Getting to Know QM(s): Exploring the Actor-Networks of Quantitative Methods across Higher Education Social Science Subjects

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This thesis results entirely from my own work and has not been offered previously for any other degree or diploma.

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Signature ....V. Gorton....

Abstract

In the UK, the need for more quantitatively-skilled citizens and employees has been widely publicised. This skills deficit has prompted a wide range of policy initiatives and academic research into quantitative methods (QM(s)) learning-teaching across all levels of education. Although the academic literature has provided useful insights into the learning-teaching of QM(s), it has overlooked key questions concerning the character of QM(s) across Social Science disciplines and the role of non-human actors.

This thesis begins to fill this gap in the literature by adopting Actor-Network Theory (ANT) to explore the learning-teaching of QM(s) within four Higher Education Social Science subjects. To investigate the actor-networks that QM(s) is comprised of, and located within, an assemblage of methods was used, including: semi-structured interviews, concept mapping, participant observation and document analysis. Together, these methods capture QM(s) across Harvey's (2004) three spaces (abstract, relative, and relational), supplementing ANT's own relational understanding of space(-time).

Challenging the passive and singular framings of QM(s), presented within policy initiatives and the literature, here, QM(s) was found to be a character occupying multiple positions of agency, taught content, and locations on participants' concept maps. Within the teaching-learning environments, the construction of QM(s) as linear, fixed and learnt through doing was translated by worksheets and correct answers, producing a characterisation of QM(s) as a passive, linear activity of completing tests. When placed within disciplinary actor-networks, QM(s) was identified as performing a variety of roles: providing patterns/trends; offering reliable answers and predictions; aiding theory testing; and assisting decision-making. However, these positionings were being challenged by new techniques, software, and learning-teaching environments. These findings imply that instead of a focus on differentiating QM(s) knowledge, to successfully integrate QM(s) with disciplinary knowledges attention should be given to QM(s') link to data and theoretical positionings.

Overall, this thesis provides an original contribution to knowledge through its adoption of ANT, a theory not before applied to QM(s) learning-teaching research. In doing this, it challenges common assumptions made within the literature to provide new insights into the character of QM(s) and the role of previously overshadowed non-human actors.

For Matt, the best black lab.

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List of Abbreviations

ACME	Advisory Committee on Mathematics Education
ANOVA	Analysis of Variance
ANT	Actor-Network Theory
A-Level	(General Certificate of Education) Advanced Level
AS-Level	(General Certificate of Education) Advanced Subsidiary level
DCSF	Department for Children, Schools and Families
ESRC	Economic and Social Research Council
GCSE	General Certificate of Secondary Education
GIS	Geographic Information System
GRANTISM	Greenland and Antarctic Ice Sheet Model
GTA	General Teaching Assistant
HEFCE	Higher Education Funding Council for England
IPA	Interpretative Phenomenological Analysis
KS4	Key Stage 4 (incorporating GCSEs)
L	Lecturer (or Teaching Staff Member)
Ofqual	Office of Qualifications and Examinations Regulation
ONS	Office for National Statistics
PISA	Programme for International Student Assessment
PG	Postgraduate
QM(s) or QM(s')	Quantitative Methods or Quantitative methods'
REF	Research Excellence Framework
S	Student
SL	Seminar Leader
RSS	Royal Statistical Society
STEM	Science, Technology, Engineering and Mathematics
STS	Science and Technology Studies
TEF	Teaching Excellence Framework
TIMSS	Trends in International Maths and Science Study
UG	Undergraduate
UK	United Kingdom

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I doubt, however, that even they can profess to know what my research is *actually* about. There are only two people that I can say for certain knew what my research was about and understood it, even when I was clueless: Prof. Paul Ashwin & Dr. Andy Folkard. They have read my scrawled diagrams, listened and provided helpful insights to my ramblings, and most importantly have always believed/trusted me enough to let me get on with "my" research. I couldn't have hoped or asked for two better supervisors.

Finally, I'd like to thank Prof. Carolyn Jackson, whose comments, and assistance, were invaluable.

> While talking through the diagram the lecturer says, "And then we wave our magic wand and say some words and get [some inferential statistics]". He clarifies saying that obviously this is just a metaphor. Continuing he asks, "So how does this magical box called inferential statistics work?"
>
> (Fieldnote: Geography, 1st year UG lecture, QM(s) module)

> The lecturer explains that in doing the binomial test you, "Get a feel for how numbers work".
>
> (Fieldnote: Psychology, 2nd year UG practical, QM(s) module)

1 Introduction

For decades, if not longer, quantitative methods have widely been acknowledged as being of the utmost importance. They have helped in the rise of the nation state (Randeraad, 2010; Reeger & Sievers, 2009), improved standards of hygiene (Attewell, 1998; Kopf, 1916), and participated in the re-writing of the scientific method (Porter, 1995). More recently, quantitative methods have become ubiquitous to our everyday lives (von Roten, 2006). In a time when we are surrounded by supposedly ever-increasing amounts of data, quantitative methods - in the broadest sense of the word - are there to transform these numbers into predictions, models, and answers. These widely valued skills enable us to step into, and make sense of, this world of numbers. Furthermore, they facilitate the creation of new numbers that can travel across time and space, as Latour's (1987) immutable, combinable mobiles (- combinable inscriptions that hold their form while moving across time and space) (Bowker & Star, 1996). Through acquiring these skills individuals are able to make a difference to both their own lives and wider society.

Given their importance, within Higher Education whole modules have sprung up to house - or to present – these methods to students. Yet in historical accounts and the Educational Research literature they are often understood simply as techniques to be used by key humans. In the above narratives of socio-cultural change, it is John Graunt, William Petty, Florence Nightingale, and Galileo that are emphasised as the key players in the unfolding events, not the quantitative methods that they worked with. The quantitative methods themselves remain understood as objects that humans retain agency over or whose agency is hidden away – if indeed they are acknowledged as having any agency.

In these tellings, agency and power lie solely with those that create, apply, and interpret the tests and results/outputs. However even from the most everyday discussions there is a sense that quantitative methods are more than this. Whilst they can be employed to work for us they remain sources of magic and mystery – as touched upon in the quotes included in the opening of this chapter. They misbehave, are boxed up, spit out results, and have a mind of their own - in short, they have a power and agency.

But this is only part of the story. If we acknowledge this agency, as has been done elsewhere in the field of science and technology (i.e. Gad Ratner & Gad, 2016; Cakici, 2016; Ruppert, 2012), then new questions about quantitative methods arise: How does this agency manifest itself? How are these methods changing others' agency and behaviour? And what other actors have been overshadowed in the dominant learning-teaching narratives?

These questions form the starting point of this thesis. However, given the pervasiveness of quantitative methods in our lives there are numerous different pathways and spheres through which the agency of quantitative methods could be traced out. This thesis chooses just one of these spheres – Higher Education. Instead of focusing on historical events, here the classroom is taken as one of the sites where the agency of quantitative methods can be mapped out in current space(-times). It is in this setting that quantitative methods are performed into life through a mixing pot of doing and theorising, where understandings of the character of quantitative methods are constructed and solidified. While all educational sites embody a frontier of knowledge in various ways, for many students Higher Education represents simultaneously the first time quantitative methods are extensively encountered within their discipline and also the final site where they will engage with quantitative methods in a formal educational setting. Given this intersection, Higher Education represents a powerful moment in the construction of knowledge and meaning around quantitative methods, through which the agency of quantitative methods can be explored.

1.1 The Percepts of QM(s): Skills for Everyday

Before discussing how this agency of quantitative methods will be captured – see Chapter 3 – or how this thesis will respond to a gap in the literature – Chapter 2 – we must first examine, in the broadest sense, where the value of quantitative methods lies, what it promises, and why its agency is of interest.

At their simplest, quantitative methods are understood as skills for everyday life, as H.G. Wells allegedly commented, 'Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write' (though the evidence Wells actually stated this is somewhat dubious, see Tankard (1979), the sentiment remains appropriate). They allow the individual to interrogate information essential for the comprehension of weather reports, medical risk, financial planning, and election campaign promises (von Roten, 2006). Given the pervasiveness of quantitative information in our everyday lives, acquiring these skills has become fundamental to becoming good citizens.

While our ability to critically evaluate quantitative data/evidence is vital to our identities as democratic citizens (Tanase & Lucey, 2015), the shift from a manufacturing-based economy to a skills-based economy has ensured that mastery of these skills has also become increasingly important for employment. Given this economic value, assessing the quantitative skills of the current and future workforce has become highly publicised in national statistics and in global rankings (e.g., the Trends in International Maths and Science Study (TIMSS) or the Programme for International Student Assessment (PISA). Recently, these reports have served to highlight the underperformance of the UK. For example, Mason *et al.* (2015) report that adult numeracy skills – here taken as a measure of the quantitative skills of the current and future workforce - in England/Northern Ireland were significantly below average among the 22 participating countries, with England/Northern Ireland being the only country identified where 16-24 year olds had lower numerical skills than 55-64 year olds. Alongside these low skills, Mason *et al.* (2015) also report that there has been a 10-percentage point increase in the number of jobs requiring 'more advanced' quantitative skills from 1997-2012. Given these trends, it becomes clear that possessing quantitative skills has become an increasing comparative advantage for those seeking employment.

As well as benefiting the daily lives and employability of individuals, at the level of the nation state, or corporation, quantitative methods are also of high value, offering a unique way of answering questions, providing – where data permits – an all-seeing eye. Through quantitative methods, knowledge and understandings can be produced that would be unobtainable by individual human perception alone. Such quantitative understandings are often invaluable when it comes to decision making within larger corporations or governments.

Quantitative methods' ability to aid decision-making and produce new knowledge is also highly valued within research and academic settings. Historically, quantitative methods have underpinned the expansion of the scientific method, positivism, and the pursuit of objective truths (Porter, 1995). Although these links to specific epistemologies have become increasingly severed, quantitative methods remain a valued approach across academic disciplines, providing a means through which to test, model and predict theories and aid the answering of research questions.

1.2 Changing Promises of QM(s)

For corporations, governments, and academics, much of the appeal of quantitative methods lies in its ability to provide reliable answers to specific questions, thus aiding decision-making and knowledge production. Most commonly, these answers have been generated through null hypothesis testing, and the quantification therein of the "significance" of differences, relationships, or other patterns within datasets as *p*-values. However, recently, this method has come under threat from the *p*-value crisis and the rise of big data.

1.2.1 <u>*P*-value Crisis</u>

The *p*-value developed its recent identity - as a marker of statistical significance and a measure of the plausibility of a hypothesis - through a misapplication of Fisher's original *p*-value to Neyman and Pearson's framework for data analysis (Nuzzo, 2014). Instead of the currently-common interpretation of a *p*-value of 0.01 as equating to a 1% chance of a false alarm, Selke *et al.* (2001) argue that the chance of a false-alarm is at least 11%, depending on the probability of there being a true effect. Confusing these two probabilities has led to a crisis where the accuracy of published research findings has been called into question, with potentially underpowered clinical trials, or exploratory epidemiology studies, producing true findings as little as one in four or five times (Ioannidis, 2005).

Within academia, this problem has been further exacerbated by publication bias and *p*-hacking. Currently, often only those studies reporting positive results are published, meaning that negative data, that could be used to generate more accurate estimates of the effect, is lost (Colhoun *et al.*, 2003). Given this publication bias and the increasing pressure researchers are under to continually publish (Miller *et al.*, 2011), the phenomenon of *p*-hacking has emerged. Characterised by Simonsohn *et al.* (2013), *p*-hacking is the conscious or unconscious activity of searching for a specific result and not publishing those analyses that produce non-significant results. *P*-hacking is generated through practices such as, analysing data midway through to decide if more data should be collected, excluding variables or outliers post-analysis, or including or removing a covariate (Head *et al.*, 2015; Simmons *et al.*, 2011). Simonsohn *et al.* (2013) argue that through *p*-hacking most studies can produce significant relationships for variables that are actually unrelated.

While these issues are not new (Sterling, 1959), the extent of this problem remains cause for concern: one study suggests evidence of *p*-hacking can be found in published work across scientific disciplines (Head *et al.*, 2015). Remedying this problem relies on more than a change of statistical tests, as many of the practices that lead to *p*-hacking are accepted scientific practice. John *et al.*, (2012) found that 78% of a sample of 2,000 anonymous psychologists responded that they had not reported all dependent measures, 72% had collected more data after looking to see if their results were significant, and that one in ten had introduced false data.

The *p*-value crisis, and the associated practice of *p*-hacking, represent a significant challenge to the promise of hypothesis tests, and quantitative methods, as providers of reliable answers. Breaking down this promise of unrivalled reliability, and objectivity, however has not destroyed the value or appeal of quantitative methods, with – as discussed in Chapter 7 – new methods, and practices emerging to mitigate these issues.

1.2.2 Big Data

While the *p*-value crisis has questioned the common promise of quantitative methods as providers of reliable answers, the big data revolution has enabled quantitative methods to make new promises.

We are now producing far larger quantities of data than ever before, quantities so vast that they are unable to be stored within conventional computer memory (Mayer-Schonberger & Cukier, 2013). With this new data, attention has shifted from quantitative methods' ability, through statistical tests of inference, to provide reliable answers, to quantitative methods as describers/translators of hitherto-unseen scales.

The term big data, itself, refers to, 'things one can do at a large scale that cannot be done at a smaller one, to extract new insights or create new forms of value, in ways that change markets, organisations, the relationship between citizens and governments, and more.' (Mayer-Schonberger & Cukier, 2013: p.6). This phenomenon, which was initially observed in astronomy and genomics, is now common across many fields. For example, the growing influence of big data within Education can be evidenced by the rising interest in learning analytics. These quantitative measures of student performance are thought to offer a way to monitor and improve students' learning and teachers' teaching, even if concerns have been voiced over the assumptions these technologies make about learning-teaching (see Knox, 2016; 2014).

More broadly, warnings have also been issued over the role private companies play in big data, as often it is these companies that are the sole purveyors of the information, limiting access to the data or the methods of analysis (Davies, 2017). Despite these concerns, big data, nonetheless, poses an interesting challenge to the current promises made by quantitative methods. Mayer-Schonberger & Cukier (2013) argue that the big data approach shifts attention from causality (questions of why) to correlation (questions of what). Thus instead of the hypothesis tests decision-makers have come to rely on, big data shifts attention to methods of correlation and modeling, bringing with it a new face of quantitative methods – a claim expanded upon in Chapter 7. Nevertheless, big data remains heralded as an asset to decision makers, allowing them to see/observe at scales never before accessed.

While not changing the quantitative methods used by the individual citizen, the *p*-value crisis and the big data revolution do offer potential to change the promise of quantitative methods for governments, corporations and academics. Nonetheless, quantitative methods remain broadly valued for their ability to provide answers across these sectors.

1.3 Skills Deficit: Policy Initiatives

With such wide-ranging values attached to quantitative methods, it is perhaps no surprise that the demand for these skills is currently outstripping supply in the UK. This skills deficit has been widely publicised in a series of government reports (Campion *et al.,* 2015; UKCES, 2015; Winterbotham *et al.*, 2014). One of the most influential reports in the last ten years of this kind was the Vorderman report (2011), which detailed that almost half of all students were failing GCSE Mathematics, and that only 15% of students were studying mathematics beyond GCSE, raising concerns over the quantitative skill set of the future workforce. This report brought the problem of adequate quantitative skills provision into the public eye, highlighting the underachievement of UK in mathematics, and quantitative skills more broadly, the impact of which has continued to be investigated (Mason *et al.*, 2015).

1.3.1 Solving the Problem

Numerous solutions have been proposed to this deficit, however, at its simplest, policymakers have characterised this problem as one of education. Namely, that by improving the teaching of, and exposure to, quantitative methods throughout the education system students will be channelled more efficiently out into the working world where they will have the necessary skills to be competent workers. For the purposes of this study, I have chosen to focus on three specific approaches adopted by policy makers to address the problem in this way: increasing enrolment into Science, Technology, Engineering and Mathematics subjects, changes to Primary and Secondary Education curricula, and changes to quantitative methods in Higher Education Social Science subjects.

The first approach adopted to remedy the skills deficit focuses on encouraging more students into Science, Technology, Engineering and Mathematics (STEM) subjects. Specific initiatives working with this aim have been widespread, in the UK the STEM Mapping Review (2004) outlined 470 science initiatives designed to motivate students to continue with science and mathematics beyond compulsory education. These schemes have concentrated on providing a wide range of activities, including: role models, mentoring schemes, career guidance, scholarships/bursaries, summer schools, and other hands on experience at laboratories and research centres (DCSF, 2004; Banerjee, 2015). One recent example of such initiatives is the government-industry-education collaborative programme Smart Futures (2014); supported by a range of public and private bodies, this programme aims to promote STEM careers to secondary school students, by increasing awareness of STEM careers through industry-education partnerships, careers information, and co-ordinating and expanding outreach programmes.

As well as improving and providing resources for all students, targeted schemes have also been developed. Organisations such as the Wise Campaign and Women in Stem have sought to particularly encourage women into STEM subjects. In addition, targeted schemes have been applied to improve the teaching of STEM, with teaching bursaries of £15-25,000 offered to those studying and/or achieving good degrees in Physics, Mathematics, Computing and Chemistry (Daly, 2014).

These initiatives, and this problem, are not unique to the UK. For example, the Australian Government recently allocated an extra AUS$12 million to increase the number of students taking STEM subjects in primary and secondary schools. Similar to the activities identified in the UK STEM Mapping Review, the 'Restoring the Focus on STEM in Schools' (Department of Education and Training, 2015) initiative provides: funding for resources; changes to the curriculum by introducing computer coding; new educational approaches; and the introduction of summer schools for STEM students.

Whilst popular, the success of these schemes has yet to be seen. While such interventions have improved the GCSE scores in participating schools, the socioeconomic status of the school is still a greater factor in predicting the overall attainment in mathematics and science (Banerjee, 2015a). Alongside this, in their 'Closing Doors' report (2013) the Institute of Physics has drawn attention to the patterns and causes of gender imbalances present within STEM education. In their study, they reported that a higher proportion of female students were found within English, Biology, and Psychology A-Levels compared to Physics, Mathematics and Economics A-Levels, in which there was a skew towards a greater proportion of male students. They suggest that the progression rates into subjects were dependent on the whole school environment, as no correlation was found between the progression to A-Level subjects and socio-economic status (measured by percentage of students receiving free school meals) or with school size (measured by the number of students at the end of KS4).

