-pure and soft-applied disciplines had higher student-focussed scores than than the hard-pure and hard-applied disciplines. On the other hand, the hard-pure and hard-applied disciplines scored higher on the teacher-focussed scales than the soft-pure and soft-applied disciplines. It will be interesting whether such variation will appear when comparing lecturer’s approaches to teaching of linear programming across the disciplines.

2.4 Approaches to Study Across Disciplines

Studies using the ATI and teaching orientation questionnaire along with “approaches to study” questionnaires such as the study process questionnaire (SPQ) and the approaches to studying inventory (ASI) have found that relationships exist between the “approaches to teaching” and the “approaches to study” (Prosser and Trigwell, 1999).

Before looking at the relationships, the ASI questionnaire is described briefly. Both the ASI and SPQ questionnaires aim at identifying the approaches to studying. The ASI latest version is the Approaches and Study Skills Inventory for Students (ASSIST) which identifies three approaches to studying by the student: the deep, surface and
strategic (Entwistle, Tait and McCune, 2000). Richardson (2005) defines the deep approach or meaning orientation as “based upon understanding the meaning of course materials”, the surface approach or reproducing orientation as “based upon memorising course materials for the purposes of assessment” and the strategic approach or achieving orientation as “based upon obtaining the highest grades”. Each of these orientations has a number of subscales associated with them to give an overall score to which orientation a student may occupy (see Table 8).

<table>
<thead>
<tr>
<th>Subscales of the three studying approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deep Approach</strong></td>
</tr>
<tr>
<td>Seeking meaning</td>
</tr>
<tr>
<td>Relating ideas</td>
</tr>
<tr>
<td>Use of evidence</td>
</tr>
<tr>
<td>Interest in ideas</td>
</tr>
<tr>
<td>Achieving</td>
</tr>
</tbody>
</table>

From Richardson (2005)

It has been found that student-focused teaching tends to be related to a deep approach to studying whilst a teacher-focussed approach relates to a surface approach (Prosser and Trigwell, 1999). It is, therefore, not surprising that ASI results when comparing across disciplines seem to mirror the results from ATI, that is, in hard disciplines students tended to have a surface study approach whilst in the soft disciplines had a deep study approach. Ramsden and Entwistle’s study in 1981 found these similar results between arts and science students (Lawless and Richardson, 2002). Similar results were also found by Lawless and Richardson (2002) in distance learning students, that is the soft disciplines promoted a deep approach whilst the hard disciplines a surface approach. Lawless and Richardson (2002) were only able to compare across six courses, so the extent to which their results are generalizable is not certain.
However, examining the scores from a study by Thang (2005) between the social sciences (soft-applied), applied sciences (hard-applied) and business administration (soft-applied) in Malaysian universities suggested that there may not be much of a difference between these three disciplines in terms of approaches to study. This may be something that is intrinsic to the Malaysian university or may suggest that the hard-applied disciplines are closer to that of the soft-applied disciplines. Further, work has to be continued to determine whether this is replicable for different university contexts and for a larger range of disciplines. It can also be that the ASI is not a “psychometric valid questionnaire” and possibly does not “measure conceptions but only what students say in response to questionnaire items” (Haggis, 2003) and may also require further scrutiny.

2.5 Concluding Remarks

Through the examination of linear programming in several disciplines, the literature review have found that although there has been a shrunken presence of linear programming within MS/ OR courses, the topic continues to grown in other subjects across a variety of disciplines. Further examination suggests there maybe lower coverage of linear programming’s mathematical topics within the business disciplines and research should focus on whether this trend will hold for the engineering and mathematical disciplines. Also that perhaps the engineering and business disciplines would focus more on the application side of linear programming such as formulating the problem and exploring the sensitivity analysis.

Literature also indicated that perhaps the low coverage of mathematics in the business discipline is due to the computer replacement of mathematical procedures.
Whether there is more computer usage in this discipline than in others has to be ascertained. However, it is likely in business disciplines the replacement is occurring through the use of spreadsheets (black-box software) whilst in the engineering and mathematical disciplines with specialised linear programming software packages (black box or white-box software).

Further, it is possible that in the business and engineering disciplines where the emphasis is on application that during the coverage of a course there may be less interaction with the software and hence the business discipline may be more likely to employ a black-box approach whilst the engineering possibly a mixture of the black-box and white-box approaches.

The recent research into the different approaches of teaching in various disciplines indicates that soft disciplines such as the social sciences tend to score higher scores on the student focussed scale than the hard disciplines such as the natural sciences and in the opposite manner for the teacher-focussed scale. Thus, because linear programming is taught in several disciplines, it provides a unique opportunity to study how different disciplines may approach teaching and studying the same topic from different perspectives. Probably, from knowing how different disciplines teach or learn through examining an area common to all of them, it will be possible to determine the varying objectives of disciplines such as what they expect their students to learn as well as what skills the student’s are expected to acquire.
Chapter 3.   Choice of Research Design and Methods

3.1 Introduction

This chapter outlines the research method that was undertaken for the research to meet the aims and objectives. The chapter first focuses on the research method employed which is followed by a description of the research design and the approach for analysing data.

3.2 Research Method

3.2.1 Rationale for the Approach

One of the challenges of this research was determining what lecturers teach and how they teach with respect to linear programming. Further, as there was limited research into linear programming particularly into its sub-topics, a questionnaire was devised. A survey was thought the best method for carrying out this research rather than doing an alternative qualitative or quantitative research as the questionnaire will provide a good indication of how lecturers from different disciplines teach and hence to some extent generalizations can be made.

This research could have been though an ethnographic method such as observing teachers in the classrooms for the various disciplines to understand their pedagogical methods or perhaps using a quasi-experiment to see how teachers approach teaching one particular linear programming sub-topic. However, since there was a lack of quantitative evidence for teaching linear programming, excepting for Albritton et al (2003), a survey
would have provided a snap shot of the state of the teaching of linear programming from which areas of interest could be further followed up with qualitative analysis to obtain a richer account of the linear programming teaching process. Besides, comparing countries is possibly more efficient this way and also there are minimal access issues.

3.2.2 Questionnaire Design

As part of this research seeks to compare results across various disciplines, the first part of the linear programming questionnaire contained such general questions as the discipline to which the lecturer belong and the software they were most likely to employ (see Appendix 1, p. 66). These general questions led to the more important part of the questionnaire where data was collected to try an answer the first 4 specific research questions (Section 1.4, p. 4). One of the specific research questions was determining the extent of coverage of linear programming in the sub-topics for the various disciplines and countries. The manner in how data is collected to support this research question is discussed further below.

Following Albritton et al (2003) and Winston (1994), three main sub-topics were identified. These were the formulation of the problem, the solution of the problem by four methods (namely, graphical method, simplex algorithm, revised simplex algorithm and interior point method), and the sensitivity analysis using both the computer printout and graphical method. Following Albritton et al, the degree of coverage, that is the intensity, was investigating using a 5 point scale.
Although, Albritton et al (2003) had used a 7 point scale, a 5 point scale was adopted to keep regularity with the 5 point “approaches to teaching” scales sent also to the lecturer and hence minimize confusion. This scale usage does provide a problem in comparing findings, however, Albritton et al results can be rescaled to that of this study. Further, the first four points ran from no coverage to extensive coverage. The last point on the scale was given the label ‘not sure’ to avoid ‘fence sitting’ by the respondent in choosing their degree of coverage (see Figure 1).

Figure 1: Example of a coverage question

<table>
<thead>
<tr>
<th>When teaching linear programming, to what extent do you cover problem/model formulation?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Further, another 5 point scale was devised to measure how and for what sub-topics software was used, the method of delivery for each of the sub-topics and the extent that linear programming software was used during coverage (see Figure 2).

Figure 2: Example of a method of delivery question

<table>
<thead>
<tr>
<th>How do you deliver the problem/model formulation section?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

This data along with the type of software employed by the lecturer provided the evidence for how linear programming software usage and extent of usage vary across disciplines.
Further, to gauge how the course teaches students to interact with software during coverage of the solutions, software interaction questions were asked for the simplex/revised simplex method, the graphical method, and the interior point method (see Figure 3).

**Figure 3: Questions for the interaction of software during coverage of the solutions**

| For the following list, indicate how are students taught to interact with the software during the iterations? (Tick all that apply) |
|------------------|------------------|
| **Simplex and Revised Simplex Algorithm:** | |
| ( ) Choosing the entering basic variable/entering column | |
| ( ) Calculating the ratio | |
| ( ) Choosing the pivot row/equation | |
| ( ) Choosing the value(s) to perform the elementary row operations | |
| ( ) Deciding when the algorithm has come to an end | |
| ( ) Don’t interact with the computer directly | |
| **Graphical Method** | |
| ( ) Graph the constraints and objective function | |
| ( ) Exploring various solutions by changing the constraints or objective function | |
| ( ) Don’t interact with the computer directly | |
| **Interior Point/Primal Dual Method** | |
| ( ) Forming the dual problem (primal-dual method) | |
| ( ) Finding the transpose (primal-dual method) | |
| ( ) Don’t interact with the computer directly | |

Also, to understand how important mathematical theory is to the linear programming, the sensitivity analysis sub-topic was explored to see where mathematical steps were needed to be calculated (see Figure 4).

**Figure 4: Questions for mathematical steps for the sensitivity analysis**

| For the following list, indicate what students are taught to find with respect to the sensitivity analysis (Tick all that apply) |
|------------------|------------------|
| The optimal range of the objective variables coefficients | ( ) | ( ) |
| The reduced cost of the objective variables coefficients | ( ) | ( ) |
| The optimal range of the right hand side (RHS) of the constraints | ( ) | ( ) |
| The dual price for the RHS constraints | ( ) | ( ) |
To explore teaching patterns within the disciplines, the approaches to teaching questionnaire developed by Norton et al (2005) was used as opposed to the Trigwell et al (1999)’s ATI. Although, there was a disadvantage of using Norton et al’s questionnaire in that there has not been sufficient validation of it by other researchers, it was felt that Norton et al’s questionnaire would allow further comparison of the disciplines on the subscales of learning facilitation and knowledge transmission. Both the linear programming questionnaire and the approaches to teaching questionnaire can be found in Appendix 1 (p. 66).

In relation to the students’ “approaches to study”, the ASSIST questionnaire (see Appendix 2, p. 79) was chosen to be administered to students as it not only provided information on the approaches to studying, but also how students evaluated the course, the preferences to their learning environments and how they prefer the course to be covered (Entwistle et al, 2000), and this may prove useful if further data was needed to differentiate the disciplines in which they study.

### 3.3 Research Design

The “approaches to teaching” and linear programming questionnaire was sent to lecturers from four different countries: Australia, New Zealand, UK and USA. These countries were chosen because they were English speaking and were more likely to have a number of universities which taught linear programming because of their population size. Since there is no known list of lecturers teaching linear programming in these countries, lists of lecturers’ email addresses were obtained through searching a popular search engine using the key words of linear programming filtered for by university
websites, that is for example web addresses whose main site ends in .ac.uk for the UK and .edu for USA. If lists of lecturers from MS/ OR courses were used, there will be no guarantee that these lecturers taught linear programming. The linear programming lecturer samples aimed only to be indicative for this pilot study, and hence a cut off mark of 100 email addresses was established. This number was exhaustive for both Australia and New Zealand.