Similarly, the provision of sources of funding for incentives, course changes and promotional material has recently been challenged by the Tough Choices report (A.T. Kearney & Your Life, 2016). This reported that boys' and girls' interest in mathematics and science declined by 56% and 74% respectively during secondary school - a phenomenon they term the 'Great British Science Turn-Off' (A.T. Kearney & Your Life, 2016: p.2). In this report the authors provide an alternative narrative to the problem of the low uptake of STEM subjects, namely that students often see these subjects as a dead end. This understanding, they argue, is based upon:

- Student's lack of knowledge about the range of careers that STEM subjects underpin.
- The decline in the practical elements of mathematics and physics curricula, which reinforces the lack of relevance to careers.
- Teachers and parents prioritising good grades and so steering students away from STEM subjects.
- STEM subjects being perceived as only for the "ultra-bright", reinforced through school policy, teachers, parents, and peers.
- Empirical evidence that suggests that higher grades are harder to achieve in STEM than vocational subjects.
- Girls seem to be put off by the "masculine" image of STEM subjects.

(A.T. Kearney & Your Life, 2016: p.2–3)

While increasing the uptake of STEM subjects represents one approach taken to increase the number of quantitatively skilled individuals, this report calls into question characterising the deficit as purely an economic problem that can be remedied by financial stimulus. The points outlined by each of the reports above suggest that unlike other calls for improvements in teaching, the problem is more of a social phenomenon than has previously been acknowledged, involving challenging beliefs around the nature of STEM subjects and the school environment which are turning off students.

1.3.2 Changing Curriculum

Alongside initiatives to change the attitudes and encourage students into STEM subjects there have also been structural changes to the curriculum within many sectors of compulsory education. Whilst there have been changes to increase the difficulty and to integrate quantitative material across the curriculum in primary schools (Department for Education, 2014), of greater relevance to this thesis are the changes that have occurred at GCSE and A-Level.

Following a government consultation, changes have been made across GCSE subjects, with course design being shifted from a modular to a linear structure, with exams taken at the end of two years of study. Across all the subjects included in this study, content at GCSE has been made more demanding and a new grading scale from 9-1 introduced. Reflecting the problems identified in the Tough Choices (2016) report, practical requirements have been increased in science subjects, though their contribution towards the final assessment has been reduced (Ofqual, 2016).

As well as changes to the structuring of courses, emphasis has been placed on increasing the quantitative content included within GCSE subjects. Across all the four subjects relevant for this study (Criminology (included as part of Sociology GCSE and A-Level), Economics, Geography, Psychology) students are required to have basic numerical skills, including using percentages and ratios (Department of Education, 2016; Department of Education, 2015a; Department of Education, 2015b; Department of Education, 2014). Furthermore, students are expected to understand and evaluate different research methodologies - including sampling and data types - and calculate basic statistics, such as measures of central tendency and correlation. In addition to these skills, which are found across all the subjects, Geography specifies students should also be able to understand and interpret cartographic/geographic elements such as gradient and population pyramids.

Similar to the changes made to GCSEs, A-Level courses have also been re-structured to be linear over two years, with the separation of AS Level and A-Level courses (Ofqual, 2016). Given the two-year gap, identified in the Vorderman report (2011), and by others (ACME, 2011), between compulsory GCSE Mathematics study and university study, strengthening the quantitative content embedded within A-Level subjects has been a key priority.

Mirroring GCSE, across all subjects, students will be expected to have basic skills in numerical computation and descriptive statistics (Department for Education, 2014a; Department for Education, 2014b; Department for Education, 2014c; Department for Education, 2013). At A-level, however, students are also expected to be able to choose appropriate statistical tests of inference, and to interpret the results. Specifically in Economics, students are expected to calculate elasticity and convert from money to real terms. For A-Level Geography, students are expected to undertake a minimum of four days of fieldwork and work with geo-located data. Whilst not specified in the Sociology or Psychology documentation, for Geography (Department for Education, 2014f) this quantitative content should form 10% of the overall assessment and in Economics 20% (Department for Education, 2014e).

Across both GCSE and A-Level these quantitative specifications represent a direct intervention by the government, and other stakeholders, to improve quantitative skills for all students irrespective of their enrolment on A-Level mathematics. Through embedding skills in subjects other than STEM subjects it is hoped that quantitative skills of all students will improve, supporting their transition into either the workplace or further education.

1.3.3 Higher Education

So far we have seen how solutions to the skills deficit have involved increasing the number of students in STEM subjects and changes to the curriculum of primary and secondary education. However, it cannot be overlooked that there are currently many more students enrolling into arts, humanities, and social sciences degrees than STEM degrees. In 2015-16, 307,000 students entered degrees in arts, humanities and social sciences, compared to only 93,000 students entering degrees in STEM subjects in the same year (HEFCE, 2017). Hence, whilst the broader focus is on encouraging more students to enter STEM subjects, the final approach to solving the deficit has been to increase the quantitative skills present within Social Science degrees to equip these students with the key skills required for employment.

Driving change at a programme level across the country is an initiative called Q-Step - a collaboration between the Economic and Social Research Council (ESRC), Higher Education Funding Council for England (HEFCE), and the British Academy. This initiative consists of a £19.5 million investment (Nuffield Foundation, 2017), delivered over five years, designed to improve the quantitative skills provision within UK Higher Education Social Science subjects. Across the UK, 15 different universities were allocated funding to develop new undergraduate and postgraduate modules and programmes, and to aid the transfer of students towards specialist quantitative methods postgraduate courses to further develop their skills.

The initiative was designed to have a trickle-out effect, with the findings being circulated to other universities, as well as a sharing of the expertise and resources developed through the programme (Nuffield Foundation, 2017). In addition to new courses and degree programmes, the scheme also aimed to cultivate ties between schools - through sending students into schools to talk about quantitative methods - and with employers - through consulting employers on relevant skills they would like to see graduates have and through work placements (which four of the universities have offered (Nuffield Foundation, n.d.).

Alongside this large-scale initiative, there is also a range of smaller scale financial incentives offered as a stimulus by individual funding bodies and universities to individual students to increase the uptake of courses including ‘advanced’ quantitative methods. These initiatives represent the final approach to solving the skills deficit within the UK, attempting to raise and promote quantitative methods to the large numbers of students who fall outside of the STEM targeted schemes, however, at present, their effectiveness has yet to be evaluated.

1.4 Contribution of this Thesis

Each of these three areas – increasing enrolment into STEM subjects, changes to Primary and Secondary Education curricula, and changes to quantitative methods in Higher Education Social Science subjects - represents one attempt to solve the problem of the UK quantitative skills deficit. However, each of these approaches rests on a shared characterisation of the learning-teaching environment as a site of unproblematic uptake of knowledge.

Given the importance of these imagined sites of transfer, increasing attention has been given to examine the learning-teaching of quantitative methods, with research asking: How should courses be designed, assessed, and delivered? What are the problems faced by students and staff when learning-teaching these courses? What role can computers, technology, and software play in aiding the learning-teaching of quantitative methods?

In the Literature Review, research responding to these questions will be examined and the assumption of an unproblematic transfer of knowledge between teacher and student will be problematized. In Section 2.2, a gap in the literature is identified through critically examining the assumptions this literature makes. Firstly, this literature frequently focuses on only the human actors present within learning-teaching environments (as seen in Garfield's (1995) principals). Secondly, these learning-teaching environments are characterised as abstract space(-times), bounded by a single module (Strangfeld, 2013; Becker *et al.*, 2006; Folkard, 2004). Finally, despite a desire to develop universal best practice (Garfield & Ben-Zvi, 2007), there is little cross-disciplinary discussion across the literature (Parker, 2011; Wagner *et al.*, 2011).

Having identified this gap in the literature, this thesis aims to explore the learning-teaching environments through a different lens, foregrounding those non-human actors that are often overlooked in educational research narratives – see Section 2.5. Chapter 5 responds to the first assumption made by the literature, illustrating how non-human actors, that are often overlooked, play an important role in quantitative methods learning-teaching environments. Here, worksheets, choice diagrams, and correct answers will be highlighted as actors controlling the actions of staff and students when performing quantitative methods. These actors translated quantitative methods (QM(s)) into an actor characterised by following and obtaining correct answers, which was markedly different to other kinds of disciplinary knowledge and to performances of QM(s) involving the use of statistical software. This supports work by others (Gorur, 2013; Fox, 2009; McGregor, 2004) that has also demonstrated the importance of non-humans in other educational settings.

By investigating how QM(s) are performed and conceptualised across Higher Education Social Science disciplines this thesis offers an understanding not only of what QM(s) is but what agency it has and how such agency is changing. In Chapter 4 and 6, a detailed account is provided of the different conceptions actors have over the relationship to, and role of QM(s) in their discipline. It is argued that a shared curriculum aligned the views of staff and undergraduate students towards of the relationship of QM(s) to their discipline, and that the data types accessed and cultivated by different disciplines controlled disciplinary narratives of the character and role of QM(s). These chapters provide a response to the second and third assumptions made by the literature, answering calls for greater cross-disciplinary discussion of research methods learning-teaching literature within the social sciences (Wagner *et al.*, 2011), and further study on interactions occurring across module boundaries (Parker, 2011). The disciplinary differences outlined here provide evidence to support the call for greater cross-disciplinary discussion, at both a national and international scale. This is of particular importance, and urgency, given the varied character of QM(s) presented here, which poses a serious challenge to the drive to identify, and implement, a universal best practice.

Building on this, by understanding the actor-networks comprising QM(s), we can begin to consider new ways to change the learning-teaching performances of QM(s) in Higher Education Social Science subjects in a way that is sensitive to the disciplines they are found within, and other key actors. In Chapter 7 and 8, attention is given to describing how performances of QM(s) learning-teaching are currently changing and how these performances may be repackaged in the future. Due to a variety of factors, QM(s) learning-teaching is increasingly making use of new techniques and data and new spaces (such as new learning-teaching environments and new placement in modules). Whilst these changes are likely to give rise to new characterisations of QM(s), it is suggested that the integration of QM(s) into disciplinary knowledge relies on reinforcing QM(s) link to data and theory.

Most importantly, this thesis provides evidence for a characterisation of QM(s) as being both singular *and* multiple, bringing a complexity and multiplicity often found in Science and Technology Studies (STS) to educational research on quantitative methods. Through doing this, this thesis makes a key first step in getting to know QM(s), and its non-human allies, providing a new account of the learning-teaching environments QM(s) is associated with in Higher Education Social Science subjects.

1.5 Structure of the Thesis

For clarity, the thesis will be structured as follows. As previously mentioned, literature surrounding quantitative methods learning-teaching will be reviewed in the following chapter, along with a statement of the study's aims. Particular emphasis will be given to problematizing the assumptions inherent in this literature, as well as identifying how Actor-Network Theory and Harvey's (2004) three spaces can be used to provide an alternative characterisation of the learning-teaching environments.

These discussions will be continued in the Methodology Chapter where a detailed account will be provided of how these theoretical frameworks have informed the methods adopted within this study. This chapter will also detail how the methods chosen challenge the assumptions identified in the Literature Review and enable the aims of the study to be achieved.

Following this, a series of chapters will trace out the multiple faces of QM(s). In Chapter 4, QM(s) will be located within words, courses, and concept maps, challenging the characterisation of QM(s) as a unified object across Social Science subjects. Following this, Chapter's 5 and 6 will explore QM(s) as a performed character, tracing out the actor-networks comprising QM(s) in the classroom and in each of the disciplines. Chapter 7 will consider QM(s) as a changing actor-network, postulating how its character may change in the future in response to perceived threats. Finally, Chapter 8 will discuss the implications of these sides of QM(s) for the learning-teaching of QM(s) and considers how QM(s) could be repackaged within Higher Education Social Science subjects in the future.

Once these have been presented the study will be evaluated in Chapter 9, with particular attention given to the experience of working with Actor-Network Theory in an Educational Research context. This thesis ends with a summary of the project, before outlining areas of future research.

1.6 Terminology

Before we can begin to explore the literature surrounding the learning-teaching of quantitative methods it is worth clarifying and defining several key terms – quantitative methods (QMs), learning-teaching, space(-time), and Social Science - used throughout this thesis.

1.6.1 QM(s)

Despite the prevalence of quantitative methods there has been very little discussion about the term itself. In the academic literature, attempts to define quantitative methods are often centred around what kinds of techniques quantitative methods teaching should cover (i.e. Johnston *et al.*, 2014). Across the literature there is an assumption that this term is universally understood, and can be used universally across all environments.

To begin to understand the meaning of the term itself, we must turn to its entomological roots. Breaking the term down, 'quantitative' is thought to stem from the Latin 'quantitas' pertaining to greatness/quantity/sum/amount. It is usually defined as 'relating to, measuring, or measured by the quantity of something rather than its quality' (Oxford English Dictionary, 2017). Secondly, 'methods' derives from the Greek 'methodos' referring to the pursuit of knowledge (Oxford English Dictionary, 2017a), and is understood as an organised or systematic way of doing. Thus, bringing these descriptions together, we can understand the term, quantitative methods, at its simplest, as being used to refer to a systematic way of measuring something.

When starting the research, the breadth of this term seemed to offer a way to capture both the overall thing that was being studied and the thing present in participant's imaginations and performances. However, as the fieldwork progressed it became increasingly clear that multiple terms were being used simultaneously and synonymously. In particular, during the interviews 'Quantitative Methods' and 'Statistics' were used interchangeably by the researcher to help explain the scope of the research and by the participants across disciplines. Unlike QM(s), Statistics has had a greater institutionalised history, thus was more universally understood. Whilst having a similar application, the term originally comes from the Latin 'status', or German 'statistik', each of which refer to the idea of a political state (Federer, 1991). To this day, statistics retains its role as a state tool through institutions such as the Office for National Statistics (ONS), whilst becoming formalised and institutionalised through organisations such as the Royal Statistical Society (RSS).

The frame of reference of quantitative methods was further complicated as in certain disciplines, such as Economics and Psychology, instead of ‘quantitative methods’ numerical and statistical elements were overly labelled as ‘Statistics’ or ‘Econometrics’ and not ‘Quantitative Methods’. When writing this account, this problem of communication resurfaced again, with the need to differentiate between the various qualities of quantitative methods, such as QM(s) as a method, a series of statistical techniques, as numerical handling, as well as QM(s) identity as an actor in various other actor-networks.

This confusion reflects the confusion present in the literature surrounding quantitative methods, with QM(s) often being understood as being comprised of, or existing alongside, elements such as quantitative skills, statistics, or numeracy. Within working environments, employers often talk about numeracy or numerical skills (Mistry *et al.*, 2009), while in the Q-Step initiative, terms such as ‘quantitative-skilled’ and ‘quantitative social science training’ (Nuffield Foundation, n.d.: n.p.) are used - yet nowhere are these terms defined. Alongside this, the literature too blurs the relationship of QM(s) and statistics. Within some academic textbooks quantitative methods are introduced as statistics (Reid, 1987); in others statistics is seen as part of quantitative methods (Harris, 2016); and in others quantitative methods are defined as being anything involving numbers (Gorard, 2001). Similarly, in degree courses quantitative methods can be found positioned against qualitative methods, or in mixed modules, often falling under the category of “research methods” or “techniques”.

Accompanying this mass of overlapping terms is a discussion over the relationship between quantitative methods and mathematics, where, similar to statistics, QM(s) can be understood as separate to, overlapping with, or part of Mathematics or Mathematics as part of QM(s). For example, in the broader teaching literature, there is talk of “mathematics” or “statistics” anxiety, and not “quantitative methods” anxiety. In some cases, these students are described as “mathophobic” – not quantaphobic – identifying these elements as mathematical, not simply quantitative. Continuing this overlap, courses can require a background in mathematics, but not in statistics – reflecting A-Level divisions - while taught quantitative methods context can overlap with other concepts such as the experimental method and positivism.

Presented as such, QM(s) can be understood as an example of Star's boundary object (Star, 1989; Star & Griesemer, 1989) with different groups using the same term but in different ways, each with different interests. In each of these worlds, these terms are being deployed to hook onto different political debates, to assimilate associated issues, and to draw attention to different scales of interaction.

Whilst Actor-Network Theory often requires a closeness to be maintained to the language of participants, here a term was needed that would provide some clarity. A system whereby the collective and singular qualities of QM(s) could be referred to, preferably simultaneously. For the purpose of this account, to differentiate the assembled 'thing' presented in this account from that referred to as quantitative methods in the literature, and that referred to by participants, the term 'QM(s)' has been adopted. This term represents a compromise between using participants' own language, favoured by Actor-Network Theory (Latour, 2005), whilst recognising the need to acknowledge the collective (QM) and multiple ('s') identity of QM(s) itself.

Given the ambiguity of the term, here the scope of the term was kept as broad as possible with QM(s) understood as referring to anything that involved numbers, or their generalised abstractions (i.e. algebra), in any form. In doing so the characteristics of QM(s) drawn out in this account can be understood to reflect participants' understandings, not simply those predefined within the literature.

1.6.2 Learning-Teaching

The second term requiring discussion is the hyphenated learning-teaching. Following Wittgenstein (Biletzki & Matar, 2016) we can understand that all words can only be understood when they are placed in relation to other things, forming language games. For example, when someone picks up the king in chess, and says 'this is the king', one can only understand what the statement means if one also understands the rules of the game of chess and the actions that the piece can do. The implication is that, as well as providing a term of reference, or description, language provokes a variety of actions, and works within a system of rules.

Applying this principle to our context, students or staff, or indeed any actor within the learning-teaching environment, cannot be understood without reference to the rules of both learning and teaching. As Ashwin (2009) describes, instead of "teaching and learning" or "learning and teaching", the hyphen in "teaching-learning" is added to acknowledge that 'they are different aspects of the same processes in which students and academics engage together' (p.2).

Following Ashwin (2009) I adopt this term to acknowledge both a constructivist understanding of the learning-teaching environment and a wider relativist understanding of space(-time) and language. However, given the Actor-Network Theory sensibilities adopted here, I would extend Ashwin's characterisation of the learning-teaching environment to include other actors, particularly non-human actors. Similarly, whilst for Ashwin the ordering of the terms is irrelevant - given that they are both constructions of the same thing - within this thesis the term has been reversed to be "learning-teaching", not only for alphabetic reasons, but to acknowledge that these environments are focused primarily on as sites of learning, which could not occur without some form of teaching, instead of vice versa.

Finally, Ashwin considers that the undergraduate and postgraduate taught and research programmes can have the same arguments applied to them, so the term does not refer specifically to undergraduate interactions. For this study, students and staff were spoken to across both undergraduate and postgraduate levels of quantitative methods learning-teaching. However, unlike Ashwin, the results presented appear to suggest that there are different understandings and dynamics present at different education levels, reflecting the different goals. Despite this variation, here the same term is adopted, nonetheless, to describe interactions occurring at both undergraduate and postgraduate levels.

1.6.3 Space(-time)

As will be outlined in the Literature Review, this thesis has been developed with reference to Harvey's (2004) three space matrix. As such, here, I have chosen to adopt the term 'space(-time)' to acknowledge that space cannot be understood without acknowledging its relationship to time. However, given the primary focus in this thesis on the characterisation of QM(s) across disciplinary spaces, both physical and imagined, here the 'time' has been bracketed.

1.6.4 Social Science

This thesis responds to Wagner *et al.*'s (2011) call for further study into the similarities and differences of research methods learning-teaching across, specifically, the social sciences. While this choice will be commented on in Section 2.2, and Section 3.5, where the specific subjects included in this study will be listed, here it is worth providing a short note on the definition of a Social Science subject. Given the blurriness of academic disciplines, no attempt will be made to argue for a separation of the social sciences from other disciplines. Here a pragmatic choice was made to work to the definition provided by the ESRC. For them, social sciences are characterised as: 'the study of society and the manner in which people behave and influence the world around us' (ESRC, 2017: n.p.). This understanding represents a definition in current use, as opposed to one informed through historical reflection (such as Biglan (1973) or Kolb (1981) who both drew on Kuhn's (1962) work), nor is it is based on a definition attempting to differentiate the kind of knowledge disciplines are involved with (as Smart *et al.*'s (2000) does). For the ESRC, Social Science disciplines include:

- Demography, Social Statistics, Methods and Computing;
- Development Studies, Human Geography, Environmental Planning;
- Economics, Management and Business Studies;
- Education, Social Anthropology, Linguistics;
- Law, Economics and Social History;
- Politics, International Relations;
- Psychology, Sociology;
- Science and Technology Studies;
- Social Policy, Social Work

(ESRC, 2017a: n.p.)

2 Literature Review

In the Introduction, current initiatives aiming to rectify the quantitative skills deficit were traced out. From this, we saw that, for policy makers, the skills deficit has been conceptualised as a problem of learning-teaching, with initiatives often resting on a model of the unproblematic transfer of knowledge from staff to students.

Given the potential impact of the skills deficit, the implementation of policy initiatives has been accompanied by a growth in academic research literature on the learning-teaching of quantitative methods, which has devoted considerable attention to identifying obstacles to quantitative methods learning-teaching and defining 'best practice'. In this chapter, this literature will be critically examined asking: 1) To what extent can learning-teaching of quantitative methods can be understood as an unproblematic transfer of knowledge? 2) What assumptions are made by this literature in its conceptualisation of QM(s) learning-teaching?

Having outlined these assumptions, the Literature Review will then discuss how Actor-Network Theory can be used to give a different understanding of the learning-teaching of QM(s). Given the criticisms of Actor-Network Theory, it will also detail how Actor-Network Theory has been supplemented in this study by a focus on performativity and Harvey's (2004) three-space matrix. The Literature Review will end with a statement of the aims of the study before presenting the Methodology in Chapter 3.

2.1 Learning-Teaching QM(s)

Amongst the UK general public, there is a widespread mistrust of statistics (European Comission, 2007) and scientific institutions (Achterberg *et al.*, 2015). Within schools, low progression rates to A-Level (outgoing syllabus) have been related to students viewing mathematics as abstract and irrelevant (Brown *et al.,* 2008). These negative attitudes are carried through into Higher Education courses, with quantitative methods modules being viewed by students as stressful and one of the most difficult modules taken within their degrees (Gladys *et al.*, 2012; Murtonen & Lehtinen, 2003). In some disciplines, for example sociology, students are reported as finding quantitative methods of little relevance to their disciplines or as having an anti-quantitative mindset (Williams *et al.*, 2007; Murtonen & Lehtinen, 2003). Even in disciplines such as psychology, students still possess negative attitudes towards quantitative methods, viewing courses with dread, despite acknowledging their value (Coetzee & van der Merwe, 2010; Conners *et al.,* 1998).

Challenging, or navigating, these attitudes is a key obstacle faced by students and staff. Research has shown that these negative attitudes are often related to students' prior experiences with mathematics (e.g. Dempster & McCorry, 2009; Fiore, 1999), and not to students' ratings of the difficulty of the course material (i.e. those who find QM(s) easy do not necessarily rate quantitative methods modules higher) (Murtonen & Titterton, 2004). Interestingly, Tempelaar *et al.* (2007) report that negative attitudes held by students do not correlate with course/test/assessment performance, however this relationship is not found across all studies (i.e. Harlow *et al.*, 2002). Irrespective of the impact that these negative attitudes have on students' course performance, negative attitudes remain a challenge for QM(s) learning-teaching.

Alongside these widespread negative attitudes another factor identified as being an obstacle to student's learning of quantitative methods is mathematics or statistics anxiety. As detailed by Ozwubeie *et al.* (1997), this term denotes a fear or anxiety experienced by some students towards anything mathematical or statistics-related. This anxiety represents a major barrier to their learning of quantitative methods, resulting in students avoiding quantitative content, procrastinating, and lowing their confidence in their abilities in mathematics/statistics (Onwuegbuzie, 2004; Onwuegbuzie & Wilson, 2003; Onwuegbuzie, 1997). Prevalence of such anxiety is though to be high, with Zeidner (1991) documented it as affecting over 70% of students in one study, or between 67-80% of students in another (Onwuegbuzie & Wilson, 2003). Mathematics/Statistics anxiety has - akin to general negative attitudes - been linked to prior negative experiences in mathematics/statistics, as well as the pace of instruction, and instructor's attitude (Malik, 2015; Pan & Tang, 2005; Cornell, 1999; Jackson & Leffingwell, 1999). Studies have found mixed results correlating this anxiety with course performance, with most detailing a negative impact (Onwuegbuzie, 2000; Zanakis & Valenzi, 1997; Onwuegbuzie & Seaman, 1995; Lalonde & Gardner, 1993), however the strength of this relationship varies across studies and instruments used to measure achievement (Ma, 1999). Nonetheless statistics anxiety remains a key focus for quantitative methods researchers and for staff and students.

In addition to statistics anxiety, course performance in Higher Education quantitative methods modules has been linked to students' abilities, their perception of their own abilities in mathematics and their application of themselves to the subject (Dempster & McCorry, 2009; Onwuegbuzie, 2003; Tremblay *et al.*, 2000; Lalonde & Gardner, 1993). However, as described in the Introduction, within the UK, mathematical ability is commonly understood by students as being confined to the 'ultra-bright' who appear to have a 'natural' aptitude at the subject (A.T. Kearney & Your Life, 2016). Set against this background, encouraging students to consistently apply themselves to increase their skill and confidence in mathematics/statistics remains a difficult obstacle for staff, especially where students have statistics anxiety (Paxton, 2006). Furthermore, in social science contexts these modules are often short, bolt-on modules (Agnew, 2000) which, when coupled with the two-year gap between compulsory mathematics education and degree courses and the low course weighting, mean that even before commencing the module students come to see these modules as something to 'get through' and assume that their performance will be poor (Paxton, 2006).

This situation is also complicated by the fact that quantitative methods courses require mastering a different skill set than other elements of a degree course (Garfield *et al.,* 2002). Quantitative material is often highly abstract with students only coming to understand and appreciate these skills when completing their dissertations, or when employed (Paxton, 2006), long after quantitative methods modules have been completed and assessed.

Furthermore, not only is material abstract but statistical ideas of probability and reasoning have been found to be particularly difficult for the human brain to process (i.e. Kahneman, 2011). Linked to this, quantitative methods have been described as encompassing a range of different skills, all of which must be accomplished for successful learning. These skills, as described by delMas (2002), can be broken into three areas – quantitative literacy, reasoning, and thinking – thought to be related to different tasks, see Table 2.1. Garfield (2002) has documented how students struggle to develop statistical reasoning through quantitative methods courses, warning while students may perform well in tests they often only have limited statistical reasoning skills needed to correctly evaluate and interpret statistical information. These problems can be characterised as students learning quantitative methods through a mathematical lens, understanding quantitative methods as a series of techniques and mathematical equations, without acquiring the necessary statistical lens through which to view these methods (Kennedy, 1998).

Basic Literacy	**Reasoning**	**Thinking**
Identify	Why?	Apply
Describe	How?	Critique
Rephrase	Explain (the process)	Evaluate
Translate		Generalize
Interpret		
Read		

Table 2.1 Tasks that distinguish the three instructional domains of statistics (taken from delMas, 2002: n.p.)

In particular, this literature has documented that students struggle with specific concepts such as: averages, probability of an outcome, representativeness of samples, categorizing and representing data, uncertainty and randomness, and judging association between variables (Delmas *et al*., 2007; Garfield, 2002; Garfield & Ahlgren, 1998).

Problems are not only faced by students. As well as having to navigate the student problems outlined above, staff can also suffer from statistics/mathematics anxiety (Brady & Bowd, 2005; Blalock, 1987). For Lewis-Beck (2001), this anxiety stems from instructors feeling unable to teach the perceived necessary level of mathematical rigor, suffering from their own fears of 'getting it right'. These issues are also compounded by the convention that junior staff are often given quantitative methods modules teaching as their first teaching assignment (Gorton, 2012; Williams *et al.,* 2004).

While this anxiety - and other issues faced by staff - are relatively under-researched there is evidence that even when staff are confident with the material they are teaching, they experience difficulty covering all the material in the often-limited allocated teaching time (Slootmaekers *et al*., 2013). This is particularly problematic given the limited backgrounds of students, with over 80% of English 19 year olds studying non-STEM degrees at UK universities reported not to have a mathematics qualification beyond GCSE (Smith, 2017). These mixed abilities and anxieties of students mean the material often needs to be started from a lower level of difficulty and worked through slower (Malik, 2015), increasing the teaching time required.

Similarly, as quantitative methods modules are usually compulsory for all students these modules can have heavy workloads with lectures, workshops, and seminars being run repeatedly. Furthermore, these modules commonly have high quantities of marking amassed from continual assessments and feedback, with students often seeking assistance from staff outside of the core contact hours (Williams *et al.*, 2004). While content is usually progressive across years, staff are also often forced to recover material students' have forgotten, adding to time pressures. In addition, as teaching is usually covered by different staff members, staff can also be required to work more closely with colleagues, providing additional constraints.

As touched upon in the Introduction, quantitative methods modules also present problems, as different stakeholders require these modules to achieve different outcomes. For example, policy makers fund schemes to improve quantitative methods modules with a goal of improving the skills of citizens and producing competent employees. However, the skills and techniques needed to achieve this goal are often markedly different to those desired for the degree programme (Mistry *et al.,* 2009). For academics, these research modules are primarily aimed at ensuring students are equipped with the skills needed to complete their dissertations (Brown, 2014; Gorton, 2012), and as such have a greater emphasis on hypothesis testing and modeling than the basic number handling and reasoning which are vital to evaluating statistics in everyday life.

2.1.1 Pedagogic Solutions

Combining these obstacles faced by staff and students we can begin to understand that the learning-teaching of quantitative methods is not just a simple, unproblematic transfer of knowledge, as is assumed within policy initiatives – discussed in Section 1.3 (Campion *et al.*, 2015; Mason *et al.*, 2015; UKCES, 2015; Vorderman, 2011; Roberts, 2002). Acknowledging this, within the literature considerable effort has been devoted to identifying, developing, or proposing solutions to these problems.

At the broadest scale, these solutions have advocated embedding quantitative methods across the curriculum, similar to the changes made at GCSE and A-level detailed in the

Introduction. By embedding skills across the degree, students are not only exposed to a greater amount of quantitative methods, which increases confidence (Grawe, 2011; Richardson & McCallum, 2004), but they learn these skills using real-life examples and data in an applied setting (Slootmaekers *et al.*, 2013; Mvududu, 2005). This strategy similarly supports research arguing that the uptake of knowledge relies on the integration of new knowledge into students' pre-existing knowledge structures (Garfield & Ben-Zvi, 2009; Hay *et al.*, 2008). Overall, by embedding quantitative methods within relevant content modules, the use and value of QM(s) can be emphasised in situ to students, though it is not without its own challenges (Slootmaekers *et al.*, 2013).

Despite this research, much of the learning-teaching of quantitative methods remains housed within specific bolt-on skills modules (Agnew, 2000). To engage students with these modules, a variety of different teaching strategies have been developed.

One strategy described within the literature is problem-based learning. In this approach, students work together in groups to solve a problem - instead of working through examples as a class. In doing this, students are thought to be actively engaged in statistical/mathematical reasoning, a skill often lacking in QM(s)/Statistics education (Garfield, 2002). This approach has been used across a range of disciplinary and educational levels with mixed success (e.g. Strangfeld, 2013; Mergendoller *et al.,* 2006; Keeler & Steinhorst, 1995; Albanese & Mitchell, 1993). In this setting, the mixed ability classes, that are problematic for staff, enable "fearful" students to work with "confident" students, enabling peer-to-peer learning, easing some of the difficulties of teaching mixed ability classes (Cumming, 1983).

Problem-based learning also links to similar student-led teaching styles that have risen in popularity recently. In these approaches, students are asked to deliver the teaching, with the teaching staff acting as facilitators of the discussion, similarly thought to promote active student engagement. This shift towards student-led teaching styles reflects a broader shift within educational research from instructivist to constructivist learning narratives (Diaz, 2000). Within the UK this shift has also been influenced by the increasing commercialization of education - with student-led modules often receiving higher feedback and greater student satisfaction (Armbruster *et al.,* 2009).

Working within more conventional learning-teaching settings, a range of instructor-led strategies have been developed to help engage students and help them conquer their fears. These classroom techniques include limiting the use of notation, and that, where used, formulas should be explained in words as well as notation (Karam & Krey, 2015; Dobni & Links, 2008; Rumsey, 2002); small group teaching to enable students to have greater one-to-one support, lowering mathematics anxiety (Folkard, 2004); and the use of continual assessment, to allow students to receive feedback throughout their learning (Jolliffe, 1976). Similarly, quantitative methods courses are advised to make use of a range of assessment techniques to challenge attitudes and to enable students to develop their literacy, reasoning and thinking skills. These assessment methods could include exams, homework, and quizzes, with some courses using team projects, lab activities and critiques of articles (Garfield *et al.*, 2002).

As previously mentioned, others argue that courses should start from a position that all students feel comfortable with (Steinhorst & Keeler, 1995) - usually foundation GCSE level, as this was when most students last engaged with mathematics and statistics. Through doing this, students build up their confidence with manipulating numbers and mathematical formulae, before being introduced to more complex statistical ideas. Finally, humor has been shown to increase engagement, reduce anxiety, and make content more memorable (Field, 2009; Schacht & Stewart, 1990). However, it has been suggested that the success of this strategy is related to the instructor's gender (Bryant *et al.,* 1980) and personality (Field, 2009). Alongside this, teaching staff are encouraged to use real data (Neumann *et al.*, 2013; Adeney & Carey, 2011; Willett & Singer, 1992), real classroom examples and to make use of technology (Becker *et al.*, 2006). In particular, technology has been influential in changing course content, pedagogy, and course format, with a wide range of software now available to assist with both the performing of statistical tests and the learning-teaching/visualization of statistical ideas (see Chance *et al.,* 2007).

Overall, these strategies are wide-reaching and heterogeneous in nature, and often developed within individual disciplines by individual teaching staff members. Given this one of the most influential papers on quantitative methods learning-teaching is Garfield's (1995) review, which set out to review work across psychology, statistics education, and mathematics educational research on Higher Education Statistics modules. This review illustrated that much of the research in this area focused on how people (mis-)understand common statistical ideas, and the practical activities involved in learning statistical and mathematical ideas. Garfield summarized this research into ten key principles for learning-teaching statistics (many of which have been covered here earlier):

1. Students learn by constructing knowledge.
2. Students learn by active involvement in learning activities.
3. Students learn to do well only what they practice doing.
4. Teachers should not underestimate the difficulty students have in understanding basic concepts of probability and statistics.
5. Teachers often overestimate how well their students understand basic concepts.
6. Learning is enhanced by having students become aware of and confront their misconceptions.
7. Calculators and computers should be used to help students visualize and explore data, not just follow algorithms to predetermined ends.
8. Students learn better if they receive consistent and helpful feedback on their performance.
9. Students learn to value what they know will be assessed.
10. Use of the suggested methods of teaching will not ensure that all students learn the material.

(taken from Garfield, 1995: 30-32)

In 2007, Garfield & Ben-Zvi published a follow up to this review arguing that while there had been an explosion in research on statistics and probability the above principals still stood. They commented that in the time between the two reviews statistics education had emerged as a field on its own, not simply as a subsection of mathematics education. As well as this they noted the potential value of cross-disciplinary and cross-institutional large-scale studies as a way to develop the field in the future.

On the whole, researchers and teachers in the field have developed numerous pedagogic solutions to the problem of quantitative methods learning-teaching. These strategies range from broad-scale structural changes, e.g. embedding quantitative methods content across different years of study and within different modules across an academic year, to smaller-scale module or instructor-focused strategies, such as different teaching or assessment methods, with ten principals of best practice provided by Garfield's (1995) paper (and follow up in Garfield & Ben-Zvi (2007)).

2.2 Assumptions Made by the Quantitative Methods Learning-Teaching Literature

Having presented literature on both the obstacles to quantitative methods learning-teaching and the various solutions/strategies proposed to these obstacles we can now critically examine this literature identifying the assumptions made about quantitative methods learning-teaching. Given the role they play in shaping understandings of quantitative methods learning-teaching, the lack of research questioning these assumptions represents a clear gap in the literature. By using alternative frameworks that challenge these assumptions, new understandings of quantitative methods learning-teaching may be produced that have hitherto been overlooked.