The Norton et al’s approaches to teaching and the developed linear programming questionnaires were sent to these university lecturers via a URL (Uniform Resource Locator) through an email where each country had a specific URL. An email method was chosen as this ensured that lecturers will receive it in time before the term closed. Further, because the survey was sent electronically to Australia, New Zealand and USA, this allowed the costs to be lower and ensure a faster acquisition of data (Dommeyer, Baum, Hanna and Chapman, 2004; Paolo, Bonaminio, Gibson, Partridge and Kallail, 2000). Also, data could be directly stored in a database and hence minimize inputting errors and increase reliability of the data input. The email method also meant that any queries from lecturers could be dealt with promptly.

Lecturers who filled in the approaches to teaching questionnaire were asked if they would distribute ASISST questionnaires to their students. In return, a summary of their student results were promised. The ASSIST questionnaire was originally to be sent by mail to the lecturers who would then distribute the questionnaires to their students. For this reason, only UK lecturers were chosen in order to minimize cost and have a quick turn around of response. However, lecturers found that it was impossible to distribute the questionnaire as some had finished teaching about a month previously. As
such, an alternative method was considered for delivering the ASSIST questionnaire and this was to upload it to the web. Lecturers were then able to forward the questionnaire through their own specifically created URL to their students. This ensured that anonymity of students was maintained. However, follow-up questions or clarification of questions could not be made because of this.

### 3.4 Analysis of Data

A large portion of the data that was collected was measured on the 5 point Likert scales. The 5 point scales do not have enough intervals to be considered as continuous (Wyrwich and Tarindo, 2004), and hence most of the data analysis was done through the grouping of answers by frequencies and employing non-parametric tests such as the chi-square analysis which would not have been appropriate if they were continuous variables.

Also, the sample size was not sufficient to ensure that there were sufficient representations of frequencies for all disciplines. As such, the study grouped disciplines according to the Biglan (1973) framework that both Lindblom-Ylänne et al. (2005) and Lueddeke (2003) employed in their analysis across disciplines. Using the Biglan framework, the disciplines were classified according to the discipline paradigm (hard or soft) and discipline application (pure or applied). Biglan (1973) other discipline classification of life or non-life was not included as there were not sufficient counts. Using the discipline paradigm and classification, only three types of disciplines were found: the hard-pure which contained mainly the mathematical disciplines, the hard-applied which contained disciplines in engineering, computer science and agriculture,
and lastly the soft-applied which contained the disciplines of business, management and economics.

Although there has been some controversy into whether computer science is a hard-applied or hard-pure discipline (Clark, 2003), computer science was still classified into hard-applied. The first reason for this is that this was the original classification of used by Biglan and secondly, it was felt that computer science was still “geared towards products and techniques” rather than having “a cumulative, ..., simplification and quantitative emphasis” (Neumann, Parry and Becher, 2002) as it is still a young discipline. Further, since the data was classified using Biglan (1973) framework, this meant that results could be now compared with the approaches to teaching results found by Lindblom-Ylänne et al (2005) and Lueddeke (2003).

### 3.5 Ethical Considerations

As a survey was conducted, the main ethical considerations were ensuring the confidentiality of the responses made by the lecturers. As such, the lists of their names and data were only handled by the researcher and survey office team that were dedicated to this project. To ensure the anonymity and confidentiality of the student responses, the students first contact point was their lecturer. The researcher had no direct access to the students, unless the students chose to contact the survey team/ the researcher. Further, summary results from the ASSIST questionnaire were only promised to lecturers if only the results were sufficient to ensure that persons could not determine which student, lecturer or university provided which results.
Chapter 4. Data Collection and Analysis

4.1 Introduction

This chapter seeks to illustrate how linear programming is taught in universities across disciplines based on the Biglan (1973) disciplinary classification. The data was collected in four English-speaking countries namely Australia, New Zealand, UK and USA and the three disciplines of hard-pure, hard-applied and soft-applied. The coverage of various linear programming and their intensity are discussed as well as the extent to which software is employed for teaching.

4.2 Response Rate

The purpose of this study was to understand the state of linear programming teaching. A linear programming and an “approaches to teaching” questionnaire was sent out to 311 lecturers in 4 countries, from which 85 persons responded. Even though, eight of these persons were no longer teaching linear programming and declined to fill in the questionnaire, the response rate was calculated as the ratio of the number of respondents teaching linear programming and the number of questionnaires sent. The details of the countries and response rate are presented in Table 9.

<table>
<thead>
<tr>
<th>Country</th>
<th>Sent</th>
<th>Teaching LP</th>
<th>Not Teaching LP</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>68</td>
<td>12</td>
<td>3</td>
<td>18%</td>
</tr>
<tr>
<td>New Zealand</td>
<td>35</td>
<td>11</td>
<td>1</td>
<td>31%</td>
</tr>
<tr>
<td>UK</td>
<td>103</td>
<td>34</td>
<td>4</td>
<td>33%</td>
</tr>
<tr>
<td>USA</td>
<td>105</td>
<td>20</td>
<td>0</td>
<td>19%</td>
</tr>
<tr>
<td>Total</td>
<td>311</td>
<td>77</td>
<td>8</td>
<td>25%</td>
</tr>
</tbody>
</table>
Recent email surveys have had about 24 to 37% response rates for email questionnaires which compares with 42 to 48% for mailed questionnaires (Dommeyer et al., 2004; Moss and Hendry, 2002; Paolo et al., 2000). Moss and Hendry (2002) reported higher email response rates (> 40%) for email surveys during the late 1980s and early 1990s and have suggested that the high email response rates would have occurred before emails’ increased popularity. As such an overall response rate of 25% seems reasonable; taking into account that unlike other email surveys where respondents are specifically targeted, there was no guarantee that all chosen lecturers were teaching linear programming within the last academic year. This response rate was higher than the 14% in Jordan et al. (1997) and the 18% in Albritton et al. (2003) studies discussed in Section 2.2.1 (p. 6) but the number of respondents was smaller.

Both Australia and USA had almost half the response rate of New Zealand and the UK. The reason for this disparity is unclear. Perhaps, cultural differences may have influenced the response rate in that it is possible that a higher UK response rate is recorded because the research was based in the UK. Further, wording of the questionnaire may have had distinct bias towards a UK-based type of education such as the words of ‘postgraduate’ versus ‘graduate’ (see Appendix 1, p. 66) within the linear programming questionnaire section or the usage of ‘secondary school’ instead of ‘high school’ in the approaches to teaching section of the questionnaire. Additionally, perhaps the overall low response rate may be due to differing pedagogical methods. For example, where there is no fixed lecturer for the linear programming section, but where simultaneous tutorial sessions are run for large classes by teaching assistants. Differences in teaching content from countries may also influence the response rate. For example, in the 9 out of the 10 courses that covered the interior-point solution method all
came from the USA, which made up 45% of all the USA courses (see Table 10). The other course was from Australia.

Table 10: Percentage of courses covering the linear programming sub-topics in the four countries

<table>
<thead>
<tr>
<th>Linear Programming Topics</th>
<th>Australia</th>
<th>N. Zealand</th>
<th>UK</th>
<th>USA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formulation</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Solution</strong></td>
<td>100%</td>
<td>82%</td>
<td>97%</td>
<td>100%</td>
<td>96%</td>
</tr>
<tr>
<td>Graphical Method</td>
<td>83%</td>
<td>82%</td>
<td>88%</td>
<td>95%</td>
<td>88%</td>
</tr>
<tr>
<td>Simplex Method</td>
<td>83%</td>
<td>36%</td>
<td>76%</td>
<td>75%</td>
<td>71%</td>
</tr>
<tr>
<td>Revised Simplex Method</td>
<td>45%</td>
<td>36%</td>
<td>31%</td>
<td>74%</td>
<td>45%</td>
</tr>
<tr>
<td>Interior Point Method</td>
<td>8%</td>
<td>0%</td>
<td>0%</td>
<td>45%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Sensitivity Analysis</strong></td>
<td>83%</td>
<td>91%</td>
<td>85%</td>
<td>85%</td>
<td>86%</td>
</tr>
<tr>
<td>Graphical</td>
<td>83%</td>
<td>64%</td>
<td>74%</td>
<td>75%</td>
<td>74%</td>
</tr>
<tr>
<td>Computer Output/ Printout</td>
<td>73%</td>
<td>91%</td>
<td>61%</td>
<td>80%</td>
<td>72%</td>
</tr>
</tbody>
</table>

* Percentages do not include ‘not sure’ and missing values

Five of the UK lecturers agreed to administer an ASISST questionnaire to their students from which 51 responses were obtained (see Table 11).

Table 11: Number of ASI responses from the students for the 5 lecturers in the UK

<table>
<thead>
<tr>
<th>Lecturer</th>
<th>Total Students</th>
<th>Responses</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52</td>
<td>10</td>
<td>19%</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>1</td>
<td>13%</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>5</td>
<td>19%</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>30</td>
<td>10%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>51</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Missing Data

**4.3 Coverage and Intensity of Linear Programming Sub-Topics**

The degree of coverage, used for determining the extent to which a topic was covered (Section 3.2, p. 23), was coded from 1 to 4 (‘no coverage’ = 1 to ‘extensive coverage’ = 4) similarly to Albritton et al (2003) study (Section 2.2.1, p. 6). Coverage of
a topic therefore occurred if the degree of coverage was more than 1. The intensity was calculated by finding the mean of the degree of coverage.

From this study, there is now additional information on the linear programming sub-topics coverage from the hard disciplines. In particular that a) all disciplines cover the formulation of the solution and sensitivity analysis to the same extent, b) there is more coverage of the solution in the hard-pure and hard-applied disciplines especially in the simplex, revised simplex and interior point method and c) that the hard-applied and the soft-applied disciplines had a higher tendency to teach the sensitivity analysis related to the computer printout/output.

4.3.1 Formulation

In terms of how linear programming was taught, this seems to vary depending on the discipline and the sub-topics of LP. The formulation sub-topic was taught by every respondent in every discipline (see Table 12).

<table>
<thead>
<tr>
<th>LP Topic</th>
<th>Hard-Pure</th>
<th>Hard-Applied</th>
<th>Soft-Applied</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulation</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Solution</td>
<td>100%</td>
<td>100%</td>
<td>77%</td>
<td>96%</td>
</tr>
<tr>
<td>Graphical Method</td>
<td>91%</td>
<td>93%</td>
<td>69%</td>
<td>88%</td>
</tr>
<tr>
<td>Simplex Method</td>
<td>86%</td>
<td>76%</td>
<td>23%</td>
<td>71%</td>
</tr>
<tr>
<td>Revised Simplex Method</td>
<td>52%</td>
<td>59%</td>
<td>0%</td>
<td>45%</td>
</tr>
<tr>
<td>Interior Point Method</td>
<td>9%</td>
<td>24%</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>Sensitivity Analysis</td>
<td>77%</td>
<td>90%</td>
<td>100%</td>
<td>86%</td>
</tr>
<tr>
<td>Graphical</td>
<td>69%</td>
<td>79%</td>
<td>77%</td>
<td>74%</td>
</tr>
<tr>
<td>Computer Printout/ Output</td>
<td>58%</td>
<td>83%</td>
<td>85%</td>
<td>72%</td>
</tr>
</tbody>
</table>
This was an expected trend as formulation is one of fundamental concepts of linear programming. The average coverage intensity of the formulation sub-topic was 3.3 (see Figure 5).