Firstly, across most – if not all – of the literature presented, attention is given to a limited number of actors involved in the learning-teaching environments. Frequently, students and teaching staff are the only actors considered – even here, discussion was centred around problems faced by students and staff and not other actors. For example, in Garfield's (1995) principals, 'students learn' and 'teachers often overestimate' (p.30-32). Here we find ourselves back to an overly simplistic characterisation of the learning-teaching environment. In the few cases where other actors are mentioned – such as the course assessments, or technology (i.e. calculators, computer, and visual aids) – these actors are understood as having limited, or no, agency of their own – agency, here, is understood as an actor's ability to create difference to another entity or network (Sayes, 2014; Latour, 2005) (see Section 2.3.3 for further discussion over the meaning of agency). These actors are instead presented as things to be used by the teacher to improve the student's learning with little consideration given to how these technologies themselves have agency over the learning-teaching environments or how they shape understandings of QM(s). This is in sharp contrast to other research on technology and learning where attention is given to how these technologies change learning-teaching (e.g. Johannesen *et al.*, 2012).

While this focus on students and teaching staff represents a simplification of the learning-teaching environment, it also can be understood as a consequence of a second common assumption made by this literature, namely, that the classroom/lecture theatre/seminar room is the only scale at which learning-teaching can be understood. Much of the literature presents solutions for application within the classroom (Paxton, 2006; Lewis-Beck, 2001), for individual modules (Strangfeld, 2013; Becker *et al.*, 2006; Folkard, 2004), or strips the learning-teaching from reference to any space. For example, work by Garfield (1995) and Onwuegbuzie & Wilson (2003) strip away the learning environment, reducing learning-teaching to the interaction between student and teacher – be that in person (Murtonen & Lehtinen, 2003), through an assessment (i.e. Hubbard, 1997) or via learning activities (i.e. Harlow *et al.,* 2002). Where mentioned spaces are often simply described as a context for the activities – e.g. 'The meetings took place in the computer lab' (Meletiou-mavrotheris, 2004: p.274) – characterized as flat spaces onto/into which learning-teaching occurs. By conceptualizing space in this way, the literature fails to explore the interactions occurring across modules, and years, which are vital to students' experiences of their degrees and to quantitative methods learning-teaching (Parker, 2011).

In addition, in understanding spaces as an abstract frame of reference, this literature overlooks space as a relational or relative construct, that our experiences of an environment are also framed by (Harvey, 2004). Furthermore, this literature has given little attention to how learning-teaching may change across the different spaces(-times) quantitative methods learning-teaching occurs in, be these the formal spaces(-times) of the seminar room, computer lab, laboratory, or the field, or informal spaces of the library or study room.

Given this universal and homogeneous understanding of the learning-teaching spaces(-times) it is no surprise that this literature has a focus on generating universally applicable schemes of best practice, such as found within Garfield (1995). The quest for best practice is perhaps also linked to the popularity of quantitative methodologies being used to research quantitative methods learning-teaching, where extensive attention has been given to modelling/predicting student performance (e.g. Tempelaar *et al.*, 2007; Onwuegbuzie, 2003; Harlow *et al.*, 2002). Garfield & Ben-Zvi (2007), themselves point towards the need for larger-scale quantitative research to further evaluate their guidelines and to strengthen the field. This dominance of the use of quantitative methods in research on QM(s) learning-teaching research also reflects the wider quantitative turn within Educational Research, with random controlled trails being an increasingly popular method to provide robust, scientifically-informed, best practice (Torgerson & Torgerson, 2011). While this approach is clearly of value, the quest for universal best practices undervalues the messy, everyday, lived performances of QM(s) learning-teaching. Through focusing on problems and solutions this literature overlooks, and undervalues, understanding the doings of QM(s).

Finally, while there are attempts to create research and guidelines published in specialist journals, such as the Journal for Research in Mathematics Teaching; the Journal for Mathematics Teacher Education; and the Journal of Statistics Education, much of the literature is published within discipline specific journals. While this acknowledges that teaching in different disciplines is different, it limits the amount of cross-disciplinary discussion about learning-teaching. In particular, Wagner *et al.* (2011) report that there is little cross-disciplinary discussion surrounding research methods teaching in the social sciences. They argue that while comparisons between Social Science and Science subjects have been made, further research is needed on the similarities and differences in research methods learning-teaching across, specifically, Social Science disciplines.

2.3 An Alternative

To problematize and challenge these assumptions, this thesis will adopt Actor-Network Theory (ANT) as a way to (re-)examine the learning-teaching of quantitative methods in Higher Education Social Science subjects.

Described as a 'ruthless application of semiotics' (Law, 1999: p.3), ANT understands the world as being comprised of actors and networks. Originating in 1980s, ANT was developed in response to the Strong Programme of Sociology, most associated with Bloor, Barnes, Collins, Shapin and McKenzie (as identified by Bloor in the preface to the second edition of *Knowledge and Social Imagery*). The Strong Programme, following from Kuhn's (1962) theory of scientific revolutions, argued that the production of scientific knowledge was based on more than a search for truths; that it was a sociological activity, thus paving the way for the sociological study of scientific knowledge claims.

As outlined by Bloor (1976), the Strong Programme of Sociology comprised four key tenants. Firstly, causality - the programme aimed to study the factors that led to scientific knowledge claims. These factors could be social, cultural, and/or psychological. Secondly, impartiality - previous weak Sociologies of Science had been criticized for focusing only on failed scientific theories. To counter this, the programme emphasised working on both failed and successful scientific theories. Thirdly, symmetry - building on the previous tenant, the programme argued that the sociological theories developed must be able to explain both failed and successful knowledge production. Finally, reflexivity - as sociology was itself a science, the theories created by the programme must also be able to be applied to the discipline of sociology as well as the harder sciences.

Whilst it was heavily criticized for its radical relativism and its focus on the scientists and not the technologies associated with the construction of scientific knowledge claims (see critiques from Laudan (1981), Archer (1987), or Slezak (1994)) the Strong Programme drew attention to science as a field for sociological study. Subsequent research would examine the practices associated with the social construction of knowledge, i.e. the performances of natural philosophers required for the dissemination of their research (Shapin & Schaffer, 1985; Shapin, 1984) or the different readings of Darwin's theory of evolution around the world (Livingston, 2005). Others such as van Fraassen (1980), and Hacking (1983) would detail empiricism and technology's role in scientific knowledge production. Through its radical relativism, the Strong Programme would question the value of science over other forms of knowledge production (Feyerabend, 1975), and the existence of objective, universal truths (Chakravartty, 2017).

Emerging from this expanding field of science studies, ANT extended the Strong Programme's tenant of symmetry to create the principal of 'generalized symmetry' (Callon, 1986: p.4), whereby all actors – human and non-human – have potential agency in the production of scientific knowledge. Whilst having similar goals of reflexivity and impartiality as the Strong Programme, ANT however developed a more radical stance on the political nature of knowledge production (Latour, 1987). Building on the Strong Programme's focus on the activities of scientists, ANT brought an ethnomethodology-inspired approach, choosing to give greater attention to current scientific activities (e.g. Latour & Woolgar, 1979) instead of focusing solely on the historical accounts Kuhn (1962) and others had favoured.

At its heart, ANT rests on the key concepts: actor-network, translation, and enrolment. Actors can be anything, including conceptual or symbolic ideas, 'that acts or to which activity is granted by others' (Latour, 1996a: p. 373). All actors, human or non-human, have the same potential agency over a network. This serves an epistemological purpose

as it allows different actors to be given equal power, thus abandoning the classical subject-object divide, as well as emphasising how non-humans can, and should, be attributed with potential agency equal to their human counterparts.
Latour provided several key examples for understanding how we can apply agency to non-humans. In the first, Latour (1994) describes the action of the sleeping policeman or the speed bump. He explains that at first there was a person stood telling people to slow down while driving, this then became a man holding a sign, and then a sign, and then just the speed bump acting as a reminder of the human presence that once had stood there. In this example, Latour demonstrates basic semiotic principals highlighting how artifacts can be understood as having meaning through their relations to other things - in this case, the speed bump's meaning is only understood when related to the policeman that once stood there. However, Latour emphasises that with this attribution of meaning, the material artifact is also attributed with an integral agency, with the object now able to change the behavior of others and therefore 'do' something.

The second classic example, provided by Latour (1994) uses the rhetoric of gun crime in America. Commonly, gun crime in America is framed as "guns kills people" or "guns don't kill people, people kill people" by the two opposing pro and anti-gun rally groups. Latour explains that both positions are 'absurdly contradictory' (1994: p. 31). He brings our attention to the fact that these two positions offer different understandings of the material agency of the gun. In the first, the gun is key; the gun changes the will, or the intentions, of the holder. As Latour says, 'The gun enables of course, but also instructs, directs, even pulls the trigger - and who, with a knife in her hand, has not wanted at some time to stab someone or something? ' (1994: p. 31). In this telling, the gun has agency so strong that it has the ability to change the intentions of the (human) holder. Here the gun is everything, as Latour explains, it is the gun that changes an innocent individual into a criminal.

By contrast in the second group the gun is passive. It is the (human) individual who has the agency; they have the moral position of being a good citizen or a bad citizen. The gun does not change this position; instead 'the gun is a tool, a medium, a neutral carrier of will' (1994: p. 31). Should the individual holding the gun be a murder, then the gun simply assists them to achieve their goals, as the gun itself would not be changed.

Instead, the gun is simply understood as an aid to more efficient killing, serving not to put ideas into the holder's head, but passively enacting prior ideas held by the gun user.

Latour is quick to point out that both of these positions are taken to the extreme. Neither group claims the act of gun crime can be achieved without the other agent. No person can shoot someone without a gun, and no gun can kill someone without a human accomplice, because of this Latour turns our attention to another agent. A composite agent - what he terms a 'hybrid actor' (1994: p. 33). This actor is a third separate actor that is a composition of, in this case, the gun and the gun holder and who can produce a series of potential outcomes, one of which is gun crime.

Latour explains that each of the actors comprising the hybrid actor of gun and gun user has their own goals, steps, or intentions. In the example of gun crime, these intentions are present in the actors before the formation of a hybrid actor. In forming a hybrid actor, the goals held by each of the actors must be negotiated, interrupted, and translated to produce the goals of the hybrid actor. For Latour (1994), this goal could be either of the two above accounts: the gun could be picked up by an angry individual and as a hybrid actor their intentions could either remain as without the gun (the narrative of the "people kill people"), it could change (the narrative of the "guns kills people") or it could become a third new goal (before you were just angry, now, combined with gun, you wish to kill). For Strathern (1996), takes this concept is extended as she argues that any time humans are combined with non-humans hybridity is inevitable.

It is important to emphasise that actors, or hybrid actors, are not only individual entities, as Callon *et al.* describes, 'the actor is both the network and a point therein' (1986: p. xvi). For ANT, the agency of actors stems from their relations to other actors in networks and their ability to construct and manipulate the networks they are present within and constructed from (Callon & Latour, 1981). The network metaphor represents a shift away from previous hierarchical social theories. It is an arrangement that 'has no a priori order relation' (Latour, 1996b: p.5), which reimagines concepts of distance, borders, and macro/micro divisions. As Latour states, 'The only question one may ask is whether or not a connection is established between two elements' (Latour, 1996b: p.6).

Networks of actors form through a process of translation – the second key concept in ANT - whereby actors make connections and establish communication (Brown, 2002). As shown in the gun crime analogy, when combining into networks, or through the creation of new hybrid actors, actors' goals may shift, or become translated. Following from Michel Serres, translation refers to, 'displacement, drift, invention, mediation, the creation of a link that did not exist before and that to some degree modifies to elements or agents' (Latour, 1994: p.32). As Callon (1986: p.28) describes, 'to translate is to speak for, to be indispensable, and to display. […] Successful translation quickly makes us forget its history'. Here we see that translation is not only about bringing actors together in networks, but that it is also a process of transformation, whereby actors are changed though their movements between networks (Gad & Jensen, 2010) and where prior identities are manipulated, and broken. As such, actors can be present in multiple networks in different ways, simultaneously being singular and multiple.

While translation describes how entities relate to one another, actors are brought into and positioned in a network through the process of enrolment (Law, 2000). Enrolment – the final key process - is a way of facilitating the growth of an actor-network, as Callon and Latour (1981: p.296) explain, 'in order to grow we must enrol other wills by translating what they want and by reifying this translation in such a way that none of them can desire anything else any longer'.

This is not a politically neutral activity. During enrolment actors own goals and interests may become displaced, as mutual concessions occur in order to reach a point of agreement (Callon, 1986). As Callon and Law (1982: p.662) state, 'the theory of enrolment is concerned with the ways in which provisional order is proposed, and sometimes achieved'. This is a process whereby new political orderings are created, or reinforced, and through which certain actors become seen as the cause of the network's effects (Murdoch, 1997). It is through this manipulation of order and the prominence of other actors, that actors are able to formulate their own space(-times). In order to stabilise networks and become black-boxed, actors must become enrolled in the network, with their goals being translated, mediated, and aligned in order to form stable actor-networks.

Despite a focus here on terminology, ANT is not just a theoretical language but also a stance on how to understand the world around us (Gad & Jensen, 2010). Influenced by the sociology of scientific knowledge, ANT encourages us to follow and trace the networks that are hidden or black-boxed within objects (Latour, 1994) or debates (Besel, 2011). Critically, it reimagines just who can have power in these networks and understands these networks as dynamic and constantly performed (Bleakley, 2012).

2.3.1 How Will ANT help?

In Section 2.2, three overarching assumptions made by the quantitative methods learning-teaching literature were identified: 1) A focus only on human actors; 2) Space(-time) characterised as an abstract container; and 3) The dominance of quantified, universal best practices. In this section, it will be argued that ANT can help challenge each of these assumptions.

Firstly, through generalized symmetry, ANT facilitates the foregrounding of other non-human actors, often forgotten within the quantitative methods learning-teaching literature. At present, little consideration is given to the statistical tests, mathematical notation, worksheets, whiteboards, teaching assistants, or pens, and paper present in the learning-teaching environments. Understanding the roles occupied by these actors is vital to enriching the understandings of QM(s) in learning-teaching environments.

As well as bringing new actors to the literature, ANT also enables us to re-examine actors already discussed in the literature, such as the timetable, assessments, students, teaching staff, and technology (software and computers). Through adopting ANT, these actors can be understood relative to one another and other actors present in the learning-teaching environments, with all actors having potential agency and power over the learning-teaching environment. Thus, instead of creating a description of teaching staff as the only agents for change (who control the assessments, handouts) here attention can be given to explore the agency of these other actors, questioning if they are indeed simply passive or controlled by the staff. Through examining these actors as networks, we can begin to understand how actors are related, producing and performing QM(s), giving rise to certain beliefs about the nature of QM(s), with such meaning created by, in, and through the relations of things, not just by human actors.

Secondly, as well as providing a framework for understanding the construction and activities of actor-networks, ANT brings to the fore different ways of imagining space(-time). In working with ANT, it forces us to reconsider fundamentals about how the world around us is thought about (and by association, researched).

For ANT, space, just like anything else in the world, is understood as a concept that is constructed through a series of relations, or networks, between things, or actors. ANT is not the sole purveyor of a networked understanding of space, with Massey's (1991) essay on a global sense of place, illustrating how places can be thought of as unique assemblages of connections and flows. For Massey, places should be thought of as being dynamic, processes, that are unbounded and have multiple identities (which may exist in conflict with one another). While not adopting ANT sensibilities, Massey's view nonetheless produces understandings that bare striking resemblance to those of ANT.

Either way, this relational characterisation of space is rarely found within QM(s) literature. Whilst some other areas of educational research have considered this alternative understanding (e.g. Johannesen *et al.*, 2012; Fenwick & Edwards, 2010; Fox, 2005), most of the QM(s) learning-teaching research focuses on the activities that occur in the (conceptual) space(-time) of the research methods/statistics module, instead of seeing QM(s) as being created through its relations to other modules (Parker, 2002) or indeed other space(-times).

By viewing space(-time) as a relative concept, we can begin to move away from conceiving of QM(s) as a universal experience to considering it as an experience that is produced/performed through interactions across space(-times). This complexity is often overlooked in quantitative methods learning-teaching literature. In exploring this other space, ANT allows us to examine QM(s) not simply as a fixed concept cross space(-times) but one that is emergent through space(-times) hitherto overlooked.

Finally, ANT's tendency for qualitative, ethnographic, and ethnomethodology methods facilitates a qualitative stance to be brought to quantitative methods learning-teaching literature. Specifically, it brings an interest to the 'doings' of QM(s), i.e. the everyday performances of the actor-network(s). Researching these performances is vital if we are to understand QM(s) as a thing both within and across disciplines. Through this and the other positions, ANT brings a complexity and a multiplicity to understanding QM(s), instead of a focus on simplified characterisations or guidelines.

2.3.2 ANT in Education Research

Although ANT has been rarely, if ever, applied to quantitative methods learning-teaching research, ANT is growing in popularity amongst Educational Researchers. Nevertheless, its application remains limited in comparison to other theoretical positionings.
While ANT application has boomed in fields such as geography and design there have only been a handful of studies that have used ANT in Education settings. These studies have tended to focus either on identifying key actors that are involved in educational settings (Hamilton, 2011; Fox, 2009; Vickers & Bailey, 2006) or in tracing out networks (Kamp, 2012; Fenwick, 2011; Gorur, 2011a; Mulcahy, 2011; Tummons, 2010; Clarke, 2002).

One landmark study in this area was Nespor's (1994) ethnographic study of Management and Physics university programmes. By following students' movements though these programmes, Nespor illustrates how different time-spaces are created within each discipline. In Physics, the programme organised students' socio-material realities to create strong, exclusive within course social bonds. In comparison, the Management programme fractured students' academic spaces. The department building mimicked that of a corporate office and professors cultivated particular business dress codes and behaviours, distancing themselves from academia and prioritising the separated business world. Nespor's study represents one of the few applications of ANT into an educational research setting which foregrounded both the actors and networks as frameworks of power, not simply as components of a system.

Alongside this, ANT has increasingly been utilised to examine educational policy and standards (Fenwick, 2011; Nespor, 2002; Edwards, 2009; Hamilton, 2009, 2011; Gorur, 2008, 2011a, 2011b; Mulcahy, 1999, 2011). Across these studies, educational standards and policies have been traced out examining their performance in educational settings. In doing so they have helped to highlight how, despite being global or national in scope, standards and policies are enacted locally through socio-material interrelations (Fenwick, 2010). As Gorur (2011b) describes, ANT enables the processes through which standards and policies emerge and are maintained to be examined, moving away from theoretical a priori assumptions to empirical investigation.