![Formulation Coverage Intensity](image)

**Figure 5: Intensity of teaching the formulation of the linear programming problem**

However, the coverage intensity of the formulation appears to be different depending on the disciplines. The hard-applied (46.4%) and the soft-applied (61.5%) disciplines had a higher percentage in the ‘extensive coverage’ category for the formulation than the hard-pure discipline (29.4%). A chi square analysis shows that, for formulation, there is a significant association between coverage intensity and discipline, $\chi^2 (4) = 10.361, p = 0.035$ (see Annex 1, p. 94). This association supports the initial hypothesis that there may be a higher degree of formulation coverage in the soft-applied disciplines.

The mean intensities of teaching the formulation (see Figure 6) for the disciplines shows that the hard-pure (3.2) and hard-applied (3.2) are both lower than that of the soft-applied disciplines (3.5).
The reason for this disparity in results between the chi-square and the means is that about 25% of the hard-applied courses were in the ‘slightly cover’ category for formulation compared to 9% and 8% for hard-pure and soft-applied disciplines respectively (see Table 13).

Table 13: The extent of coverage for the formulation of linear programming problem

<table>
<thead>
<tr>
<th>Formulation Coverage Intensity</th>
<th>Disciplines</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hard-Pure</td>
<td></td>
</tr>
<tr>
<td>Slight Coverage</td>
<td>9%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(7)</td>
</tr>
<tr>
<td>Some Coverage</td>
<td>62%</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>(21)</td>
<td>(8)</td>
</tr>
<tr>
<td>Extensive Coverage</td>
<td>29%</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(13)</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>(34)</td>
<td>(28)</td>
</tr>
</tbody>
</table>

This suggests there may be differences within the hard-applied disciplines in the teaching of formulation, and perhaps is the result of combining the engineering and computer science disciplines in this category. However, examining the individual results...
shows that there are almost equal amounts of courses in both the engineering and computer science that had slight coverage of the formulation. The results suggest that the applied disciplines perhaps placed more emphasis on the formulation of the problems.

4.3.2 Solution

Linear programming solution was covered in 96% of the courses (Table 12, p. 34). A chi-square analysis of the coverage between the three disciplines reveals that there is a significant association between the disciplines and the solution coverage, $\chi^2(2) = 14.904, p=0.001$ (see Annex 2, p. 94). The soft-applied discipline was the only discipline that did not teach the LP solution methods in all their courses (10 out of 13 courses taught the solution). However, it is difficult to say whether the solution is taught less in the soft-applied courses as the number of business courses is small (13 courses). Nevertheless, considering that in the remaining 62 courses, the respondents made it clear that solution was taught, it may suggest that soft-applied courses may place less emphasis on the teaching of the solution. By examining the overall mean coverage intensities for solution, the soft-applied (2.4) had the smallest mean intensity in comparison to the hard-pure (3.5) and hard-applied (3.6) disciplines (Figure 6, p. 36).

There is a possibility that respondents were influenced by the layout of the questionnaire and could have thought that the solution types stated in the questionnaire (simplex algorithm, graphical method etc) were the only types being considered and courses which taught computer solutions only may have responded as ‘no solution’ taught.
The low importance that soft-applied courses placed on solution is possibly reflected in the coverage of solution types. In all four solution types, that is, graphical method, simplex algorithm, revised simplex algorithm and the interior-point method, the soft-applied courses had either a lower percentage or no courses teaching these methods (see Table 14).

Table 14: Courses covering the various solution methods in the three discipline categories

<table>
<thead>
<tr>
<th>Solution Method</th>
<th>Disciplines</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphical Method</td>
<td>91%</td>
<td>93%</td>
</tr>
<tr>
<td>(32)</td>
<td>(27)</td>
<td>(9)</td>
</tr>
<tr>
<td>Simplex Algorithm</td>
<td>86%</td>
<td>76%</td>
</tr>
<tr>
<td>(30)</td>
<td>(22)</td>
<td>(3)</td>
</tr>
<tr>
<td>Revised Simplex Algorithm</td>
<td>52%</td>
<td>59%</td>
</tr>
<tr>
<td>(16)</td>
<td>(17)</td>
<td>(0)</td>
</tr>
<tr>
<td>Interior Point Method</td>
<td>9%</td>
<td>24%</td>
</tr>
<tr>
<td>(3)</td>
<td>(7)</td>
<td>(0)</td>
</tr>
<tr>
<td>Number of Courses</td>
<td>34</td>
<td>28</td>
</tr>
</tbody>
</table>

Chi square analysis suggests that there is no significant association between the discipline groupings and the graphical method, $\chi^2 (2) = 5.560, p=0.062$ (see Annex 3, p. 95). The coverage percentage of the graphical method, suggests that the hard-pure (91%) and the hard-applied (93%) are similar to each other and higher than the soft-applied (69%) disciplines. Further chi-square analysis, by combining the hard-pure and hard-applied disciplines, to reduce the number of expected variables that are less than 5, indicates that there is indeed a difference between the soft and the hard disciplines, $\chi^2 (1) = 5.517, p=0.019$ (see Annex 4, p. 95). This analysis indicates that lecturers in the hard disciplines are 5 times more likely to teach the graphical method.

Chi-square analysis also implies that there is no significant association between the disciplines and the teaching of the interior-point method, $\chi^2 (2) = 5.444, p=0.066$.
(see Annex 5, p. 96). However, there are a limited number of courses to make this conclusive. Examining the data (Table 14, p. 38), it seems that the hard-pure and hard-applied disciplines are more likely to teach the interior point method, but, generally, most courses (87%) containing linear programming opt to not teach interior point method.

Strong evidence of chi-square associations were also found between the disciplines and the coverage of the simplex algorithm, \( \chi^2 (2) = 18.672, p<0.001 \) (see Annex 6, p. 96) and the revised simplex algorithm, \( \chi^2 (2) = 13.346, p=0.001 \) (see Annex 7, p. 97). Courses teaching these two methods seem to reside mostly in the hard-pure and hard-applied disciplines. The percentage coverage of the revised simplex algorithm were lower than that of the simplex algorithm for the hard-pure (52% vs 86%) and the hard-applied (59% vs 76%) disciplines (Table 14, p. 38).

On examination of how coverage of solutions may vary across countries, the data analysis found that over 80% of all lecturers in the four countries taught the graphical method. However, significant associations were found between the disciplines and in the coverage of the simplex algorithm (\( \chi^2 (3) = 8.009, p=0.046 \)), the revised simplex algorithm (\( \chi^2 (3) = 9.085, p=0.028 \)) and the interior point method (\( \chi^2 (3) = 24.231, p<0.001 \)). For the simplex algorithm, New Zealand (36%) had the lowest coverage of this topic compared to the other countries which had at least 70%. The coverage in USA for both the revised simplex algorithm (74%) and the interior point method (45%) were the highest compared to the other countries which had less than 50% and 8% for the solutions respectively. However, this may be because there were more respondents in the USA from the hard-applied disciplines.
4.3.3 Sensitivity Analysis

Most of the courses (86%) covered some type of sensitivity analysis (Table 12, p. 34). The chi-square analysis of sensitivity coverage and disciplines shows no significant association, $\chi^2(1) = 4.634$, $p=0.099$ (see Annex 8, p. 97). It is difficult to be conclusive, but the data may imply that since all of the soft-applied courses taught some sensitivity analysis versus only 90% of the hard-applied and 77% of the hard-pure disciplines, that the soft-applied may concentrate on this topic more and hence should have higher coverage intensities. However, upon conducting a chi-square analysis for the sensitivity analysis coverage intensity, no conclusive evidence could be found to support this $\chi^2(6) = 8.636$, $p=0.195$ (see Annex 9, p. 98), possibly because 6 cells had expected counts of less than 5. Further examination into the mean intensities (Figure 6, p. 36) suggests that there might be some merit in this supposition, as the soft-applied disciplines had the highest mean intensity (3.4) amongst the hard-applied (3.1) and hard-pure (2.6) disciplines. The high intensity of the hard-applied and the high percentage of the hard-applied courses doing sensitivity analysis, points to perhaps that the applied subjects may have a higher tendency to cover the sensitivity analysis. A chi-square analysis between the pure and applied disciplines, shows that there is a weak evidence of significant association between the applied disciplines and sensitivity analysis, $\chi^2(3) = 7.700$, $p=0.053$ (see Annex 10, p. 98).

Further analysis shows that about 70% of the courses in all three disciplines teach a graphical sensitivity component (see Figure 7).
Over 80% of both the hard-applied and soft-applied disciplines teach the interpretation of computer printout/output sensitivity analysis which is almost the same as the graphical sensitivity component, but just 58% in the hard-pure discipline. Chi-square analysis shows that there is a significant association between the disciplines and the teaching of the computer output/printout sensitivity analysis, \( \chi^2(2) = 6.097, p=0.047 \) (see Annex 11, p. 99). This indicates that the disciplines with an applied component are 1.8 times more likely to teach the computer printout/output sensitivity analysis than the hard-pure discipline.

Examination into how sensitivity analysis varies across countries indicated that there are no significant association between countries and the types of sensitivity analysis. For each country, at least 80% of the courses taught some type of sensitivity analysis. Most countries covered graphical and the computer printout/output sensitivity analysis almost equally excepting New Zealand which had only 64% of its courses.
covering graphical sensitivity analysis but 91% covering the computer output/ printout sensitivity analysis.

The sensitivity analysis topic was also used to test the extent of mathematical steps used in the various disciplines (see Section 3.2, p. 23). For each mathematical step, a point of 1 was scored if the mathematical step was covered and 0 otherwise. In terms of the mathematical content used in the sensitivity analysis, there appears to be no difference between the disciplines, that is over 70% of the disciplines do some mathematical calculation for the graphical sensitivity analysis and 90% for the computer printout/ output sensitivity analysis.

4.4 Software Usage in Linear Programming Sub-Topics

The variation of teaching of linear programming in various disciplines was further explored through looking at the extent of software usage in teaching linear programming overall.

4.4.1 Types of Software

The types of software in use were partitioned into four groups, namely, spreadsheets, linear programming software, mathematical programming software and other types of software. Spreadsheet software included the use of any spreadsheet including Excel and any of its add-ins such as Solver, What If and What’s Best. Linear programming software were considered software that was dedicated to linear programming or MS/OR applications, and these included software such as Lindo, Lingo, Win QSB and QuickQuant. Software that was placed into mathematical programming software included CAS and software that were used for general
mathematics and had a fair amount of programming such as Matlab, Mathematica, Macsyma and AMPL. The last grouping of ‘other’ including software that came with textbooks, java applets and software created for the course. Generally, spreadsheets or linear programming software (60%) were used by most courses (see Table 15).

Table 15: Type of software used across the disciplines

<table>
<thead>
<tr>
<th>Type of Software</th>
<th>Hard-Pure</th>
<th>Hard-Applied</th>
<th>Soft-Applied</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreadsheet</td>
<td>20%</td>
<td>69%</td>
<td>77%</td>
<td>48%</td>
</tr>
<tr>
<td>LP software</td>
<td>23%</td>
<td>35%</td>
<td>31%</td>
<td>29%</td>
</tr>
<tr>
<td>Spreadsheets and/ or LP</td>
<td>37%</td>
<td>72%</td>
<td>92%</td>
<td>60%</td>
</tr>
<tr>
<td>Maths software</td>
<td>23%</td>
<td>24%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>Math and/ or LP</td>
<td>46%</td>
<td>55%</td>
<td>31%</td>
<td>47%</td>
</tr>
<tr>
<td>Other</td>
<td>14%</td>
<td>7%</td>
<td>8%</td>
<td>10%</td>
</tr>
<tr>
<td>None</td>
<td>26%</td>
<td>10%</td>
<td>8%</td>
<td>17%</td>
</tr>
<tr>
<td>Any Software</td>
<td>74%</td>
<td>90%</td>
<td>92%</td>
<td>83%</td>
</tr>
</tbody>
</table>

Statistical evidence, \( \chi^2 (2) = 15.101, p < 0.001 \) indicates that the hard-applied (72%) and soft-applied (92%) disciplines used the spreadsheets and linear programming software more than the hard-pure discipline (37%).

4.4.2 Software Usage in LP Sub-Topics

Although, 84% of all the courses employed one or more software, only 52% of all courses employed any software at all during the coverage of the specified linear programming sub-topics. It is likely that the other 48% of the course used software for finding the solution only. Over 35% of the courses for each linear programming sub-topic were covered using software (see Figure 8).
Figure 8: Percentage courses that use software in the teaching of the linear programming sub-topics

However, for most of these sub-topics, only about 5-7% was found in the ‘somewhat extensively’ category, excepting the interior point method (0%) and computer printout/output sensitivity analysis (24%). Predictably, the computer output/printout sensitivity analysis used the most amount of software (73%). Interestingly, in 42 courses, the formulation was covered through computers, a task that was thought to be undertaken predominantly through print/slides. This may mean however that students were taught how to input the formulated problem correctly into the software package to generate the answer rather than formulating the problem with the help of the software.

4.4.3 Software Usage in the Coverage of LP Sub-Topics

A mean software usage value was calculated for each course, where a software usage in each of the linear programming sub-topics were given a score from -2 to 2, where -2 represented ‘predominantly whiteboard/slides/print’ and 2 represented...
‘predominantly computer demonstrations’ (see Section 3.2.2, p. 24). Any topic that had a ‘not sure’ value was considered to be missing. A mean software usage was calculated by adding the individual linear programming sub-topics software score, and dividing by the number of sub-topics taught in the course. Using this mean software usage, it was found that the three disciplines had significantly different software usage, $F(2,74) = 8.674$, $p<0.001$. Interestingly, all three discipline groupings had a software usage value that was negative indicating that little or no software was used. The soft-applied discipline (-0.7) used the most software, followed by the hard-applied (-1.2), with the hard-pure (-1.6) having the lowest software usage score. The software usage score was further correlated with the ‘use of media’ scale in the approaches to teaching questionnaire to determine if there were any linkages. A relationship was found that only explained 12.4% of the variance, $F (1, 71) = 10.054$, $p = 0.002$ (see Annex 12, p. 99).

4.4.4 Computer Interaction for the Various Disciplines

Computer interaction is based on whether students were taught to interact with software directly for different solutions (see Section 3.2.2, p. 24). For each interaction, a point of 1 was scored if the interaction was covered and 0 otherwise, which was then sum to obtain an interaction score for that solution.

Statistical analysis tests were used to test if there was any difference between having at least one interaction and not having any interaction for each solution. The first test shows that there was no significant evidence to suggest that having software interactions for simplex/ revised simplex method vary between the disciplines, $\chi^2 (2) = 0.631$, $p=0.730$. At least 30% of the courses in each of the discipline that used software and taught the simplex/ revised simplex method had some type of interaction with the
software. Overall, 29% of all courses that taught the graphical method and used software had some type of interaction with the software. However, for the courses teaching the graphical method, there were more soft-applied disciplines (56%) interacting with the computer, $\chi^2 (2) = 6.649, p=0.036$, than the hard-applied (37%) and hard-pure (16%) disciplines. For the interior point method there wasn’t sufficient data to compare if one discipline had more interaction or no interaction. However, 4 of the courses that taught the interior point method did have some sort of interaction (see Table 16).

<table>
<thead>
<tr>
<th>Solution Methods</th>
<th>% of courses having some interaction</th>
<th>Number of courses having some interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplex/ Revised Simplex Method</td>
<td>49%</td>
<td>27</td>
</tr>
<tr>
<td>Graphical Method</td>
<td>29%</td>
<td>20</td>
</tr>
<tr>
<td>Interior Point Method</td>
<td>40%</td>
<td>4</td>
</tr>
</tbody>
</table>

### 4.5 Approaches to Teaching and ASSIST scores for the LP Courses

Further work into how the teaching of linear programming differs is found through examining the approaches to teaching scores. The analysis looks at whether the learning facilitation and knowledge transmission scores are dependent on the disciplinary groupings. The statistical analyses found no significant difference between the different disciplines for these two scales, $F_{learning\ facilitation}(2,70) = 2.276, p=0.110$ and $F_{knowledge\ transmission}(2,70) = 0.539, p=0.586$. On the subscales, no significant differences were found across disciplines except on the lecturer’s intention for problem solving scale $F_{problem\ solving}(2,65) = 4.717, p=0.012$, where the hard-applied discipline (4.7) score was
similar to the soft-applied discipline (4.5) but significantly different to the hard pure discipline (4.3).

The 51 student ASI scores from the 5 lecturers when combined provided a score of 13.0 on the surface approach scale, 15.0 on the strategic approach and 14.9 on the deep approach scales. The deep approach mean scores were found to vary significantly from that of a normal distribution, Shapiro-Wilk statistic (48) = 0.946, \( p=0.027 \), since it was negatively skewed. To carry out further analysis, the deep approach mean was transformed using a logarithmic approach. Further examination was carried out on how the ASSIST scores can differ depending on the discipline in which the course was based and was determined by using the lecturer’s discipline. The lecturers to whom the ASSIST questionnaire was sent to were based in either hard-pure or hard-applied disciplines. Interestingly unlike in the approaches to teaching questionnaire, it was found that the strategic approach was dependent on the discipline in which the course was based in, \( F_{\text{Strategic Approach}}(1,39) = 7.625, \ p=0.009 \). The hard-applied subjects scored 15.7 for the strategic approach whilst the hard-pure subjects only 13.2.

This pattern is reflected somewhat when looking at which discipline the student based in and these included all three disciplines. It was found that both the deep and strategic approach scores were different for disciplines, \( F_{\text{Deep Approach}}(2,38) = 4.559, \ p=0.017 \) and \( F_{\text{Strategic Approach}}(2,38) = 7.347, \ p=0.002 \). Further post-hoc analysis showed that students belonging to the hard-pure (14.2) and hard-applied (14.5) disciplines had a smaller deep approach score than for the soft-applied disciplines (16.0). This is illustrated in Figure 9.
Interestingly, in the strategic approach, the students in the soft-applied disciplines (16.6) also significantly outperformed the students in the hard-pure (13.2) and hard-applied disciplines (14.3). The similarity between results when analyzing the ASI scores based on the lecturer’s disciplines and when analyzing based on the student’s disciplines is perhaps a reflection on how closely students’ disciplines are correlated to the lecturer’s discipline, $r = 0.883, p < 0.001$.

### 4.6 Concluding Remarks

Although the response rate was low for the linear programming and “approaches to teaching” questionnaire, trends and patterns between disciplines and countries could have still been determined. Interesting points to note with respect to the linear
programming sub-topics is that all disciplines covered the formulation with the soft-applied and hard applied disciplines having more intensity.

With respect to the solution sub-topic, data analysis suggests that if the course was from a hard-pure or hard-applied discipline, then it will cover linear programming solutions but this will not hold true for about a quarter of the soft-applied courses. For the individual solutions, such as the graphical method, if a course resided in a hard discipline there were higher odds that the graphical method will be taught more than in a soft discipline. Both the simplex and revised simplex algorithm appeared more likely to be covered in the hard-applied and hard-pure disciplines, whilst the interior point method was barely taught with its highest coverage in the hard-applied discipline.

Most courses in all the disciplines covered some type of sensitivity analysis. The applied disciplines seemed more likely to teach sensitivity analysis than the pure disciplines particularly for the computer output/ printout sensitivity analysis. There was no difference in the calculations required to be conducted by students from the varying disciplines for the graphical and computer printout/ output sensitivity analysis.

Most courses used at least one type of software. The hard-applied and soft-applied disciplines were more likely to use spreadsheets and/ or dedicated linear programming software whilst the hard-pure discipline used more mathematical software and/ or dedicated linear programming software. However only about half of the courses used software during the teaching of at least one linear programming sub-topic and perhaps the software packages were only used for finding the solution. Although
software usage was low during teach, the soft-disciplines were found to have a higher mean software usage than the hard-applied and the hard-pure.

With regards to the interaction of software, half of all courses that taught the simplex algorithm and used computer software had some interaction with the computer. Also about a third of those courses that used software packages and taught the graphical method had students interacting with the software. However, students in the soft-disciplines had more interaction with the computer for the graphical method than the other disciplines, whilst for the simplex algorithm interaction the interaction amount was similar across disciplines.

Using the “approaches to teaching” scales, all disciplines appeared to approach the teaching of linear programming similarly as their scores in both the learning facilitation and the knowledge transmission scales were not different. However using the ASSIST scores, students based in the soft-applied disciplines had higher deep and strategic approach scores than for their counterparts in the hard-applied and hard-pure disciplines.

Further examination into what these results may mean and how they relate to the research questions are followed up in the next chapter.
Chapter 5. Interpretation of Results

5.1 Introduction

This chapter intends to demonstrate how the data collected and analysed supports the research aims. After first revisiting the overall research question, the discussion embarks into the teaching of the linear programming sub-topics, in particular its coverage and intensity, by comparing the results in this study with that of Albritton et al (2003). The discussion then goes further by looking into the pedagogical methods for teaching linear programming particularly in covering sub-topics with LP software such as the extent students interact with software for finding the solutions. The chapter concludes by looking at linear programming in the different countries and the approaches to teaching of the lecturers. Throughout the chapter, the disciplinary differences are used as the main unit of analysis for discussion, with comparisons of country being used to a lesser extent.

5.2 Research Questions Revisited

Previous work into research into the teaching of linear programming have all been a part of larger studies whose main aims were to investigate what is taught in operation research and management science courses. The majority of these studies have been conducted in USA and targeting degrees in the business discipline. This research goes further and looks into not only the specific topics that are taught in linear programming, but to what extent software is used, and further how linear programming is taught across various disciplines as well as in various countries. Therefore, to answer
the research question how is linear programming taught (Section 1.4, p. 4), this chapter looks into how the data has shaped the answering of the five specific research questions.