As well as examining how educational phenomena are enacted, ANT has also facilitated a focus on the (socio-)materiality within educational research, decentring the human (Fenwick & Landri, 2012). In Mulcahy's (1999) study of competency standards she describes how competency is not just found on paper as 'cognitive categories' (p. 95), but, in the case of cooking teachers, competency standards are found in the material, as dishes which must be tasted. Whilst Mulcahy describes these material artifacts as a passive embodiment of standards, work by Gorur (2013) illustrates how this materiality has agency to disrupt the implementation of policy reforms. By examining the development of the My School website, Gorur argues that, although initially designed to assist with the lack of comparable information about Australian schools, the website became a driver of marketization, mobilizing parents and creating national competition between schools. Similar to this, Yasukawa (2003) considers how a workload formula, used to codify academic work, serves as a mediator between academic staff, their unions and the university management, translating the goals of each to form new practices of academic work.

ANT has also helped to draw attention to the (socio-)materiality of learning-teaching. When describing Mr Ojo's lesson on measuring length, Fox (2009) discusses how the technology used by Mr Ojo 'permitted a new way of knowing mathematical knowledge, and a new way of learning it, facilitating the emergence of a new network of practice' (p. 40). Through using a low cost and easily reproducible technology - card and string – Mr Ojo not only changed his students' learning practices, but also the practices of other teachers, their students, and the Institute of Education staff. While Fox (2009) uses ANT to discuss an instance of successful adoption of new technology, Smørdal & Gregory (2003) draw on ANT to examine a less successful integration of new technology into learning-teaching environments. In their study of the use of PDAs by medical students and researchers, Smørdal & Gregory (2003) highlight how the prior infrastructure of the hospital served to recast the PDAs as gateway devices, instead of their intended use as digital assistants.

More broadly, McGregor's (2004) account of the spatiality of schools brings together the material and the social to reconsider the everyday interactions that make up a school. In this reimagining the classroom is understood as a persistent network of objects, relationships and activities, which both reflect prior assumptions about the kinds of relations and activities that should occur, but that also control the relationships and practices can occur. Outside the classroom, spaces such as the department office served as nexus of flows of people and materiality. In these spaces, materials such as student records drew staff into the room, whilst displays of staff cartoons and messages generated interaction across a variety of spaces and times. Through this examination of school environments, teachers come to be understood as effects of the network, with their identity as teachers residing in a specific assemblage of socio-material relations. McGregor's (2004) close analysis of the spatiality of schools demonstrates how ANT can help to develop new understandings of education environments and identities, removed from longstanding binaries of inside/outside, structure/agency or local/global.

This growth of studies applying ANT to a range of educational contexts has given rise to Fenwick & Edward's (2010) textbook *Actor-Network Theory in Education*. However, despite numerous authors identifying the benefits of ANT (Bleakley, 2012; Thompson & Pinset-Johnson, 2011; Mlitwa, 2007), Fenwick and Edward's remains the only introductory text to ANT in educational research.

Overall, these studies illustrate ANT's potential to bring new insights to educational research and illustrate the power of ANT to foreground non-human actors in learning-teaching narratives.

2.3.3 Criticisms of ANT

As with any theoretical position, ANT is not without its limitations and critics. Here, three key criticisms that are of particular relevance to this thesis are commented upon. These include criticisms surrounding: the allocation of agency, the network metaphor, and ANT's characterisation of space.

Since its origin, authors have questioned ANT's principal of generalised symmetry in attributing agency to non-humans. In general, ANT is commonly understood as attributing equal agency to both human and non-human actors. In opposing this, one of three broad positions is instead argued for. The first is that agency cannot be applied to non-humans - this is the approach taken by humanist theories and accounts. The second is that non-humans have agency, but that it can be reduced back to human actors, and thus is not true agency (Schaffer, 1991). The third is that non-humans have some agency but that it is not the full agency held by human actors (Pickering, 1995).

For these first two positioning, agency is defined as the *will* to do something, not as an ability to do something. As humans are commonly understood as being the only actors that possess this intentionality (Shapin, 1988) (perhaps with the exception of other living things), it is hence argued that non-humans cannot have any agency of their own.

The third position, as characterized by Pickering (1995), dismisses the link between agency and intentionality. In *The Mangle of Practice*, Pickering argues that we can think of material agency as 'temporally emergent' in relation to practice (1995, p.14), meaning that, unlike human agency, material agency is something that is not known in advance, instead emerging through a process of "tuning". For Pickering, scientists are constantly exploring the agency of different machines, with solutions to scientific/experimental problems being developed through the subtle tweaking and tuning of the experimental assemblage. This tuning involves an interplay of agency between human and non-human actors, what Pickering describes as a "dance of agency". Here, then, it is acknowledged that non-humans do have agency, but that it is a different kind to that of human agents, i.e. that there is not the intentionality held by human actors.

Each of these criticisms is based on questioning, fundamentally, the possibility of attributing agency to non-humans. However, in perhaps one of the most famous exchanges surrounding ANT, Collins and Yearly (1992) criticise the removal of the divide between humans and non-humans because of the potential consequences for the field of the Sociology of Science. They argue that in giving non-humans agency, authority over the Sociology of Scientific Knowledge is given back to scientists, as they are the sole purveyors over determining the power non-humans have. This criticism is much more intricate than the simple question of if non-humans can have agency discussed above. In their paper, Collins and Yearly argue that ANT takes the Sociology of Scientific Knowledge back to the 1970s and realist explanations of scientific endeavours (a marked contrast to the subsequent social-constructivist turn Collins & Yearly were part of).

Callon and Latour (1992) refute Collins and Yearly's claims, arguing that Collins and Yearly are working from a yardstick with nature and society at opposite ends, i.e. either the social is explained from the natural or the natural is explained from the social. For Collins and Yearly, this means agency can only be drawn from either end of this yardstick. Callon and Latour are quick to point out that this divide between nature and society originates from the very scientists whose authority Collins and Yearly's are trying to destabilise. Callon and Latour hence argue that in their case generalised symmetry offers a way to understand nature and society as related outcomes of another activity – network building – not as two positions to be alternated between.

Whilst Callon and Latour provide a direct response to Collin's and Yearly's criticism, to counter the broader criticisms about the potential for agency to be applied to non-humans we must examine carefully what the term agency means for ANT. For ANT, agency is removed from intentionality, subjectivity, and freewill (Sayes, 2014), and thus immediately we can discount the first two criticisms of the attribution of agency to non-humans outlined early. Instead, Latour (2005:71) suggests we ask, 'Does it make a difference in the course of some other agent's action or not? Is there some trial that allows someone to detect this difference?'. As Sayes (2014) describes, in this way it is not that non-humans are given the same agency as that held by humans (despite this phrasing offering a shorthand to refer to the approach adopted), it is that any entity, be they human or not, that creates a difference in another entity or network is understood as exercising agency. Furthermore, as Sayes (2014) goes onto to eloquently describe, ANT does not offer a general theory of agency, instead it purposely introduces an uncertainty towards the nature of agency, with the exact agency an actor has being understood as an empirical question not one that can be answered prior to the analysis. Thus ANT's understanding of agency can be understood as similar to Pickering's, with both understanding agency as temporally emergent not predetermined.

Along with the criticisms of the application of agency by ANT, concerns have also been voiced about the network metaphor utilised. Famously, Latour remarked that four of his biggest mistakes with ANT were the, '[W]ord actor, the word network, the word theory and the hyphen!' (Latour, 1999: 15). The network metaphor, drawing on Deleuze and Guattari's rhizome (1987), has been a widely criticised aspect of ANT. In particular, feminist scholars, have criticised this all encompassing network metaphor as it erased/ignored the ever-present other (Lee & Brown, 1994), and that these accounts presented a grand narrative where the positionality of the researcher was removed (Martin, 1998). In early ANT, the network was understood as all-encompassing, however following these criticisms others have since drawn attention to the multiplicity and partiality of actor-networks found within post-ANT studies (Gad & Jensen, 2010). Emphasising the partiality of the network to mitigate this criticism, however, brings two new questions to ANT projects: 1) How to cut the network, 2) How to acknowledge the position of the researcher (whose voice is often downplayed in ANT narratives).

Through work by Annemaire Mol and Marilyn Strathern the partiality and multiplicity of actor-networks has been widely acknowledged. Famously, in her study of atherosclerosis, Mol (2002) illustrates how patients' and doctors' framings of the disease were multiple and layered, being unified through a range of activities, thus providing a direct contrast to the simple narratives early ANT was associated with. Alongside this, Strathern has illustrated how ANT is grounded in Western notions of a divide between humans and things. In her account (1999) of the International Convention on Biodiversity, she demonstrates how the practices and local knowledge of the people of the Papua New Guinea Highlands are bound up in an absence of a divide, instead being understood through their relations. In addition, Strathern (1996) puts forth an argument that network narratives are not endlessly emerging, as the metaphor may be used to suggest, but limited by can be limited by factors such as property and ownership. Each of these additions brings a position of complexity to ANT and in each case, actor-networks take on the potential to be layered, and held in tension with each other.

Nevertheless, these accounts remain rooted in a singular characterisation of space, the final criticism of ANT to be outlined here. For Latour, the network metaphor was used as a way to remove the Cartesian container of space and the dimensions of macro and micro. Through the network, a relational understanding of space was emphasised, through which other common sociological terms become understood as effects. This relational understanding also served to give space malleability. Serres and Latour (1995) illustrate this malleability by asking us to consider a handkerchief. They describe that when laid flat fixed distances can be measured, but if you then crumple the handkerchief up, far-off points are now close to one another. Similarly, if one were to tear the handkerchief, points that were close then become distant from one another.

This malleability of space is crucial for ANT, as it is through the manipulation of space-time that actor-networks gain/exert their power. For Latour (1990), actor-networks are not just simply about connections that exist between things but that the actor-networks have a power to bring things together through different means. As Murdoch (1998) highlights space(-time) is not only understood as being malleable but, for ANT, it is actively woven together by different network assemblages through different resilient materialities – known as immutable and combinable mobiles (Latour, 1987).

Although the foregrounding of relative space(-time) serves a particular purpose for ANT, for me, this foregrounding occurs at the expense of recognising other characterisations of space(-time), such as abstract and relational space(-time). Given the emphasis on the complexity, multiciplity, and partiality of actor-networks found within post-ANT studies, it seems an oversight that spaces(-times) of ANT would continue to be characterized in such a simplistic manner, ignoring the complexity, multiplicity and partiality of imaginings about space(-time) itself.

2.4 ANT Here

Having briefly discussed three common criticisms of ANT – generalized symmetry; all encompassing nature of the network; focus on relative space - we can now turn our attention to discussing how these limitations of ANT will be addressed in this study.

Despite its criticism, here agency is theorized following ANT sensibilities – that any object (human or non-human) has the potential for agency - to enable actors commonly overlooked to become characters in the QM(s) learning-teaching actor-networks. This represents an epistemological decision to facilitate the inclusion of non-human actors.

Secondly, while much of the later post-ANT research now assumes a partiality of the network narrative and emphasises this in its writings, here this recognition will be supplemented by understanding actor-networks as performances (as opposed to practices).

The concept of performativity draws from two key fields, firstly within Sociology and Cultural Geography performativity comes from Butler's (1990) early work on identity. For her, performativity offered a way of moving beyond permanent or deterministic writings of identity. Capturing both the idea that characteristics are 'performed': i.e. in the case of gender, that genders are not just pre-existing types, they are constructed, and, as such, are dynamic and changeable (Thrift & Dewsbury, 2000). Often these constructions emerge through a process of imitation, where 'femininity and masculinity are but imitations with no original' (Campbell & Harbord, 1999: p.229-230). McNay (1999) highlights that for Butler the idea of performativity also refers to a notion of comprising an assemblage of acts/practices, i.e. it is not a single act that constructs the identity of an individual but a collective of acts/practices that are used to inscribe the identity to others and by others on the self. Here the focus is on a breaking/fracturing of time-space, acknowledging a string of fleeting/dynamic present(s). Butler (1993) later also extended performativity to enable seemingly conflicting or opposing characterisations to co-exist.

Secondly, performativity also draws from the field of non-representational theory, where everyday actions/practices are understood as embodied. These practices are rooted in a context, the interplay of which creates meanings and symbols – similar to Wittgenstein's idea of language games (Biletzki & Matar, 2016). Similar to Butler, Deleuze – one of the key non-representational theorists - moves us away from a world of contrasts to one of multiplicity. He argues against a Platonic arboreal structuring of forms - a narrowing progression towards generalizations of forms - instead promoting a rhizomatic understanding, which promotes difference and complexity. This rhizomatic structuring allows for things to be both connected and separated: as different but the same (Thrift & Dewsbury, 2000).

Furthering this, Deleuze shifts our attention to a performed world of flows and fluxes. This is a moveable world where the representations favoured by earlier philosophy are reframed as outcomes of flows not *a priori*. This dynamism, gives rise to an interest in the intersection of things, and the connections between things, rather than their individual separated identities. This focus on flow and mobilities shifts the focus away from ways of being in the world to ways of becoming in the world (Cresswell, 2015). Here emphasis is no longer on meaning that is created through fixed characteristics, but through connection and flow/exchange.

Bringing these strands of performativity literature together we can understand performativity as bringing attention to the embodied construction of qualities through flows. A construction that is dynamic and partial. Whilst ANT does often emphasise the dynamism of actor-networks (Gad & Jensen, 2010), here it was felt important to reinforce these characteristics through the addition of performativity to mitigate ANT's tendency for grand narratives (Lee & Brown, 1994).

The final criticism of ANT – its focus on one characterisation of space – will be addressed by supplementing ANT with Harvey's three-space matrix. For Harvey (2004), space can be understood through a matrix of overlapping spatial theories. Here just one dimension of this matrix is used; that which understands space as abstract, relational and relative.

Classically, thinking about space has been dominated by the opposing arguments of Newton and Leibniz. Newton, and Descartes, conceived of space as being absolute - separate from the body and any events that may occur within the world, with space acting as a fixed reference point that could be used to evaluate the positions of objects. Here, space was conceived of as a never-ending immovable grid providing a landscape for calculation, mapping, and engineering using Euclid geometries (Harvey, 2004). While sections or regions of space could be described, space itself could not be separated or divided from any other section (McDonough, 2014). Independent of time and the perceiver, space, and time, were characterised as a feature of an independent reality.

However, for Leibniz space was not just contextual, being understood as an ordering of co-existences, produced from the relations between objects, where processes define their own spaces (McDonough, 2014). As such, space cannot exist outside of the processes that define it, i.e. it is not separated from the body or events in the world (Ben-Zvi, 2005). Given its internalized nature, events or points in space can only be understood with reference to other past, present and future influences (Harvey, 2004).

Following on from the work of Newton and Leibniz, Einstein's work on general relativity gave rise to another conception of space. Through his principal of covariance, space and time became linked, giving rise to space-time. Space was no longer conceived of as independent of time, and together space-time actively affected things, in this case the movement of matter (Nerlich, 2005). Associated with non-Euclidean geometries, relative understandings of space recognized that there are multiple spatial geometries, which are dependent on who, and what, is being represented (Harvey, 2004).

As discussed in Section 2.3.3., ANT favors relational and relativistic positions over absolute. However, following Harvey, these spaces are overlapping and layered in a kind of palimpsest (Marshall *et al.*, 2017). By bringing ANT and Harvey's (2004) ideas on the dialectics of space together, we can bring a variety and multiplicity to the analysis of quantitative methods learning-teaching. In adopting this position, we are forced to have a new sensibility towards space(-time), something that has often been overlooked in recent quantitative methods learning-teaching research.

Using these ideas of space(-time), QM(s) becomes a concept whose meaning is constructed through performances occurring in abstract space (i.e. inside classrooms and courses, positioned and constrained), relational space (i.e. each actor has their own individual idea of QM(s)) and relative space (i.e. through interactions across space). Applying Massey's thinking of place (as a balance of flows) and Harvey's (2004) matrix we start to see how QM(s) meaning in learning-teaching environments is created through the overlap of all of these space(-times), not just performed onto it.

Overall, a focus on performativity and space attempts to bring a partiality, multiplicity, and a complexity to ANT and QM(s). Having discussed the criticisms of ANT and how these will be addressed here, we can now turn to defining the aims of this study.

2.5 Research Questions

This Literature Review began by asking what extent QM(s) learning-teaching could be conceptualised as a non-problematic transfer of knowledge from staff to students. Through examining the literature around QM(s) learning-teaching, it was stated that learning-teaching was not a non-problematic transfer of knowledge. By critically examining the literature of best practice of learning-teaching of QM(s), a series of assumptions made by this literature was identified. Here, ANT has been proposed as a way to challenge these assumptions and bring a new characterisation of the learning-teaching of QM(s). Through doing this it asks the fundamental question of what are quantitative methods? Not in terms of what techniques are quantitative methods. But what ideas and performances construct QM(s), and how these are translated and enrolled into by different disciplines.

Acknowledging the limitations of ANT, this Literature Review has presented how ANT is supplemented here with Harvey's (2004) three-space matrix. Despite growing popularity, ANT remains infrequently applied to an educational research setting, even less so in the QM(s) learning-teaching literature, being more commonly applied to sites of controversy (Law & Mol, 2008; Garrety, 1997) or instances of technological innovation or deployment (Whatmore & Thorne, 2000; Latour, 1996a). Given this, this research also aims to offer educational researchers new to ANT a relatable account of working with the theory and seeks to evaluate the use of concept mapping when working with ANT. It attempts to bring a more performative stance to QM(s) learning-teaching research, highlighting the agency of actors that have been left out of other research accounts.

Specifically, this research aims to answer the following questions:

1. What are the actor networks that make up quantitative methods in Higher Education Social Science disciplines?
2. How are these networks performed, conceptualised, and created by actors?
3. How do these performed actor-networks vary across Social Science disciplines?

3 Methodology

Given the criticisms surrounding the production of ANT narratives, this chapter seeks to provide a detailed account of the methods and methodological choices taken to generate this study. It begins reflexively, broadly discussing the experience of researching quantitative methods using qualitative methods. From this introduction, the chapter is split into three substantive sections. The first - Threads - examines the role different methods played in capturing the actor-networks of QM(s) across Harvey's three spaces. In the second - Assembling - the methods used to analyse and bring together these different capturings into the actor-network presented here are discussed. In the third and final section – Cutting – attention is given to the decisions over the scope and boundaries of the study.