5.3 Extent that Linear Programming is Taught

*To what extent are linear programming sub-topics taught in the various disciplines and countries?*

This section compares the results from Albritton *et al.* (2003) whose work was in the business discipline. It seems that perhaps there are similar coverage and intensities scores with their study and that of the soft-applied discipline which contained the business courses.

5.3.1 Linear programming Course Content in Disciplines

The linear programming sub-topics coverage values are almost the same as the study conducted by Albritton *et al.* (2003) particularly for the soft-discipline (see Table 17).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulation</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>91%</td>
</tr>
<tr>
<td>Solution</td>
<td>100%</td>
<td>100%</td>
<td>77%</td>
<td>96%</td>
<td>-</td>
</tr>
<tr>
<td>Graphical Method</td>
<td>91%</td>
<td>93%</td>
<td>69%</td>
<td>88%</td>
<td>79%</td>
</tr>
<tr>
<td>Simplex Method</td>
<td>86%</td>
<td>76%</td>
<td>23%</td>
<td>71%</td>
<td>19%</td>
</tr>
<tr>
<td>Revised Simplex Method</td>
<td>52%</td>
<td>59%</td>
<td>0%</td>
<td>45%</td>
<td>-</td>
</tr>
<tr>
<td>Interior Point Method</td>
<td>9%</td>
<td>24%</td>
<td>0%</td>
<td>13%</td>
<td>-</td>
</tr>
<tr>
<td>Sensitivity Analysis</td>
<td>77%</td>
<td>90%</td>
<td>100%</td>
<td>86%</td>
<td>83%</td>
</tr>
<tr>
<td>Graphical</td>
<td>69%</td>
<td>79%</td>
<td>77%</td>
<td>74%</td>
<td>-</td>
</tr>
<tr>
<td>Computer Printout/ Output</td>
<td>58%</td>
<td>83%</td>
<td>85%</td>
<td>72%</td>
<td>-</td>
</tr>
</tbody>
</table>

*: Albritton *et al.* (2003) did not cover this sub-topic.
The study found that there was 100% coverage for formulation and sensitivity analysis in the soft-applied disciplines. This figure is high when compared to Albritton et al (2003) and is perhaps due to them having a larger number of responses (126 vs 77) and hence having a better probability of finding courses that teach linear programming but do not cover some of these sub-topics explored here.

Further, the intensity of coverage for the soft-applied disciplines compares somewhat to that of Albritton et al (2003) study. Although the intensity of the formulation appears to be similar between the studies (see Table 18), the intensity found for sensitivity analysis is higher by 0.2 to 1.0 points in this study than that of Albritton et al (2003).

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulation</td>
<td>3.2</td>
<td>3.2</td>
<td>3.5</td>
<td>3.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Solution</td>
<td>3.5</td>
<td>3.6</td>
<td>2.4</td>
<td>3.4</td>
<td>-</td>
</tr>
<tr>
<td>Sensitivity Analysis</td>
<td>2.6</td>
<td>3.1</td>
<td>3.4</td>
<td>2.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Overall</td>
<td>3.1</td>
<td>3.3</td>
<td>3.1</td>
<td>3.2</td>
<td>-</td>
</tr>
</tbody>
</table>

* Values were originally on a 7 point scale and was rescaled to a 4 point scale
- : Albritton et al (2003) did not cover this sub-topic

In fact, Albritton et al’s intensity scores seem closer to that of the hard-pure disciplines. One possible reason for this is that perhaps because Albritton et al (2003) used more points on the scale, a more accurate intensity could have been pin-pointed. However, it is more likely that since all the soft-applied disciplines in this study covered the sensitivity analysis there will be higher intensity scores than for Albritton et al (2003) which only covered 83%.
Contrarily however, whereas the hard-pure disciplines were expected to teach more mathematically intensive solutions such as revised simplex and interior point method, it appears as if the hard-applied disciplines were more likely to teach these (Table 17, p. 52). The apparent reason for the difference is not clear, but perhaps there is more emphasis on mathematical solutions in the hard-applied disciplines whilst in the hard-pure disciplines it is on the theory (Neumann et al, 2002).

### 5.3.2 Linear Programming Course Content in Countries

As considered in Section 2.2.1 (p. 6), as to whether there are less mathematically intensive linear programming courses in the UK, the study indicates that the extent of intensive mathematical topics in the linear programming solution seems comparable to that of every country except the USA (Table 10, p. 33).

USA seems more focussed on the more intense mathematical topics such as revised simplex method and interior point method. This may be an indication that countries may promote different course content for the same subject and could be a result of the academic culture in the various countries.

### 5.4 Usage of Different Types of Linear Programming Software

Do the types of linear programming software employed vary across disciplines?

Albritton et al (2003)’s study also compares favourably with the use of different types of software in the soft-applied disciplines in that the percentage of software use is similar (see Table 19).
Table 19: Type of software used across the disciplines and in Albritton et al (2003) study

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreadsheet</td>
<td>20%</td>
<td>69%</td>
<td>77%</td>
<td>48%</td>
<td>76%</td>
</tr>
<tr>
<td>LP software</td>
<td>23%</td>
<td>55%</td>
<td>31%</td>
<td>29%</td>
<td>-</td>
</tr>
<tr>
<td>Spreadsheets and/ or LP</td>
<td>37%</td>
<td>72%</td>
<td>92%</td>
<td>60%</td>
<td>88%</td>
</tr>
<tr>
<td>Maths software</td>
<td>23%</td>
<td>24%</td>
<td>0%</td>
<td>20%</td>
<td>-</td>
</tr>
<tr>
<td>Math and/ or LP</td>
<td>46%</td>
<td>55%</td>
<td>31%</td>
<td>47%</td>
<td>34%</td>
</tr>
<tr>
<td>Other</td>
<td>14%</td>
<td>7%</td>
<td>8%</td>
<td>10%</td>
<td>-</td>
</tr>
<tr>
<td>None</td>
<td>26%</td>
<td>10%</td>
<td>8%</td>
<td>17%</td>
<td>-</td>
</tr>
<tr>
<td>Any Software</td>
<td>74%</td>
<td>90%</td>
<td>92%</td>
<td>83%</td>
<td>-</td>
</tr>
</tbody>
</table>

- : Albritton et al (2003) did not cover this software

As suggested by Winston (1996), it seems that the soft-applied disciplines are more likely to use spreadsheet applications, whilst the hard-pure and hard-applied disciplines use more dedicated linear programming software and mathematical software.

Although no statistical significance was found, it appears as if the hard-applied used more of the dedicated linear programming software than the hard-pure. Probably in this discipline as opposed to that of the hard-pure, it is not necessary to use software in a regular basis for other mathematical needs, and hence may not consider a multi-purpose mathematical software such as Matlab or Mathematica.

5.5 Extent of Software Demonstrations in the Teaching Process

To what extent are computer software used in the teaching process?

Given that the intent of the research question is to determine how linear programming teaching varies in disciplines, it is particularly disappointing that some of the answers from the questionnaire had to be amalgamated to perform any statistical analyses because of the small number of respondents. For example, in the questions
related to the use of software for demonstration of solutions particularly that of the interior point and revised simplex method the data had to be grouped into ‘using software’ and ‘not using software’ in the teaching process. Hence, variation in the extent of software could not be ascertained. Even so, the study does point to those disciplines that tended to use at least one software package in all of the linear programming sub-topics under study here. Unfortunately, in the study there was no specific question on the coverage and degree of coverage to which computers were used for only generating the solution that is using software in a black-box manner. However, it is possible that using the number of courses that indicated that some type of software package was used; an estimate of the coverage of the solution by computers only can be found. This is calculated by finding the difference between number of courses using at least one software package for the four linear programming solutions and the total number of courses using at least one software package. Using this, it was found that 33% of all the courses perhaps used software for computer solutions only. It was also found that when teaching any of the LP topics at least 35% of the courses employed some type of software during the teaching process.

A further limitation of the questionnaire is that for the specific solutions such simplex algorithm, graphical method and so on, the degree of coverage was not asked, rather only if software was used during its coverage and whether the solution was covered or not. Although, knowing the coverage of the solution method was not necessary for the interior point and revised simplex method because of the low number of responses, it would have been interesting to determine if there was variation in the degree of coverage of the graphical and simplex method which had a high coverage percentage.
5.6 Students’ Interaction with Linear Programming Software

Does students’ interaction with linear programming software for finding the solutions vary across disciplines?

The research was able to uncover to what extent the student was taught to interact with software for particular steps in the methods and from this gauge how these topics were taught in the various disciplines. For example, it was found that in almost half the courses for all disciplines that taught the simplex algorithm and used computers, students used the software equally for doing various steps in the simplex algorithm whilst for the graphical method, the students in the hard-pure and hard-applied disciplines used software less for investigating steps than for the soft-applied discipline. This is perhaps a contributing reason for the soft-applied courses having a higher mean software score than other two disciplines.

However, the results are surprising as it suggests that more courses in the soft-applied disciplines are using white-box software for a wider range of topics than the hard-applied or hard-pure disciplines. It was expected since the hard-pure or the hard-applied which should be theoretical would use more white-box software (see Section 2.2.3, p. 11). However, the results may suggest that the hard disciplines are using a combination of black-box software and white-box teaching approach and this is possibly a reason for their low software usage.
5.7 Lecturers’ Disciplinary Teaching Patterns

Do lecturers’ disciplinary teaching patterns influence the studying and teaching of linear programming?

Whilst Lueddeke (2003) and Lindblom-Ylänne et al (2005) found differences in the ATI scores across disciplines, this study was unable to detect any differences in the “approaches to teaching” questionnaire scores for the linear programming lecturers. Perhaps, the underlying reason for this is the use of the two different questionnaires. Whilst in the two previous studies, the ATI employed was that of Prosser and Trigwell (1999), the approaches to teaching questionnaire in this study used was developed by Norton et al (2005). Although the concepts are generally the same between the two questionnaires, undeniably the questions are different and perhaps can be measuring different things. Differences were found between the students approach to studying across the disciplines and perhaps other environmental factors such as the disciplinary culture may influence how the students study rather than the lecturer’s disciplinary teaching patterns.

The primary reason for using Norton et al’s approaching to teaching questionnaire was because of its advantage in having a number of sub-scales for which the disciplines can be compared. Even so, all of these sub-scales had appeared to be statistically similar for each discipline excepting for the subscale on the intentions of problem solving (for which hard-pure was less than hard-applied). The apparent reason for the difference is not clear, but it is perhaps a similar reason to that discussed in Section 5.3.1 (p. 52), in that there is more emphasis on problem solving in the hard-
applied disciplines (reflected in the higher percentage doing solution methods) whilst in the hard-pure disciplines emphasis is on the theory (Neumann et al, 2002).

5.8 Concluding Remarks

Whilst there have been some limitations in the questionnaire and sample size in being able to receive a full comprehension of the state of linear programming teaching in universities, the results do show that there are disciplinary differences in teaching linear programming. The three disciplines fall almost in a continuum, with hard applied bridging the gap between hard-pure and soft-applied. For example, some characteristics such as solution methods, the hard-pure and hard-applied seems the same whilst in comparing the extent of sensitivity analysis coverage, hard applied is closer to the soft-applied disciplines. The differences do not only apply to the coverage of the linear programming sub-topics, but as well as the use of computer usage as a means of teaching solution methods, and the types of software used for finding the solution of the linear programming problem.

There were also some surprising findings in that the soft disciplines seem more inclined to use white-box software than the hard disciplines. Also unexpected was that no variation in the “approaches to teaching” could be found across the disciplines for the same linear programming topic.
Chapter 6. Conclusions and Recommendations

6.1 Introduction

This chapter aims to summarize the main findings of the study and to present the limitations and further recommendations for future studies.

6.2 Main Findings of the Study

This study aimed to determine how linear programming was taught in various disciplines and in countries. This was done mainly through an online survey which contained a linear programming questionnaire and an “approaches to teaching” questionnaire. This was sent to 311 lecturers in four English speaking countries. The response rate from this questionnaire was low but still some conclusions and trends were able to be identified.

The research because of its small sample which was not fully randomised can only at best show an indication of how linear programming is taught but cannot make any solid claims for all disciplines, especially as disciplines were amalgamated into three groupings.

In general, the linear programming sub-topics of formulation was taught in every discipline. The solution methods of revised simplex and interior point were the least popular in the coverage of any course. The interior point method was mostly found to be taught in the hard disciplines and in the USA.
Further, there is a higher popularity of linear programming and spreadsheet software in the hard-applied and soft-applied disciplines, whilst in the hard-pure discipline it runs in favour of mathematical programming and linear programming software. Over half of the courses that used computer software, used it as a means for demonstration especially in the formulation of the LP model, the computer output/printout of the sensitivity analysis and the simplex method.

Further, this study could not find any empirical evidence to support Lindblom-Ylänne et al (2005) and Lueddeke (2003) findings that there exists a difference in the ‘approaches to teaching’ in varying disciplines.

6.3 Limitations and Recommendations

Some of the limitations of the study is the small sample size (311), for which there was only a 25% response rate. This means that if there were any other variation within the sample, the statistical evidence will not be strong enough to determine where the variation lies. Further, because of the sample size, many categories had to be combined, and hence data was lost (see Section 5.5, p. 55). As such, there is a need for a larger study to ensure that the findings found in this study are replicable and whether any other variations may be found.

Also, the sample itself is based on self-selection from the internet and hence may not represent the true population distribution disciplines and linear programming courses. Further, the sample has a bias towards courses that have provided information on the internet and it is subjected to the vagaries of the search engine rating system.
Also, the sample consists of only English-based courses and may not be representative of the other courses possibly held in other non-English speaking countries.

A qualitative study can follow up this research to explore the reasons for choosing the types of software in the various disciplines. Further, a qualitative study could gauge as to whether the using of these various types of software makes a difference in how the course is taught and how the student studies. Although software has been used as a means of teaching the course, there has not been a large influence in the course itself. The reasons for this low influence should be explored on why lecturers prefer some methods versus others and how this influences the learning and teaching of the linear programming process.

Unfortunately, this study was limited and could not delve further into how these disciplines may mix black-box or white-box software with teaching in black-box and white-box manner. A study of this type will add further to how linear programming is taught and perhaps detect disciplinary differences in teaching approaches which the “approaches to study” questionnaire was unable to do.
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Appendices

Appendix 1: Linear Programming and ATI Web Questionnaire

Survey of Linear Programming Education

The purpose of this questionnaire is to obtain data on the teaching of linear programming education in New Zealand as part of research being undertaken at the Open University. The questionnaire should be completed by lecturers teaching the linear programming component in their course. All data will be confidential and be analysed anonymously.

If you have any further questions or queries, you can contact Anesa Hosein via email: A.Hosein@open.ac.uk or telephone (UK) 01908 659866.

Instructions: As you proceed through the questionnaire, answer the questions in relation to only the linear programming component of one of your courses.

Part One - General Questions

1. Which department is the course based in?
   Please select...
   If you selected 'Other' please state which:

2. What is the Course Code and Title?
   Course Code:
   Course Title:
3. Which students does the course target?  
(Please select all that apply)

- [ ] Agriculture  
- [ ] Business  
- [ ] Economics  
- [ ] Engineering  
- [ ] Mathematics  
- [ ] Operations Research  
- [ ] Other

If you selected 'Other' please state which:  

4. What level of students does the course target?  

Please select ...  

If you selected 'Other' please state which:  

5. Approximately, how much study time are students expected to spend on the linear programming component?  

[ ] hours
6. Which software do you use in association with the linear programming component?  
(Please select all that apply)
- Excel Solver
- WinQSB
- Lindo
- Lingo
- Java Applets (please state)
- Other Excel/Spreadsheet Add-in (please state)
- None
- Other (please state)

Part Two - Formulation

1. When teaching linear programming, to what extent do you cover problem/model formulation?
- No coverage (please go to part three)
- Slight coverage
- Some coverage
- Extensive coverage
- Not sure
2. **How do you deliver the problem/model formulation section?**
   - Predominantly whiteboard/slides/print
   - Mostly whiteboard/slides/print with some computer demonstrations
   - Mostly computer demonstrations with some whiteboard/slides/print
   - Predominantly computer demonstrations
   - Not sure

   **Please state software used (if any)**

3. **In which of the following notations are students taught to formulate problems?**
   *(Please select all that apply)*
   - [ ] Algebraic notation
   - [ ] Matrix notation
   - [ ] Other *(please state)*

**Part Three - Linear Programming Solution**

1. **When teaching linear programming, to what extent do you cover solving the linear programming problem/model?**
   - [ ] No coverage *(please go to part four)*
   - [ ] Slight coverage
   - [ ] Some coverage
   - [ ] Extensive coverage
   - [ ] Not sure
2. How do you deliver the linear programming solution section when teaching the following methods/algorithms? (If at all)

a) Simplex Algorithm (Tableaus)
- Predominantly whiteboard/slides/print
- Mostly whiteboard/slides/print with some computer demonstrations
- Mostly computer demonstrations with some whiteboard/slides/print
- Predominantly computer demonstrations
- Not sure
- Not taught

Please state software used (if any)

b) Revised Simplex Algorithm (Matrices)
- Predominantly whiteboard/slides/print
- Mostly whiteboard/slides/print with some computer demonstrations
- Mostly computer demonstrations with some whiteboard/slides/print
- Predominantly computer demonstrations
- Not sure
- Not taught

Please state software used (if any)

c) Graphical Method
- Predominantly whiteboard/slides/print
- Mostly whiteboard/slides/print with some computer demonstrations
- Mostly computer demonstrations with some whiteboard/slides/print
- Predominantly computer demonstrations
- Not sure
- Not taught

Please state software used (if any)
d) Interior Point/Karmarkar’s Method
- Predominantly whiteboard/slides/print
- Mostly whiteboard/slides/print with some computer demonstrations
- Mostly computer demonstrations with some whiteboard/slides/print
- Predominantly computer demonstrations
- Not sure
- Not taught

Please state software used (if any)

Choose one:

Please state software used (if any)

Choose one:

3. When teaching the linear programming solution component, to what extent is the computer used for exploring feasible solutions?
- Not at all
- Occasionally
- Regularly
- Extensively
- Not sure
4. From the following lists, please indicate how students are taught to interact with the software during the iterations. (Please select all that apply)

   a) Simplex and Revised Simplex Algorithm:
      □ Choosing the entering basic variable/entering column.
      □ Calculating the ratio.
      □ Choosing the pivot row/equation.
      □ Choosing the value(s) to perform the elementary row operations.
      □ Deciding when the algorithm has come to an end.
      □ Don’t interact with the computer directly/don’t teach.

   b) Graphical Method
      □ Graph the constraints and objective function.
      □ Exploring various solutions by changing the constraints or objective function.
      □ Don’t interact with the computer directly/don’t teach.

   c) Interior Point/Karmarkar’s Method
      □ Forming the dual problem
      □ Doing the centering transformation
      □ Don’t interact with the computer directly/don’t teach.

Part Four - Sensitivity Analyses

1. When teaching linear programming, to what extent do you cover sensitivity analysis for the following methods?

   a) Sensitivity Analysis (Graphical)
      □ No coverage
      □ Slight coverage
      □ Some coverage
      □ Extensive coverage
      □ Not sure

   b) Sensitivity Analysis (Output/Printout)
      □ No coverage
      □ Slight coverage
      □ Some coverage
      □ Extensive coverage
      □ Not sure
If you've selected 'No coverage' for both Sensitivity Analysis (Graphical) and Sensitivity Analysis (Output/Printout), please go to part five.

2. How do you deliver the sensitivity analysis interpretation section for the following methods? Please indicate any software used (if any)?

   a) Sensitivity Analysis (Graphical)
      - Predominantly whiteboard/slides/print
      - Mostly whiteboard/slides/print with some computer demonstrations
      - Mostly computer demonstrations with some whiteboard/slides/print
      - Predominantly computer demonstrations
      - Not sure
      - Not taught

   Please state software used (if any) [ ]

   b) Sensitivity Analysis (Output/Printout)
      - Predominantly whiteboard/slides/print
      - Mostly whiteboard/slides/print with some computer demonstrations
      - Mostly computer demonstrations with some whiteboard/slides/print
      - Predominantly computer demonstrations
      - Not sure
      - Not taught

   Please state software used (if any) [ ]
3. For the following lists, please indicate what students are taught to find/calculate with respect to the sensitivity analysis.
(Please select all that apply)

   a) Graphical Method
      - The optimal range of the objective variables coefficients.
      - The reduced cost of the objective variables coefficients.
      - The optimal range of the right hand side (RHS) of the constraints.
      - The dual price for the RHS constraints.

   b) Computer Output/Printout
      - The optimal range of the objective variables coefficients.
      - The reduced cost of the objective variables coefficients.
      - The optimal range of the right hand side (RHS) of the constraints.
      - The dual price for the RHS constraints.

Part Five - Approaches to Teaching

This part of the questionnaire contains 34 statements. For each statement, please select on the scale, the one that best describes your approach to teaching.