Acknowledging Law's (2004) emphasis, that methods are not simply descriptive but are involved in the production of the social reality being explored, throughout this chapter attention will be given to how this methodological grouping brings to light the agency of the non-human actors, a performative characterisation of the learning-teaching environment, and a multiplicity to QM(s) – the three ways this account challenges the common assumptions made by the literature, as discussed in Section 2.2.

3.1 Exploring Quantitative Methods Qualitatively

Across the social sciences, a multiplicity of research methods are employed by researchers to explore and understand the world, yet during the course of this study the idea of using a qualitative approach to explore quantitative methods was often met with amusement and intrigue.

While many would renounce the 'divide' between quantitative and qualitative methods (i.e. Johnston *et al.*, 2014), each nevertheless present their own frameworks, standards, contexts of evaluation, and ways of thinking (Buckler, 2008). Here that meant that the qualitative research project was often placed in an uncomfortable position as its quantitatively minded participants evaluated it. "What is your sample size?", "How is that reproducible?", "How are you going to analyse this data? Everyone's will be different", they asked, leaving me flummoxed as I tried to translate one methodological framework into the other.

At first glance, I understood this as hostility towards qualitative research methods. As defensiveness and valorisation of their own quantitative sensibilities above my own. However, these questions simply draw attention to the differing discourses used by quantitative and qualitative research. As I grew in confidence, I came to understand that these represented not an attack on me or an error in my methods, but instead that these comments illustrated a lack of exposure to, and understanding of, qualitative research methods, as well as a curiosity about the research.

Nonetheless, this novelty factor remained. An irony, somehow. I found myself wondering if I could have used quantitative methods to answer my research questions, despairing at the lack of useable quantitative data from my study (especially as I had originally intended to compare statistically the data gathered from the concept maps, but never achieved a large enough sample size to do so). Similarly, the questions led to me consider if it would be ironic to study qualitative methods quantitatively and the comments/sentiments such a project might provoke from qualitative research participants.

However, these hypothetical projects were just that: hypothetical. Qualitative methods do not have the same discourse of demand surrounding them, hence they were not the object of my study. The concept maps provided a broad framing of QM(s) and to have compared them quantitatively would have required more time to format the data (Hay *et al.*, 2008; Mavers *et al.*, 2002) and stricter enforcement of the guidelines given to participants for drawing their concept maps than was adopted here. Finally, a quantitative approach would have changed my research questions, distancing me from the everyday performances I wanted to explore and felt the literature had overlooked.

Yet these questions did provide an insight into my participants' characterisations of QM(s) outside of those recounted in the interview settings. In having my own research put under the microscope, I was thus able to experience personally part of the work of the net-*work* of QM(s) and its prevalence in my participants' mindsets.

3.2 Threads

Overall, four threads comprised the qualitative approach adopted here: document analysis, observation and fieldnotes, interviews, and concept mapping. Despite the irony of using qualitative methods to study quantitative methods, this assemblage of qualitative methods enabled the everyday performances of QM(s) learning-teaching to be accessed whilst foregrounding the non-human actors. Furthermore, these methods were selected individually for their ability to trace QM(s) through one (or more) of Harvey's (2004) three spaces – abstract, relative, and relational.

An overview of the relationship between the methods chosen for the study and the theoretical frameworks is shown in Figure 3.1. As discussed in Section 2.4, Harvey's three-space framing provided a useful way to extend the spaces QM(s) was theorised as occurring within/through. As illustrated in Figure 3.1, ANT is often understood as occupying a relational understanding of space (Murdoch, 1998). Here, both actor-network theory and QM(s) learning-teaching are understood as performed across Harvey's three spaces. Whilst specific methods were used to access QM(s) actor-networks in each space(-time), information gathered from each of these methods supplemented and informed one another, as illustrated in Figure 3.1.

A detailed discussion of each of the methods used for the study is presented in the sections that follow, with each section discussing the methods adopted to access one of Harvey's spaces. The discussion is arranged in this way to emphasise the links between the methodology and the theoretical framework.

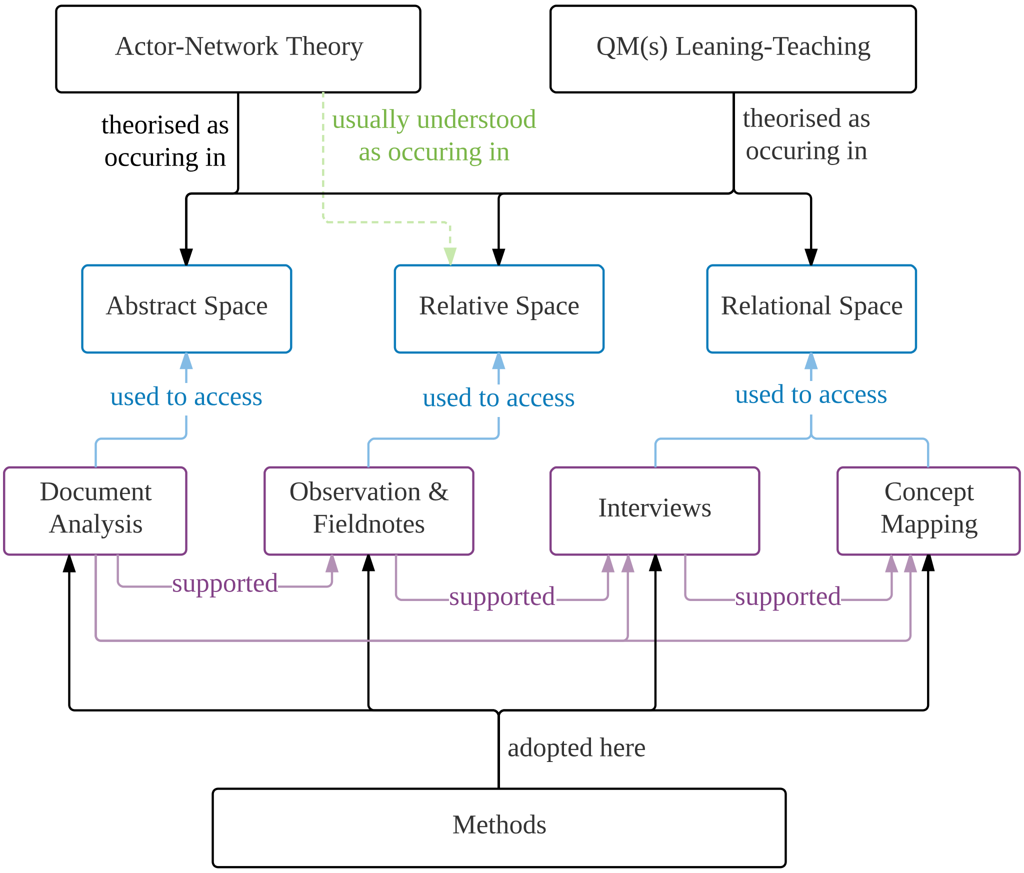


Figure 3.1 Overview of methods and theoretical framings adopted in the study.

3.2.1 Abstract Space(-time)

To access QM(s) in abstract space(-time) a range of documents were accessed and gathered from each of the departments. University webpages and course descriptions formed the co-ordinates for where to find QM(s), providing information from which modules were identified for inclusion in the study. Modules included both those with an overt reference to quantitative methods as well as those where QM(s) were, or could be, embedded within, i.e. those modules where QM(s) was included as a learning outcome or as part of a lecture or practical.

This was a direct response to Parker (2011), who expressed that much of the research on quantitative methods learning-teaching had focused only on the learning-teaching that occurred in specific quantitative methods modules, instead of that occurring across the curriculum. This oversight is particularly problematic given that it is widely argued that embedding content across the curriculum promotes a more successful uptake and retention of quantitative methods skills (Williams *et al.*, 2016; Buckley *et al.*, 2015; Conners *et al.*, 1998). Given the importance of this embedded knowledge, it was felt important to briefly explore the spread and kinds of quantitative methods across the identified programmes within the departments – however, by nature, much of this hidden curriculum could not be accessed from course documentation.

Nonetheless, module descriptions were collected for all modules where QM(s) was mentioned in the course description (not simply in the title). This was supplemented by Module screenshots, assessment criteria, lecture slides, lecture handouts, worksheets and question/problem sheets gathered from the learning-teaching sessions. Together these served as an abstract point of comparison of the content, structuring, and assessment used across the departments, and modules, included in the study. Furthermore, these documents provided contextual information which aided later interviews and observations.

Within this study, all these documents are understood as fixed: fixed objects, with a fixed frame of reference. Although these documents are dynamic, changing year on year, or sometimes constructed as the module progresses, they all become stable and fixed within the space(-time) of the QM(s) classroom. To students interacting with these documents they are viewed as final, fixed objects, as evidenced by students' negative reactions when finding any mistakes within the documents.

Casting these documents as fixed represents not only the methodological choice to use them as reference points, but also reflects the study's interest in capturing the everyday, present performances of QM(s) in the learning-teaching environments. As such, treating these documents in this way represents one of the necessary cuts made to the infinite and endless actor-networks to enable their study.

3.2.2 Relative Space(-time)

To capture QM(s) in the relative space(-time) unstructured observation of the learning-teaching sessions across Undergraduate and Postgraduate programmes was completed. This allowed the real-time performances, not simply reconstructions or representations, of QM(s) actor-networks in the learning-teaching environment to be explored.

Observation offered a way to be, to an extent, detached from both the students and staff, allowing me to freely observe the interaction between several actors (Cotton *et al.,* 2010). As I had little prior experience with the modules included in the study, or the actor-networks present, and did not wished to test any interaction hypothesis, the observation completed was unstructured.

During the observation sessions, I took notes on the interaction occurring, the actors, module content, and any other points of interest. Broadly, this approach is similar to the ethnographic (Hitchings & Jones, 2004), and ethnomethodology styles (Garfinkel, 1967) favoured by ANT studies. However, in this study no attempt was made to probe/question participants in real-time about the activities occurring in the learning-teaching sessions. Despite the potential of these methods, such an approach would be almost impossible in many of the learning-teaching sessions, given the disruption that would have been caused.

In total, 59 hours of observation across 16 modules was completed for the study. Where possible, all aspects of the formal teaching were observed for the module, i.e. lectures, practicals/workshops, seminars/tutorials. To maximise the range of actors that could be observed, and to minimise the practical disruption caused, in each of the observation sessions I positioned myself at the back of the academic spaces.

Unstructured notes were taken overtly during the sessions observed, with a general focus on noting the actors involved and the characteristics of, or assumptions about, QM(s) being performed. As soon as possible after the session I wrote any specific reflections down into a research diary. The field notes were subsequently typed up, including any preliminary analytical comments and points of interest. These comments were then used to guide subsequent observation sessions and any specific questions regarding them were brought up in the interviews with staff members in the form of stimulated recall, through discussing extracts from the fieldnotes (Cotton *et al.,* 2010).

For the majority of the teaching sessions, I did not formally introduce myself to the students, unless prompted to by the teaching staff or by a student. Hence, whilst I did not attend any session without the knowledge, and consent, of the teaching staff, across the sessions the level of overt acknowledgement did vary - from one staff member to all members of the group knowing who I was. In sessions involving group work, I chose to focus on the interactions occurring within one group, in such cases I introduced myself to the group and sought their consent before observing them. For each learning-teaching session I introduced myself to the staff member leading the teaching session, usually at the end of the observation. In doing this at the end of the session staff were able to make any comments or provide initial reflections to me. These moments helped to build rapport and served as useful opportunities to discuss any preliminary ideas with participants.

It is worth noting that during some of the observation sessions, notes were taken not only on the activities occurring but also on the examples and mathematical notation being used. While these extracts were noted to provide an account of the learning-teaching environment – as were snippets of dialogue – recording these sequences proved problematic. In writing down these mathematical sequences I became involved in the learning-teaching session, participating as students were: struggling to keep up and note down the expression before it had been removed from the board. This interaction was explicitly caused by the notation - a theme that will be touched upon later in Section 8.1- causing my focus to shift from the interaction that was occurring at that moment to instead focusing on noting down equations that were being written up. Similarly, mathematical notation caused distraction when typing up these notes in Microsoft Word, with the choice being made to transcribe the equations using less of the original mathematical notation to save time. For clarity, where included here, equations are written using the original standard mathematical notation.

In addition to field notes, lecture handouts, lecture slides, worksheets, question/problem sheets, were also gathered from the observed learning-teaching sessions. Overall, these documents were collected throughout the academic year from staff as well as during the observation sessions. In some cases, certain course documents were only seen by the researcher during interviews with staff and students. When discussing assessments or describing specific modules several participants brought out physical or digital examples of specific assessment question sheets or assessment feedback sheets from different modules or from learning-teaching sessions that I had not attended. In these cases notes on the documents were added to my research diary and were added to the interview transcript.

Gathering these documents served as a way to capture the non-human actors in the learning-leaching environments that were involved in the relative performance of QM(s). At the beginning of the study most of these documents were believed to be simply passive mediating actors, however as the study progressed several documents became identified as key actors in the learning-teaching environments, with each taking on particular roles and expressing specific goals – see Chapter 5. Importantly such actors were not limited to those present in the learning-teaching environments, with course documents – collected to gain an understanding of the performances of QM(s) in abstract space (presented in Chapter 4) – also enabling the voices of actors such as the timetable and the modules to be heard.

3.2.3 Relational Space(-time)

To capture QM(s) in the relational space(-time), interviews and concept mapping were adopted. These methods enabled participants' own conceptions of QM(s) to be understood – through direct probing - as well as providing a link to the performances and disciplinary narratives of QM(s).

Diagrams are often found within ANT accounts offering a visual representation of the network. In particular, network diagrams (Wright, 2014; Martin, 2000), spider diagrams (Potts, 2008), and concept maps (Galofaro, 2016) have all been used by authors to represent the actors and relations within an actor-network. Despite their success in providing a representation of actor-networks, ANT researchers rarely use diagrams as a method for gaining an insight into participants' understandings. Given this, their use here will be specifically evaluated in Chapter 9.

In contrast, interviews are commonly employed by ANT researchers to gain an insight into actor's goals and beliefs (i.e. Ruming, 2009). However, given its roots in ethnomethodology, these interviews are often conducted while observing the work of participants, or are conducted after the observation to allow the actions observed to be discussed. In this study, the second approach was adopted with the staff members, with interviews taking place after observation session to allow specific questions generated from the observation sessions to be asked.

Given the time constraints a different approach was adopted with the student participants. Some were interviewed without their classes being observed and unlike the teaching staff the students were not questioned about specific individual observed actions but instead were asked to talk through general activities that were included in a QM(s) class.

Despite treating these interviews and concept maps as representative of participants' understandings – and thus QM(s) in relational space - it is important to state that these understandings are acknowledge as being multiple and dynamic (Hay *et al.,* 2013). However, within this project there was not scope to explore these personal views in greater depth via repeated interviews, a choice similarly reflecting the study's emphasis on the everyday present performances of QM(s) learning-teaching.

In total, 32 interviews were completed with staff and student participants. Interviews consisted of an initial introduction to the study, information on the educational background of the participant, the drawing and talking through of the concept map, and an unstructured discussion around the following topics:

- Research methods used by their discipline.
- Modules or courses that the participants associated with learning QM(s).
- A description of the teaching structure and course details of these modules.
- Software and techniques associated with research methods.
- Changes in their thinking about the discipline/ teaching research methods.

This order enabled rapport to be built with participants easily early on in the interview, and meant that the concept map could be used as a stimulus for, and a reference point in, the final unstructured discussion.

When drawing the concept maps participants were provided with coloured pens, blank paper, and a sheet of hand-drawn example concept maps – see Appendix 12.1 for these examples and Appendix 12.2 for the interview schedule. Participants were asked to include descriptions, i.e. "is", "links to", etc., for all links drawn between concepts on the concept map, and to underline or drawn in bold any key concepts or links included (following Nicoll's scoring system, 2001).

In contrast to standard practice for drawing concept maps (as outlined in Novak & Musonda, 1991), participants were instructed that they could include pictures or names, and could begin drawing from either the top of the page downwards, or from the centre outwards – a structure more associated with drawing mind maps (Cañas & Novak, 2006). Participants were also asked to place themselves on the concept map and to explain their positioning. In this way the concept maps used here were less constrained than those initially outlined in Novak & Musonda (1991). These choices reflect an emphasis here on the concept maps as a tool for the representation of knowledge (Shavelson *et al.,* 1993) and stimulus for discussion, instead of its original function as a tool for learning and education (Novak & Cañas, 2006). Despite the need to train participants in the technique of concept mapping, this technique provided a clear visual representation of the relationships between concepts, instead of presenting a series of sub-topics as provided by mind maps (Eppler, 2006). As such, concept maps provided not only a representation of participants' knowledge about their discipline and quantitative methods, but a visual representation of the relationship between QM(s) and the discipline.

To ensure that the concept maps captured the participants' understandings of QM(s) and its link to their discipline, the aims of the study were kept purposely general at the beginning of the interview, referring to 'research methods' instead of 'quantitative methods'. Similarly, for the concept maps participants were asked to answer the focus question 'What is [their discipline]?'. In doing this, the position of research methods, and QM(s), could be traced out in relation to their discipline as a whole. In cases where research methods were not mentioned by participants in their concept maps (10 cases), participants were subsequently probed specifically about the methods used to research the content on their concept map.

At a suitable point within the unstructured discussion, the specific focus of the study was explained to the participants and they were given the opportunity to comment on any aspect of quantification in their discipline. Consent forms were signed at the end of the interviews after participants had been made fully aware of the details of the study (Crow *et al.*, 2006).

Where possible, students were interviewed in rooms that were located in their department, usually in seminar rooms. In all bar one case, staff were interviewed in their offices, after any agreed upon observation sessions. In both cases these rooms were chosen to ensure that the participant was in a familiar academic environment, with space for the participant to draw the concept map, and to minimise any noise disturbances on the audio recording (as can be generated in coffee shops (Bartlett, 2005)). Specifically in the case of students, it was hoped being in academic rooms might help as a memory aid, similar to the effect generated through walking interviews (Evans & Jones, 2011).

All interviews were transcribed, by the researcher, and the concept maps were redrawn using the software CmapTools (Nouwens *et al.*, 2007; Novak & Cañas, 2006). CmapTools is a free, easy to use, concept mapping application that operates across platforms and that enables concept maps to be easily drawn, compared, and saved as non-editable graphical files (Nouwens *et al.,* 2007). Originally, participants' concept maps were redrawn due to concerns over anonymity and legibility. However, after completing several of the interviews it became clear that participants responded differently to the technique, with some drawing diagrams similar to mind maps (radiating from the centre outwards, structured around a series of branching, sub-topics that were not connected to one another) instead of concept maps (a cross-connected structure, where the relationships or links between concepts described (Eppler, 2006)), thus redrawing offered a way to partially standardise the concept maps. In addition, when asked to explain their concept map, and in the following unstructured discussion, participants would often add further information verbally which they did not add to the concept map. As the goal of the exercise was to gain an understanding of their knowledge structures, and not to evaluate their concept map, it was felt important to add this verbal information to their concept map by redrawing it.