5 - means that you definitely agree
4 - means that you agree, but with reservations
3 - means that you really find it impossible to give a definite answer
2 - means that you disagree, but with reservations
1 - means that you definitely disagree
1) In my lectures, I spend more time directing discussion than standing up and giving information.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

2) I try to use audio-visual materials in my teaching.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

3) Higher education should convert students from secondary school type learning (eg memorisation into tertiary type, problem solving).
   Definitely Agree  5  4  3  2  1 Definitely Disagree

4) I try to get students to participate as much as possible in my tutorials/seminar.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

5) As a lecturer one of my principal aims is to provide an environment in which students are helped to ‘learn for themselves’ rather than be taught.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

6) I try to put into practice my belief that an important part of teaching is keeping in touch with students’ problems.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

7) I try to help my students develop into self-motivated individuals.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

8) I try to pass on what information I know to the students.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

9) I try to teach my students how to use logical and rational thinking.
   Definitely Agree  5  4  3  2  1 Definitely Disagree

10) The main aim of higher education should be to prepare students for their future careers.
    Definitely Agree  5  4  3  2  1 Definitely Disagree

11) I try to ensure that by the end of their course my students will be well qualified in their particular subject.
    Definitely Agree  5  4  3  2  1 Definitely Disagree

12) A good lecturer is one who recognises the personal needs of his/her students.
    Definitely Agree  5  4  3  2  1 Definitely Disagree

13) A good lecturer is one whose main role is to impart information to his/her students.
    Definitely Agree  5  4  3  2  1 Definitely Disagree
14) I try to show that I am concerned with my students’ well-being.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

15) I spend a lot of time ensuring that I have a thorough knowledge of my subject.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

16) I try to give as much information as possible to my students.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

17) The most important skill graduates can develop is the ability to carry on learning when they leave higher education.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

18) I spend much of my time trying to present subject material in a way which will stimulate the interests of the students.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

19) I try to prepare students for the roles they will have when they leave the institution.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

20) Teaching is about the transmission of knowledge.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

21) Good lecturers should have a genuine interest in their students’ well-being.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

22) Teaching is about providing an environment in which students are encouraged to do the learning themselves.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

23) I try to teach my students how to analyse information critically.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

24) A good lecturer should incorporate student discussion as part of his/her teaching.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

25) It is really important that a lecturer is able to enthuse his/her students.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

26) It is fundamental that lecturers know the latest advances in knowledge related to their subject area.
   Definitely Agree  ○  5  ○  4  ○  3  ○  2  ○  1  Definitely Disagree

27) A good lecturer is one who can motivate students to learn.
<table>
<thead>
<tr>
<th>Question</th>
<th>Definitely Agree</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>Definitely Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>28) Lecturers should encourage participation from their students.</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>29) I try to keep abreast of my field of knowledge all the time.</td>
<td></td>
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<tr>
<td>30) An important function of higher education is to produce graduates for certain professions within the community.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>31) Lecturers present information more effectively if audio-visual materials are used.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>32) A good teacher has to be an expert in their subject matter.</td>
<td></td>
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<tr>
<td>33) New technology is going to revolutionise teaching.</td>
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<tr>
<td>34) I actively encourage my students to word-process their coursework.</td>
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<td></td>
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</tr>
</tbody>
</table>

**Comments**

If you would like to share anything that is interesting or special about your course and/or add any other comments, please type them here:

---

Anesa Hosein  
U800  
X1001044  
Dissertation
Data Protection Act

In accordance with the Data Protection Act, we need to have your consent by ticking the consent box and filling in your name and email address. You can be confident that the information we collect from you will be used only for the purposes of research, and that no person will be identified in any report of our findings. Your individual responses will be kept confidential to the research team; they will not be released to your University or to anyone else.

I agree that the data collected from me may be held and processed by the team for the purposes of research: ☐

Contact Details
Name: 
Email Address: 

Thank you very much for taking the time to complete this questionnaire.
Please submit your response by clicking on the button below.

Submit

If you have any difficulty using this questionnaire, please e-mail the OU’s internet survey staff.
Appendix 2: ASSIST Web Questionnaire

### A.S.S.I.S.T.
**Approaches and Study Skills Inventory for Students**

This questionnaire has been designed to allow you to describe, in a systematic way, how you go about learning and studying. The technique involves asking you a substantial number of questions which overlap to some extent to provide good overall coverage of different ways of studying. Most of the items are based on comments made by other students. Please respond truthfully, so that your answers will accurately describe your actual ways of studying, and work your way through the questionnaire quite quickly.

#### Background information

<table>
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<tr>
<th>a) Gender:</th>
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<table>
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<th>c) Department</th>
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<table>
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<th>d) Year of Study:</th>
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<tr>
<td>2nd Year - Undergraduate</td>
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<td>3rd Year - Undergraduate</td>
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<tr>
<td>4th Year - Undergraduate</td>
</tr>
<tr>
<td>Masters - Postgraduate</td>
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<tr>
<td>Other - Postgraduate</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
### A. What is learning?

**When you think about the term 'LEARNING', what does it mean to you?**
Consider each of these statements carefully, and rate them in terms of how close they are to your own way of thinking about it.

1) Making sure you remember things well.
   - Very close
   - Quite close
   - Not so close
   - Rather different
   - Very different

2) Developing as a person.
   - Very close
   - Quite close
   - Not so close
   - Rather different
   - Very different

3) Building up knowledge by acquiring facts and information.
   - Very close
   - Quite close
   - Not so close
   - Rather different
   - Very different

4) Being able to use the information you've acquired.
   - Very close
   - Quite close
   - Not so close
   - Rather different
   - Very different

5) Understanding new material for yourself.
   - Very close
   - Quite close
   - Not so close
   - Rather different
   - Very different
6) Seeing things in a different and more meaningful way.
- Very close
- Quite close
- Not so close
- Rather different
- Very different

B. Approaches to studying

The next part of this questionnaire asks you to indicate your relative agreement or disagreement with comments about studying, again made by other students. Please work through the comments, giving your immediate response. In deciding your answers, think in terms of the linear programming component. It is also very important that you answer all the questions.

1) I manage to find conditions for studying which allow me to get on with my work easily.
- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

2) When working on an assignment, I'm keeping in mind how best to impress the marker.
- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

3) Often I find myself wondering whether the work I am doing here is really worthwhile.
- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree
4) I usually set out to understand for myself the meaning of what we have to learn.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

5) I organise my study time carefully to make the best use of it.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

6) I find I have to concentrate on just memorising a good deal of what I have to learn.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

7) I go over the work I’ve done carefully to check the reasoning and that it makes sense.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

8) Often I feel I’m drowning in the sheer amount of material we’re having to cope with.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

9) I look at the evidence carefully and try to reach my own conclusion about what I’m studying.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
10) It's important for me to feel that I'm doing as well as I really can on the courses here.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

11) I try to relate ideas I come across to those in other topics or other courses whenever possible.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

12) I tend to read very little beyond what is actually required to pass.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

13) Regularly I find myself thinking about ideas from lectures when I'm doing other things.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

14) I think I'm quite systematic and organised when it comes to revising for exams.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree
15) I look carefully at tutors’ comments on course work to see how to get higher marks next time.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

16) There’s not much of the work here that I find interesting or relevant.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

17) When I read an article or book, I try to find out for myself exactly what the author means.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

18) I’m pretty good at getting down to work whenever I need to.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

19) Much of what I’m studying makes little sense: it’s like unrelated bits and pieces.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

20) I think about what I want to get out of the linear programming component to keep my studying well focused.
   - Agree
   - Agree somewhat

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>21) When I’m working on a new topic, I try to see in my own mind how all the ideas fit together.</td>
<td>Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td></td>
<td>Agree, Agree somewhat, Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td>22) I often worry about whether I’ll ever be able to cope with the work properly.</td>
<td>Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td></td>
<td>Agree, Agree somewhat, Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td>23) Often I find myself questioning things I hear in lectures or read in books.</td>
<td>Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td></td>
<td>Agree, Agree somewhat, Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td>24) I feel that I’m getting on well, and this helps me put more effort into the work.</td>
<td>Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td></td>
<td>Agree, Agree somewhat, Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td>25) I concentrate on learning just those bits of information I have to know to pass.</td>
<td>Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td></td>
<td>Agree, Agree somewhat, Unsure, Disagree somewhat, Disagree</td>
</tr>
<tr>
<td>26) I find that studying academic topics can be quite exciting at times.</td>
<td>Unsure, Disagree somewhat, Disagree</td>
</tr>
</tbody>
</table>
27) I'm good at following up some of the reading suggested by lecturers or tutors.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

28) I keep in mind who is going to mark an assignment and what they're likely to be looking for.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

30) When I am reading, I stop from time to time to reflect on what I am trying to learn from it.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

31) I work steadily through the term or semester, rather than leave it all until the last minute.
   ○ Agree
   ○ Agree somewhat
32) I'm not really sure what's important in lectures so I try to get down all I can.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

33) Ideas in course books or articles often set me off on long chains of thought of my own.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

34) Before starting work on an assignment or exam question, I think first how best to tackle it.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

35) I often seem to panic if I get behind with my work.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

36) When I read, I examine the details carefully to see how they fit in with what's being said.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
37) I put a lot of effort into studying because I'm determined to do well.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

38) I gear my studying closely to just what seems to be required for assignments and exams.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

39) Some of the ideas I come across on the linear programming component I find really gripping.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

40) I usually plan out my week's work in advance, either on paper or in my head.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

41) I keep an eye open for what lecturers seem to think is important and concentrate on that.
   - Agree
   - Agree somewhat
   - Unsure
   - Disagree somewhat
   - Disagree

42) I'm not really interested in the linear programming component, but I have to take
it for other reasons.

- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

43) Before tackling a problem or assignment, I first try to work out what lies behind it.

- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

44) I generally make good use of my time during the day.

- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

45) I often have trouble in making sense of the things I have to remember.

- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

46) I like to play around with ideas of my own even if they don't get me very far.

- Agree
- Agree somewhat
- Unsure
- Disagree somewhat
- Disagree

47) When I finish a piece of work, I check it through to see if it really meets the requirements.

- Agree
- Agree somewhat
- Unsure
48) Often I lie awake worrying about work I think I won’t be able to do.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

49) It’s important for me to be able to follow the argument, or to see the reason behind things.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

50) I don’t find it at all difficult to motivate myself.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

51) I like to be told precisely what to do in essays or other assignments.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree

52) I sometimes get ‘hooked’ on academic topics and feel I would like to keep on studying them.
   ○ Agree
   ○ Agree somewhat
   ○ Unsure
   ○ Disagree somewhat
   ○ Disagree
C. Preferences for different types of course and teaching

This part of the questionnaire asks you to consider your like or dislike to different methods of teaching in courses. Rate them in terms of how close they are to your own preference.

1) Lecturers who tell us exactly what to put down in our notes.
   - Definitely like
   - Like to some extent
   - Unsure
   - Dislike to some extent
   - Definitely dislike

2) Lecturers who encourage us to think for ourselves and show us how they themselves think.
   - Definitely like
   - Like to some extent
   - Unsure
   - Dislike to some extent
   - Definitely dislike

3) Exams which allow me to show that I’ve thought about the course material for myself.
   - Definitely like
   - Like to some extent
   - Unsure
   - Dislike to some extent
   - Definitely dislike

4) Exams or tests which need only the material provided in our lecture notes.
   - Definitely like
   - Like to some extent
   - Unsure
   - Dislike to some extent
   - Definitely dislike

5) Courses in which it’s made very clear just which books we have to read.
   - Definitely like
   - Like to some extent
6) Courses where we’re encouraged to read around the subject a lot for ourselves.
- Definitely like
- Like to some extent
- Unsure
- Dislike to some extent
- Definitely dislike

7) Books which challenge you and provide explanations which go beyond the lectures.
- Definitely like
- Like to some extent
- Unsure
- Dislike to some extent
- Definitely dislike

8) Books which give you definite facts and information which can easily be learned.
- Definitely like
- Like to some extent
- Unsure
- Dislike to some extent
- Definitely dislike

9) Finally, how well do you think you have been doing in your assessed work overall, so far?
   Please rate yourself objectively, based on the grades you have been obtaining.
   - 9 Very well
   - 8
   - 7 Quite well
   - 6
   - 5 About average
   - 4
   - 3 Not so well
   - 2
   - 1 Rather badly
D. Comments

If you would like to share anything interesting or special about the linear programming component and/or add any comments, please type them here:

Thank you very much indeed for your time and effort in completing this questionnaire. Please submit your response by clicking on the button below.