Transcripts and copies of original and redrawn concept maps were then emailed back to participants to allow member checking and give participants the option to remove any content. Where participants did not reply to this email, it was assumed they were happy with the content, as consent had been given during the interview.

3.3 Assembling

While I have outlined the methods used to capture QM(s) across space(-times) separately, as Harvey (2004) originally specifies, these space(-times) co-exist simultaneously. Thus to understand the characteristics of QM(s) - as housed within Higher Education learning-teaching environments - the data gathered from each of these threads were woven together to enable an account of the multifaceted and performed actor-networks to be produced/crafted.

However, despite being understood by some as a method (notably Latour (1999)), this stage of assembly is often loosely described by ANT scholars (Hitchings & Jones, 2004). Given the dissatisfaction with the lack of practical methodological discussion, the following section provides an account not only of the methods of analysis employed but a reflection of the journey that led to the adoption of these methods of analysis.

3.3.1 Perplexed

As a novice researcher I was left perplexed when first thinking about my approach to analysis. To remedy this, I began by evaluating approaches to qualitative analysis commonly used outside of ANT fields. Three methods - grounded theory, Interpretative Phenomenological Analysis (IPA), and thematic analysis - were examined because of their focus on finding broad patterns or themes within a dataset, as I believed that it was through identifying these patterns that an account of QM(s) actor-networks across the disciplines would be constructed.

Developed by Glaser & Strauss (1967), grounded theory offers a detailed series of steps, which the researcher should follow to generate a robust and accessible theory of the phenomenon. Textbook guides (i.e. Corbin & Strauss, 2015) to applying the approach tend to outline four key activities that make up grounded theory analysis. Firstly, open coding is used to identify and organize the data, often through in vivo codes, which make use of the actual words said by the participant. Following this, axial coding is used to refine the codes across the dataset, through the process of constant comparison. Codes are then drawn together through selective coding, in which over-arching categories are developed to form an explanation of all of the codes and to produce a theory of the phenomenon. Finally, further data must be collected to test the initial theory – a process that is repeated until the theory can explain all the variation within the data.

While grounded theory does offer a systematic way of analysing qualitative data (Corbin & Strauss, 2015; Strauss and Corbin, 1994), for me its epistemological standpoint did not align particularly well with ANT. ANT accounts commonly involve identifying actors, and exploring the ways in which these actors interact as part of a network of connections. In relying on grounded, in vivo, codes from interviews there was potential that key non-human actors would be overlooked – as participants' conceptions of the world will often be grounded in the social and not the material everyday realities, as illustrated by Hitchings and Jones (2004). While this issue could potentially be overlooked in my own research - as I used a range of methods to foreground different actors - grounded theory's focus on theory development (Strauss and Corbin, 1994) contrasts to ANT's own aims of constructing a partial and messy account of the world(s), with emphasis on description and not theory.

Having rejected grounded theory, I turned to a second common approach to qualitative data analysis - Interpretative Phenomenological Analysis. IPA, as developed by Smith and Osborn (2003), is concerned with understanding how participants make sense of experiences. It involves a double hermeneutic, whereby: 'The participants are trying to make sense of their world; the researcher is trying to make sense of the participants trying to make sense of their world' (Smith & Osborn, 2003: p.53).

In practice, IPA usually involves small, homogeneous datasets that are analysed on a case-by-case basis (Chapman & Smith, 2002). Analysis consists of first, a form of free text analysis, where notes are made on what the respondent has said. The transcript is re-read and the initial notes are transformed into concise emerging themes, which are more abstract than the initial notes, but that still retain the essence of what was identified in early readings. These emergent themes are then listed chronologically and re-ordered to give a series of superordinate themes. This stage involves the evaluation and synthesis of any overlapping themes. These final themes are then tabulated with a page number, indicating where themes are found in the transcript, and an illustrative quote from the text. This processes is repeated again for each individual case, after which all the superordinate themes are drawn together to create a final table of themes.

Initially, IPA did appear to hold some potential for working alongside ANT; it focused on understanding particular groups, adopted a selective approach to sampling, and emphasised the role of the researcher (Chapman & Smith, 2002). However IPA is most commonly used with semi-structured interview data where the researcher can probe the participant's responses (Eatough & Smith, 2007), meaning its scope for application was limited in my own study. Furthermore, while IPA and ANT do both favour narrative accounts, IPA accounts advocate separating the participants' narratives and the researcher's interpretation. These relatively fixed roles are in contrast to ANT's more playful style of presentation where the divide between researcher and participant is blurred (most likely because of their use of more ethnographic methods).

Continuing the search, I began exploring thematic analysis. Unlike grounded theory and IPA, thematic analysis is not a clearly defined analytical tradition (Ryan & Bernard, 2000). As such, it is not closely tied to a distinct epistemological position. As Floersch *et al.* (2010) describe, thematic analysis is broadly used, 'to identify, report, and analyse data for the meanings produced in and by people, situations, and events' (p.408). It offers a way of seeing, drawing together, and analysing qualitative data as well as a technique for converting qualitative data into quantitative data (Boyatzus, 1998).

As an approach it makes use of systematic coding to ensure the reliability of the account produced. Braun and Clarke (2006) describe thematic analysis as being formed of six phases. First, the researcher must familiarise themselves with the data, through transcription and reading of the data. From this, interesting features are coded in a systematic fashion to generate initial codes. These initial codes are then grouped into themes, either in a linear or networked hierarchy (Attride-Stirling, 2001). Following this, these themes are reviewed against the coded extracts and the entire data set. Throughout this phase of refinement, themes are named and defined. After this, a final report is produced with compelling extracts presented and related back to the research questions and the wider literature.

Given its lack of direct epistemological claims, it is not surprising that thematic analysis was the only named qualitative approach to analysis to have been specified within the ANT accounts outlined within the Literature Review (Hitchings, 2003). As an approach it can be applied to large, heterogeneous datasets, where other approaches to analysis may have been applied (Guest *et al.*, 2012) and it provides a clear systematic approach to analysis - something often lacking from ANT accounts.

Despite its clear potential for use with ANT, for me, following such a narrow approach to data analysis seemed to jar against ANT's acceptance and avocation of mess (Fenwick & Edwards, 2010). Mess both in the sense of the kinds of social realties present (Law, 2004), and in the research process itself. Furthermore, thematic analysis seemed too neatly ordered, boxing data up in hierarchies (i.e. Friese, 2014), thus going against ANTs ever-present network metaphor – was I not supposed to be creating networks and rhizomes, not trees and tables?

Having searched around for a clear method to follow I now found myself appreciating why ethnographic approaches were so prevalent within ANT studies: 'the mystique is still there' (Russell, 1995: p.vii). Ethnography, itself, is a term that evades a standard, universal definition (Milgate, 2006; Gordon *et al.*, 2001; Hammersley & Atkinson, 1983). Here, ethnography is taken, in the broadest sense, to refer to the study of everyday life, which often involves participant observation and the writing of accounts to represent the environment under study (Emerson *et al.*, 2011). While there are ethnographic principles that can be followed (i.e. Hammersley & Atkinson, 1983), and attempts have been made to illuminate the analytical processes that go on practically (i.e. Jones & Watt, 2010), ethnographies still offer the potential for a mix of processes to be used. For ANT, this mix enables the researcher to form their own network of methods with which to construct their account of the actor-networks being studied.

As a novice researcher, though, I still needed some form of guide. For me, Brewer's (2000) steps provided a path to follow without being prescriptive. He suggests that analysis consists of some or all of the following steps: data management, coding, content analysis, qualitative description, establishing patterns, developing open codes, and examining the negative cases. More generally these steps suggest a focus on what people (in this case actors) are doing and saying, patterns within the data, the development of typologies, and the identification of deviant cases (Becker, 1998).

These activities resonated with my own aim of tracing out the actor-networks of QM(s), as well as allowing space for differing methods of identifying codes and patterns within the data to be used. Similarly, postmodern ethnographies actively argue for the presence of multiple accounts within the same dataset (Brewer, 2000), a position that has been similarly supported within more recent ANT studies (Mol, 2002).

Furthermore, ethnographers have tended to accept that there is no 'correct' way to write up research (Light, 2010). For my own study, I was aware that my construction of the world around my participants was likely to be very different to their views of the world (a feeling also described by Law (1994)). Acknowledging this, adopting an ethnographic approach became appealing as it allowed me to actively step away from more scientific styles of reporting, giving a clear break between myself and the often more positivist and experimental mindset of my participants.

Through exploring these other approaches to analysis I was forced to move away from imaging my data as a series of individual strands that needed to be analysed. As described above common approaches to analysing such strands just did not seem to 'fit' with ANT. Acknowledging this, I found myself instead thinking of my study as an ethnography, which uses an assemblage of methods (Law, 2004) or a configuration of methods (Suchman, 2012) to analyse the data gathered. In coming to this conclusion, I came to appreciate the vagueness of ANT. It is through this vagueness and methodological freedom that such strikingly different views of the world can be produced – a feature which had the potential to illuminate and craft new understandings of the construction of QM(s).

3.4 Approach to Analysis

In practice, for the analysis all documents were imported into the qualitative analysis software Atlas.ti, to enable the data to be understood as a whole, re-read, and initially coded. Codes were drawn from: the data, ideas developed through the fieldwork, and the focus areas of the research questions. When analysing the documents gathered attention was given to the specific content included - similar to the coding of the interviews - but also to the choice of layout, fonts, images, colours, and tone used. In doing this, a list of codes was developed which was both descriptive - i.e. actors and techniques - and analytical - i.e. 'enrolling actors through hands on data'.

After coding a subsection of the data, an initial trail overview of the codes was constructed (see Appendix 12.3), where codes were grouped around different conceptual ideas about QM(s) and different practical activities that occurred in the learning-teaching interactions. While constructing these concept maps, ideas were discussed with research participants, allowing them to shape and interrogate the research.

After all the data had been coded this process was repeated without reference to the initial network diagram that had previously been constructed. Codes were printed out and grouped by hand, after which concept maps were drawn to consider the relations between the codes – see Appendix 12.4. As previously mentioned, organising codes into networks instead of hierarchies served to maintain ANT's theoretical stance throughout the study. Furthermore, as will be discussed in the Evaluation, concept maps acted as a useful aid for considering, not only the grouping of codes, but also the kinds of links and work occurring between codes.

While the initial conceptual network diagram could have been added to subsequent concept maps the choice to start 'blind' from the final code list and reorganise a second time was felt to be important to allow different tracings to emerge and be constructed. These diagrams were left intentionally temporary, and are presented as such in Appendix 12.4 to emphasis the potentially dynamic, partial, and changing nature of the codes and networks produced here. These maps were then used as a basis for initial writing trails, through which ideas were further reviewed against the initial data, and with participants, before being written up.

3.4.1 A Note on Latour's Notebooks

A notable absence in the collection of methods journeyed through above is Latour's four notebooks. Outlined in '*Reassembling the Social*' (2005) Latour's four notebooks is presented as a method through which ANT accounts can be constructed. The first notebook is designed to keep a log of the study, the second to organise the information gathered in multiple ways to allow the evolution of categories, the third for writing trials, and the fourth to keep a note of the effects of the written account on the actors (Latour, 2005).

Latour's four notebooks concept is very similar to that of the general approach adopted in an ethnographic study, or to the role of a research diary (Browne, 2013; Engin, 2011), providing little to differentiate itself. Despite this, given its popularity amongst ANT researchers, it was felt important to provide a brief comparison here between the methods outlined by Latour and the approach adopted within this study.

As Latour (2005) notes the second diary can be compiled using digital means, here Atlas.ti was used to gather and (re-)organise all the documents. As most of the information gathered was already in digital forms, and given the length of some of the documents, Atlas.ti offered a greater flexibility in organising and coding the data than a paper system could have offered. In addition, throughout the study the researcher kept a research diary, an activity that has become common practice in qualitative research studies (Newbury, 2001). This was used to note down, both reflections on the interviews and observation sessions, but also general points of interest that emerged through the study. Alongside this, a diary of the activities of analysis was kept, noting down which documents were coded when, and points of concern or any assumptions that were being made. The combination of these two diaries and the code network diagrams constructed can be understood as encompassing Latour's first, third and fourth notebook.

3.5 Cutting the Network

Having discussed how the methods adopted in this study were designed to capture QM(s) in different space(-times), and how these strands were then assembled/woven together to craft this account, in this final section we turn to what is often the most contested element of ANT – how the network was cut and shaped.

If we accept that actor-networks are multiple and layered, the first 'cut' was to identify which actor-network this study would focus on. This study aimed to explore only Higher Education QM(s), not its forms found in other environments. Given the lack of cross-disciplinary research on QM(s) (Wagner *et al.*, 2011), a practical choice was made to explore the actor-networks present within just one university. While this choice quietened the voice of the institution as an actor in the actor-network, it allowed greater attention to be given to the voices of the disciplines – similar to Nespor's study (1994). The institution selected for the study was a research-led, UK university, at that time, home to around 12,000 undergraduate and postgraduate students. It worth noting that undergraduate students studying at the university were required to study a minor subject (one from another department) in their first year, and were all required to complete a dissertation.

The second cut to the network came in the selection of the disciplines included in the study. As previously mentioned this research responded to Wagner *et al.*'s (2011) call for further research on QM(s) learning-teaching in specifically Social Science subjects, as well as the policy attention given to improving Higher Education quantitative methods provision. Social Science disciplines were defined according to the ESRC's definition (2017a), see Section 1.6.4.

The research completed here consisted of an initial pilot study - completed in early 2014 with two departments within the Management faculty - and a second main study. To avoid issues of re-sampling, subjects for the pilot study were chosen specifically as they met the criteria of being Social Science subjects, but were subjects that were unlikely to be included in the main study. For the main study, five disciplines – Criminology, Economics, Geography, Psychology and Sociology - were shortlisted which were felt to represent a broad range of the Social Science subjects taught at the institution. Sociology was eliminated from the study early on as no reply was received to the invitation sent to the Heads of Department to participate in the study, this left a final 'cut' of four disciplines: Criminology, Economics, Geography and Psychology.

While disciplines were selected due to their identification as Social Science subjects, within the university these disciplines were housed within different faculties. Of the four disciplines studied for the main study, only one - Criminology - was found within the Social Science Faculty, see Figure 3.2 on the next page. The three other disciplines were housed either within the Management Faculty or the Science and Technology Faculty - a reminder that these disciplinary boundaries are never fixed or universal.

A third cut came when allocating timings to the study. To allow timely completion of the PhD, the pilot study was completed across one academic term, and the fieldwork for the main study completed over the 2014-15 academic year. This year of fieldwork enabled modules running across the academic year to be included in the study (thus increasing the reach of the actor-networks).

The final cut of the network centred around the enrolment of actors. Given the importance of disciplinary narratives, short (less than 45 minutes) meetings were held with Heads of Department (or an acting representative) to gain consent to complete fieldwork in their departments and to contact other staff members within their departments. In one case, the Head of Department agreed to participate without a meeting, due to their own time constraints.

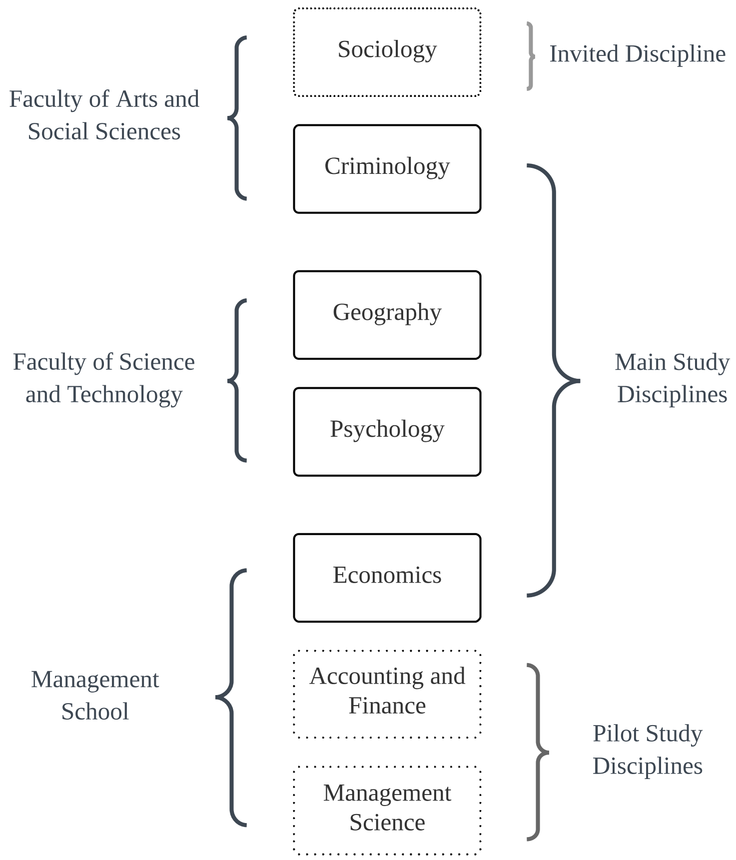


Figure 3.2 Breakdown of disciplines included in the main study and pilot study by faculty.

After enrolling Heads of Department, a list of relevant modules which offered potential to be enrolled in the study was generated from course handbooks, that were accessed online or via administrative staff. During the meetings with Heads of Department, some recommendations were made to the researcher about courses and staff members that were of relevance to the study. These recommendations were used along with the module lists to generate a list of course convenors to be contacted. This independent identification of relevant courses/staff was completed to ensure that the widest range of modules containing quantitative methods were included in the study.

All staff from these lists were emailed and invited to participate in the study. Following this, short (30 minute) meetings were arranged individually with the staff member to discuss: the project, the modules they taught - to validate the material read online -, and their involvement in the study, e.g. observation, interview, or both. In several cases, an initial meeting was not requested or organised; these were cases where the staff member agreed to the observation but did not wish to be involved in any other way in the project.