If you have any difficulty using this questionnaire, please e-mail the OU's internet survey staff.
### Appendix 3: Statistical Analyses

**Annex 1: Chi-square analysis for formulation coverage intensity and disciplines**

<table>
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<tr>
<th>Formulation Coverage Intensity</th>
<th>Disciplines</th>
<th>Total</th>
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<tr>
<td>Slight Coverage</td>
<td>3</td>
<td>7</td>
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<tr>
<td></td>
<td>(8.8%)</td>
<td>(25.0%)</td>
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<tr>
<td>Some Coverage</td>
<td>21</td>
<td>8</td>
</tr>
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<td></td>
<td>(61.8%)</td>
<td>(28.6%)</td>
</tr>
<tr>
<td>Extensive Coverage</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(29.4%)</td>
<td>(46.4%)</td>
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<tr>
<td><strong>Total</strong></td>
<td>34</td>
<td>28</td>
</tr>
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<td>(100.0%)</td>
<td>(100.0%)</td>
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**Chi-Square Tests**

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<tbody>
<tr>
<td>Pearson Chi-Square</td>
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<td>Likelihood Ratio</td>
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<td>N of Valid Cases</td>
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*3 cells (33.3%) have expected count less than 5. The minimum expected count is 1.91.*

*b ‘Not Sure’ options not included*

---

**Annex 2: Chi-square analysis for solution coverage and disciplines**

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<th>Solution Coverage</th>
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<tr>
<td>Hard-Pure</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>(100.0%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>(100.0%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>(23.1%)</td>
<td>(76.9%)</td>
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<tr>
<td><strong>Total</strong></td>
<td>3</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>(4.0%)</td>
<td>(96.0%)</td>
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<td>(100.0%)</td>
<td>(100.0%)</td>
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**Chi-Square Tests**

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<th>Value</th>
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*3 cells (50.0%) have expected count less than 5. The minimum expected count is .52.*

*b ‘Not Sure’ options not included*
Annex 3: Chi-square analysis for graphical method solution coverage and disciplines

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<th>Disciplines</th>
<th>Graphical Method Taught</th>
<th>Total</th>
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<td>Coverage</td>
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<tr>
<td>Hard-Pure</td>
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<td>32</td>
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<td></td>
<td>(8.6%)</td>
<td>(91.4%)</td>
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<tr>
<td>Hard-Applied</td>
<td>2</td>
<td>27</td>
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<tr>
<td></td>
<td>(6.9%)</td>
<td>(93.1%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(30.8%)</td>
<td>(69.2%)</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>68</td>
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<td></td>
<td>(11.7%)</td>
<td>(88.3%)</td>
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<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
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<tbody>
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<td>Pearson Chi-Square</td>
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<tr>
<td>Likelihood Ratio</td>
<td>4.464</td>
<td>2</td>
<td>.107</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>2.924</td>
<td>1</td>
<td>.087</td>
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<tr>
<td>N of Valid Cases</td>
<td>77</td>
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a 3 cells (50.0%) have expected count less than 5. The minimum expected count is 1.52.

Annex 4: Chi-square analysis for graphical method solution coverage for the hard and soft disciplines

<table>
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<tr>
<th>Discipline</th>
<th>Graphical Method Taught</th>
<th>Total</th>
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<tr>
<td></td>
<td>No Coverage</td>
<td>Coverage</td>
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<tr>
<td>Hard</td>
<td>5</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>(7.8%)</td>
<td>(92.2%)</td>
</tr>
<tr>
<td>Soft</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>(30.8%)</td>
<td>(69.2%)</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>11.7%</td>
<td>88.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
<th>Exact Sig. (2-sided)</th>
<th>Exact Sig. (1-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>5.517b</td>
<td>1</td>
<td>.019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuity Correction</td>
<td>3.517</td>
<td>1</td>
<td>.061</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>4.401</td>
<td>1</td>
<td>.036</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisher's Exact Test</td>
<td>1.000</td>
<td></td>
<td>.994</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>5.445</td>
<td>1</td>
<td>.020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Computed only for a 2x2 table
b 1 cells (25.0%) have expected count less than 5. The minimum expected count is 1.52.
Annex 5: Chi-square analysis for interior point method solution coverage and the disciplines

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>Interior Point Method</th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Coverage</td>
<td>Coverage</td>
<td></td>
</tr>
<tr>
<td>Hard-Pure</td>
<td>30</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>(90.9%)</td>
<td>(9.1%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>22</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>(75.9%)</td>
<td>(24.1%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(100.0%)</td>
<td>(100.0%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>(86.7%)</td>
<td>(13.3%)</td>
<td>(100.0%)</td>
</tr>
</tbody>
</table>

Value df Asymp. Sig. (2-sided)
Pearson Chi-Square 5.444a 2 .066
Likelihood Ratio 6.741 2 .034
Linear-by-Linear .023 1 .879
Association N of Valid Cases 75b

a 3 cells (50.0%) have expected count less than 5. The minimum expected count is 1.73
b ‘Not Sure’ options not included

Annex 6: Chi-square analysis for the simplex algorithm solution coverage and the disciplines

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>Simplex Algorithm</th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Coverage</td>
<td>Coverage</td>
<td></td>
</tr>
<tr>
<td>Hard-Pure</td>
<td>5</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>(14.3%)</td>
<td>(85.7%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>7</td>
<td>22</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>(24.1%)</td>
<td>(75.9%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>10</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(76.9%)</td>
<td>(23.1%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>55</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>(28.6%)</td>
<td>(71.4%)</td>
<td>(100.0%)</td>
</tr>
</tbody>
</table>

Value df Asymp. Sig. (2-sided)
Pearson Chi-Square 18.672 2 .000
Likelihood Ratio 17.326 2 .000
Linear-by-Linear 14.767 1 .000
Association N of Valid Cases 77

a 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.71.
Annex 7: Chi-square analysis for the revised simplex algorithm solution coverage and the disciplines

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>Revised Simplex Algorithm</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard-Pure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Coverage</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>Coverage</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(48.4%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>No Coverage</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(41.4%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>No Coverage</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(100.0%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>(54.8%)</td>
<td>(45.2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(100.0%)</td>
</tr>
</tbody>
</table>

Value  | df  | Asymp. Sig. (2-sided) |
-------|-----|------------------------|
Pearson Chi-Square | 13.346 | 2 | .001 |
Likelihood Ratio    | 18.248 | 2 | .000 |
Linear-by-Linear Association | 6.223 | 1 | .013 |
N of Valid Cases    | 73\(^{b} \) |

a 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.88.
b ‘Not Sure’ options not included

Annex 8: Chi-square analysis for the sensitivity analysis coverage and the disciplines

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>Sensitivity Analysis</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard-Pure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Coverage</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>Coverage</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(22.9%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>3</td>
<td>29</td>
</tr>
<tr>
<td>No Coverage</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10.3%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>No Coverage</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(100.0%)</td>
<td>(100.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>(14.3%)</td>
<td>(85.7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(100.0%)</td>
</tr>
</tbody>
</table>

Value  | df  | Asymp. Sig. (2-sided) |
-------|-----|------------------------|
Pearson Chi-Square | 4.634 | 2 | .099 |
Likelihood Ratio    | 6.239 | 2 | .044 |
Linear-by-Linear Association | 4.559 | 1 | .033 |
N of Valid Cases    | 77 |

a 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.86.
Annex 9: Chi-square analysis of sensitivity analysis coverage intensity and the disciplines

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>Sensitivity Analysis Coverage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Coverage</td>
<td>Slight Coverage</td>
</tr>
<tr>
<td>Hard-Pure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>(22.9%)</td>
<td>(11.4%)</td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>(10.3%)</td>
<td>(10.3%)</td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>(7.7%)</td>
<td>(46.2%)</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(14.3%)</td>
<td>(10.4%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>8.636</td>
<td>6</td>
<td>.195</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>10.485</td>
<td>6</td>
<td>.106</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>7.207</td>
<td>1</td>
<td>.007</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>77</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a 6 cells (50.0%) have expected count less than 5. The minimum expected count is 1.35.

Annex 10: Chi-square analysis of sensitivity analysis coverage intensity for the pure and applied disciplines

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Sensitivity Analysis Coverage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Coverage</td>
<td>Slight Coverage</td>
</tr>
<tr>
<td>Pure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>22.9%</td>
<td>11.4%</td>
</tr>
<tr>
<td>Applied</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>7.1%</td>
<td>9.5%</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>14.3%</td>
<td>10.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>7.700a</td>
<td>3</td>
<td>.053</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>8.000</td>
<td>3</td>
<td>.046</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>6.697</td>
<td>1</td>
<td>.010</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>77</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a 2 cells (25.0%) have expected count less than 5. The minimum expected count is 3.64.
Annex 11: Chi square analysis of computer output/ printout sensitivity analysis for the disciplines

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>Computer Sensitivity</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Coverage</td>
<td>Coverage</td>
<td>Total</td>
</tr>
<tr>
<td>Hard-Pure</td>
<td>14</td>
<td>19</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>(42.4%)</td>
<td>(57.6%)</td>
<td></td>
</tr>
<tr>
<td>Hard-Applied</td>
<td>5</td>
<td>24</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>(17.2%)</td>
<td>(82.8%)</td>
<td></td>
</tr>
<tr>
<td>Soft-Applied</td>
<td>2</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(15.4%)</td>
<td>(84.6%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>54</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>(28.0%)</td>
<td>(72.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>6.097(^a)</td>
<td>2</td>
<td>.047</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>6.131</td>
<td>2</td>
<td>.047</td>
</tr>
<tr>
<td>Linear-by-Linear</td>
<td>4.929</td>
<td>1</td>
<td>.026</td>
</tr>
<tr>
<td>Association</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>75(^b)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) 1 cells (16.7\%) have expected count less than 5. The minimum expected count is 3.64.
\(^b\) ‘Not Sure’ options not included

Annex 12: Regression analysis for mean software usage and the ‘use of media’ approaches to teaching subscale score

Variables Entered/Removed\(^b\)

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average ICT(^a)</td>
<td></td>
<td>Enter</td>
</tr>
</tbody>
</table>

\(^a\) All requested variables entered.
\(^b\) Dependent Variable: Use of Media

Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>(R^2)</th>
<th>Adjusted (R^2)</th>
<th>Std. Error of Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.352(^a)</td>
<td>.124</td>
<td>.112</td>
</tr>
</tbody>
</table>

\(^a\) Predictors: (Constant), Average software

ANOVA\(^b\)

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>(F)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
<td>7.761</td>
<td>1</td>
<td>7.761</td>
<td>10.054</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>54.809</td>
<td>71</td>
<td>.772</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>62.570</td>
<td>72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Predictors: (Constant), Average software
\(^b\) Dependent Variable: Use of Media
Coefficients\(^a\)

<table>
<thead>
<tr>
<th></th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>3.776</td>
<td>.203</td>
<td>18.633</td>
<td>.000</td>
</tr>
<tr>
<td>Average software</td>
<td>.433</td>
<td>.137</td>
<td>.352</td>
<td>3.171</td>
</tr>
</tbody>
</table>

\(^a\) Dependent Variable: Use of Media