After enrolling staff members, attention turned to enrolling student participants. To access disciplinary narratives, only those students studying on single honours courses in the selected disciplines were initially included in the study. However, given the flexible nature of the Undergraduate programmes some of the students interviewed were registered on joint honours programmes, but in these cases their major discipline was one of the four included in the study.

To ensure that students had been exposed to some of the quantitative methods teaching-learning within their department, students were contacted at different times during the academic year. Final year undergraduate students were contacted at the middle of the first academic term, as in most cases they would have completed quantitative methods modules during their first and second years, however this received no responses. Subsequent repeated invites were sent out to second and final year students during the second term, as this would be either after they had completed any modules running in the first term or started modules in the second term. First year students were contacted mid-way through the second term and into the third term, to coincide with the later timing of quantitative methods modules and the completion of summer examinations.

For postgraduate students, email invitations were less targeted as it was assumed most students would have had quantitative methods modules as part of their Undergraduate degrees, furthermore QM(s) courses ran earlier in the academic year or, in the case of most PhD programmes, were not required to be taken by students. In some cases postgraduate individuals were identified either by the course convenor or during the observation sessions given their roles as general teaching assistants (GTAs) on quantitative methods modules.

Supplementing this specific targeting, the study was also advertised in university newsletters and posters placed around the departments and wider university. This was later accompanied by recruiting students at lectures and seminars. Given the low response rates from these methods snowball sampling was also implemented with the student participants. This was felt appropriate given the limited risk of any ethical repercussions.

The results of these cuts is shown in Table 3.1. In total, 33 participants across four disciplines, were interviewed, with each drawing a concept map, overall most were from the discipline of Geography. At the time of study, Criminology did not offer any Masters' programmes and had very few PhD students, hence explaining the lack of postgraduate criminologists in the study.

Discipline	Staff	Students		Total
		Undergraduate	*Postgraduate*	
Criminology	1	3	0	4
Economics	3	2	2	7
Geography	4	4	6	14
Psychology	2	2	4	8
Total:	10	11	12	**33**

Table 3.1 Breakdown of participants by discipline and level of study.

Along with this, as previously mentioned, 16 modules were observed across Undergraduate and Taught Postgraduate programmes, with a full breakdown of the timing and credits of these observed modules being presented in Table 4.2 (page 80). Finally, 64 documents (which included course documentations, degree handbooks, lecture slides, handouts, and Moodle screenshots) were gathered across disciplines, with a breakdown by discipline included in Appendix 12.5.

3.6 Who's Holding the Scissors?

While attention has been given to how the actor-networks were cut, and why, all that remains is the question of, 'Who was holding the scissors?'.

Having previously completed research on the attitudes held by Geography staff and students towards statistics (Gorton, 2012) and developing, and evaluating the potential of, a new form of creative public engagement with statistics (Gorton, 2013), I found myself dissatisfied with the literature surrounding quantitative methods learning-teaching. Whilst I had initially stumbled into researching statistics from my own confusing, and frustrating, experience of being taught quantitative methods during my Geography Undergraduate degree, my choice to continue researching this field lay in a desire to explore a gap in the literature – as identified in Section 2.2. To me, this literature seemed unaware of the philosophical assumptions underlying its studies, or in exploring learning-teaching environments as key sites of knowledge construction, not simply knowledge transmission. From these starting points I thus found myself, somewhat surprisingly, researching quantitative methods learning-teaching, despite having had no experience teaching these methods and only limited experience learning and working with them.

Holding the scissors as a white, Western researcher studying a Northern Hemisphere research site I embodied a position ANT accounts are often criticised for (Strathern, 1999). Although, acknowledging the problems associated with accounts generated from this position, by researching an educational/cultural setting I was familiar with, it was perhaps easier to become an insider and to examined the actor-networks that had not been understood in this way before.

As a holder of a Geography Undergraduate degree I did have some familiarity with the content included in Geography degrees and other quantitative methods courses. However, I had no prior exposure to the Geography course at this institution, nor was familiar with any of the other disciplines included in the study. As such, interaction with participants always included navigating both positions of familiarity and newness, insider and outsider; positions often occupied by those employing ethnographic methods.

This commonly faced problem of navigating insider and outsider identities was set against the issue of the labelling of myself as an Educational Researcher. In accepting that position, for the fieldwork at least, participants often made assumptions about the kinds of information I was interested in and was looking for. This was particularly prevalent in the observation of the learning-teaching sessions where staff would jokingly ask, "Is this OK?" and I would find myself reassuring them, despite the fact that I was not there to evaluate their teaching - a fact I found myself constantly repeating to staff.

As well as labelling myself as an Educational Researcher, I often found myself being viewed as either an expert in quantitative methods teaching or an expert in student's opinions of the teaching - both positions I found uncomfortable, as I was an expert in neither, and remained perplexed by both. It was assumed that I had a strong familiarity with the quantitative methods being taught - as it was my research topic - a position I had to mitigate through my own reading as well as seeking clarification from participants.

Whilst my identity as a PhD student from an external discipline allowed me to ask for further information without my competency being questioned. In a few cases, interviews with staff did prove to be a tricky power negotiation, common when interviewing more powerful elites (Campbell, 2003). Despite these issues, my position of student and Educational Researcher allowed a purposeful distancing of myself from my participants.

3.7 Conclusion

This chapter has provided a detailed account of the methodology used to answer the research questions outlined in Section 2.5.. While remarked upon by participants as being ironic, here, a broadly qualitative approach to researching quantitative methods was adopted to gain an understanding of the everyday, performed actor-networks of QM(s). The process of capturing and (re-)presenting these actor-networks was divided into three stages: Threads; Assembling; Cutting. In the first, the individual methods – the threads - used in the study – document analysis, interviews, concept mapping, and observation – to access QM(s) actor-networks were outlined. In this section, the ability of each of these methods to access Harvey's (2004) three spaces – used to bring a more complex understanding of space(-time) to ANT - was traced out. Following this, the second section detailed how, moving from an initial position of perplexity, a method of analysis was selected through which to assemble the account presented here. Broadly ethnographic, the approach to analysis made use of collecting together and coding the data on Atlas.ti and the drawing of concept maps of these codes. Finally, in the last section, choices over the cuts made to the actor-networks of QM(s) to allow its exploration were presented. These cuts included choices made over the disciplines selected, the sampling approach, and participant recruitment. This section also provided a short reflection on the positionality of the researcher who was holding the scissors with which the network was cut. Together this methodology is felt to draw attention to the agency of non-humans and a performative characterisation of QM(s) learning-teaching.

4 Locating QM(s): The Search for a Unified QM(s)

In the chapters that follow, four sides to QM(s) will be presented and discussed, represented in Figure 4.1. These sides include: QM(s) as constructed in classroom actor-networks (b), QM(s) in disciplinary actor-networks (c), and QM(s) as changing (d). Together these narratives form the actor-networks of QM(s) in Higher Education Social Sciences – responding to Aim 1. However before reconstructing QM(s) as a network of actors, this chapter provides an initial sketch of the thing QM(s), shown in Figure 4.1 a). Specifically, this asks: Where do we find QM(s)? How is it labelled? What is the content of QM(s) modules? How is it positioned?

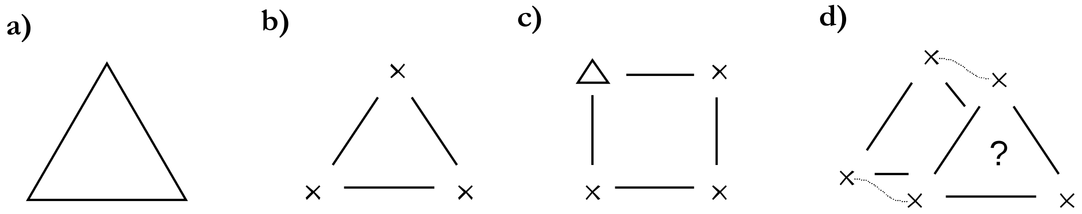


Figure 4.1 A figurative representation of the sides of QM(s) explored in this thesis: a) QM(s) as an object, b) QM(s) as constructed through module actor-networks, c) QM(s) as constructed through discipline actor-networks, d) QM(s) as a changing actor.

These questions will be answered by exploring, in turn, the words used by actors to describe QM(s), the curriculum structures housing QM(s), and finally the placement of QM(s) on disciplinary concept maps. Together, these locations can be understood as tracings of the object of QM(s), which form perhaps the most familiar side of QM(s). Through exploring these locations, a multiplicity of QM(s) character emerges, contrasting to the unified QM(s) represented in the literature.

4.1 QM(s) in Actors' Words

We begin our sketching of QM(s) in the words of participants and course documents. When examining the words used in association with QM(s), five distinct themes emerged. Instead of telling of a unified character of QM(s), these words drew attention to the different agency attributed to, and possessed by, QM(s).

Perhaps the most familiar, the first theme captured QM(s) passive nature. These words described how students were "equipped" to "use", "apply", and "run" QM(s). Although commonly referred to as "techniques", which linguistically are defined as, 'a way of carrying out a particular task; skill or ability in a particular field; a skilful or efficient way of doing or achieving something' (Oxford English Dictionary, 2017c: n.p.), here the framing of QM(s) lacked any evidence of QM(s) as a method or skill. In this setting, QM(s) was understood a tool, which human actors had full control over. Analogous to the screwdriver or wrench of a craftsman QM(s) were selected from toolboxes or toolkits, as described in the following quotes:

> The lecturer explains that his colleagues would say that the course is designed to "provide a toolkit for use in the third year project that they can apply without too much assistance".
>
> (Fieldnote: Psychology, 2nd year UG lecture, QM(s) module)

> This module lays the foundations for preparing you for research in economics or for work as a professional economist, and covers different aspects of the research toolbox of modern economists, with a practical and applied focus.
>
> (Economics, Postgraduate handbook, Research methods module description)

> Seminar leader addressing the class: "Lecture slides go through in a very regimented way […] all you need to know is look at the problem and work out which tool you need to use, because we've taught you lots of different "tools" and you've just got to pick one and relate the result to the question."
>
> (Fieldnote: Economics, 1st year UG tutorial, QM(s) module)

Through framing QM(s) as a tool, QM(s) was emphasised as an implement to complete a certain function, with the agency of both QM(s) and the user pacified.

In the second theme, QM(s) was understood as having slightly more agency. Instead of using tools, here QM(s) was described as something to be "manipulated", "transformed", "performed", "solved", and "built". In contrast to the techniques for hypothesis testing associated with the first theme, the words used in the second were more associated with mathematical exercises that involved algebra or modelling techniques. Although in this framing humans are still in control, this understanding of QM(s) hinted at QM(s) as a way of doing, not simply a passive tool to be applied. In this way, this second theme of words were linguistically closer to the definition of QM(s) as a method – see Section 1.6.1 – or technique.

In the third, the power relation between QM(s) and human actors was reimagined, instead of humans dominating, as in the first, here QM(s) was something to "work with", as one lecturer explained in an interview:

> Working with quantitative data means that you know where the data is, you can, you know how you can handle it, you know how you can read it [mm] whether it, whether it's in a table, or whether it's in a spreadsheet and you want to draw some graphs out of it [mm]. That's kind of data and quantitative skills. It's working with the data, being able to analyze and interpret it [mm]. […] And so, you know, so they're learning how to work with data, they're also, in the lectures they're getting a background as to what is, and what isn't included in these crime figures [mhm] – so this is all quantitative skills [yeah].
>
> (Staff member, Criminology - Doug)

Discussing QM(s) or data as something to be "worked with" brings a notion of collaboration and co-operation to the identity of QM(s). Instead of the human actors having full agency/control over QM(s), here QM(s) are reframed with almost equal agency. They require tinkering, and jiggery-pokery, a 'dance of agency' (to borrow from Pickering, 1995: p.21).

Continuing this concept of equal agency, the fourth theme presented QM(s) as a personified actor. Students were "introduced" to QM(s), they had to "get to know them" as if meeting a new acquaintance. Through this, individuals developed a "familiarity" with QM(s) and over time human actors learned how to "interpret" them. In these third and fourth themes, QM(s) was conjured up as a character, almost a human colleague - a far cry from the understanding of QM(s) as tools or techniques. However, in each of these themes the relationship of humans and QM(s) was friendly. But in the fifth, and final, theme a glimpse of a darker, sci-fi side to QM(s) was given. In this theme, numbers were "stuck" and "chucked into" software and formulas, subsequently crunched up and spat out by the "beast" of the technique-software assemblage. Here users became tamers, forced to "get to grips with" the software, learning how to 'handle' and deal with both the software and the quantitative techniques. To assist with this process of taming, and its consequences, "stats surgeries" were offered to students where their quantitative ailments would be diagnosed and repaired.

In this final framing, the terrain of QM(s) became less fixed. Instead of a passive application of a tool, there was a process of exploring data, techniques, and questions, travelling through a jungle where these techniques waited to scare you. As with any wild animal it had a 'beauty', a mystery, a 'magical' quality, and a fantasy side. But the user had first to locate these techniques, navigating through the possibilities until finding, or chancing upon, the one they wish to tame, work with, and apply. Once tamed only then could these beasts lead users to new areas, either "showing" or "telling" users things. While in these settings QM(s) were used, this use is not passive, instead with QM(s) actively exerting agency over its users.

Overall, despite the similarities in the language used across disciplines and participants, these words cultivate an understanding of QM(s) as occupying multiple identities each of which embodies different levels of agency. From passive tools to mysterious beasts, these words also hint of the different doings of QM(s), a theme, which will be revisited in the following chapters. Here though, we turn our attention from the linguistic narratives of QM(s) to the identity of QM(s) housed within the curriculum.

4.2 QM(s) in the Curriculum

As discussed in the Literature Review, within research on quantitative methods there is a tendency to focus only on one module, usually an overt quantitative methods module, as opposed to content embedded across a degree (Parker, 2002). To counter this, here content from across degree courses was examined, with an emphasis on Undergraduate programmes, which had higher numbers of QM(s) modules.

Across all disciplines included in this study, QM(s) were identified as a core component of degree schemes, with handbooks stating:

> The general aim [of the degree] is to provide students with a broad understanding of economic theory and the application of quantitative methods to economics.
>
> (Economics, UG student handbook, Programme description)

> To progress to Part II as a Psychology major, a student must achieve an overall aggregation score of 10.3 or above in both [Psychology 1.1 and 1.2], plus an aggregation score of 9 in both coursework and exam elements.
>
> (Psychology, UG student handbook, Progression requirements)

> Students taking this course will gain knowledge of current issues in criminology, understand their determinants and appreciate varying contested perspectives on for example how best to understand crime statistics and how to explain and tackle various forms of crime. You will learn how to find, gather, collate and use - in written analysis and in discussion - a range of theoretical and empirical research materials such as crime surveys and academic journal articles.
>
> (Criminology, UG student handbook, Academic aims of 1st year content module)

Across disciplines, much of the learning-teaching of QM(s) was provided through compulsory skills modules. In each of the disciplines, compulsory modules that included some element of QM(s) content in their module descriptions were concentrated within the first two years of degree schemes. Only Economics provided a compulsory third year QM(s) module, on Econometrics. The majority of these modules taken by undergraduates across the four disciplines ran during the first two academic terms – see Table 4.1, with Economics and Geography having slightly more modules that ran during the first academic term. Geography also ran two numerical skills modules in the first and second term, which were compulsory for those students who did not have A-Level mathematics (these modules were excluded from the table below as they were not compulsory for all students).

Modules observed as part of the study, which included five option modules and nine content modules from both Undergraduate and Postgraduate degrees, were similarly evenly split across the first two terms with only Economics delivering QM(s) content in the third term – see Table 4.1. Of the modules delivering specifically QM(s) content, highlighted in bold, most were taught in modules that ran over two terms or just the second term.

Discipline	Modules[1] Taught During		
	Term 1[2]	Term 2	Term 3
Criminology	3	3	0
Economics	8	7	3
Geography	6	4	2
Psychology	4	4	2
Total:	22	17	8

Table 4.1 Indicative timings for compulsory modules that included QM(s) content.

[1]Compulsory modules from all years of undergraduate courses that specified some element of QM(s) in their module aims.

[2]Modules taught over more than one term are counted in each term they occurred in.

Discipline	Module	Term Taught During			Credits
		1	2	3	
Criminology	1.1	✓	✓		40
	2.1[1]		✓		15
Economics	**1.1**	✓	✓	✓	40
	2.1	✓			15
	3.1	✓			15
	4.1[2]	✓	✓		15
Geography	**1.1**	✓	✓		24
	1.2		✓		8
	2.1	✓			15
	2.2	✓			15
	3.1	✓			15
	3.2	✓			15
Psychology	2.1	✓	✓		15
	2.2	✓	✓		15
	4.1		✓		20
	4.2		✓		20
Total:	16	12	10	1	-

Table 4.2 Timings and credits for observed modules.

[1]Core QM(s) skills modules are highlighted in bold. Those not in bold were content modules or skills modules containing limited QM(s) content.

[2]Modules are coded [year of study. order observed] with Undergraduate modules labelled 1-3, and Postgraduate modules, 4.

On average QM(s) skills modules across Undergraduate and Postgraduate programmes were twenty credit modules (median = 15; mode = 15) with the exact breakdown also shown in Table 4.2. In Appendix 12.6, the maximum credits allocated to compulsory QM(s) skills courses across degrees is presented. For undergraduates, compulsory QM(s) content accounted for just over 20% of the total degree course credits, however these figures should be treated with caution as some compulsory skills modules included content other than QM(s), i.e. qualitative methods, and in some disciplines content was embedded in option modules. Option modules were excluded from the comparisons here to give a comparison of the QM(s) content covered by every student, instead of a representation of the maximum QM(s) content that a student might encounter.

A comparison of the content included in these compulsory modules, across all years (in Undergraduate and Postgraduate programmes) and disciplines, is provided in Table 4.3. Looking at disciplines in more detail, it is worth noting that Criminology did not provide any QM(s) content during the first year. In all other disciplines, content was delivered through specific skills modules, with Geography also including content in broader content and specific numerical modules that students lacking A-Level mathematics were enrolled onto. Of these courses, first year modules were found to have the most content overlapping across disciplines, with common material covered including: information on data types, sampling, hypothesis testing (t-test/chi-squared tests), ANOVA, and linear regression. Similarly, techniques most frequently included on participants' concept maps – see Appendix 12.7 - were statistics, hypothesis testing and experiments, perhaps reflecting this overlapping QM(s) content.

In the second year, there was less overlap in content between the disciplines, with Criminology and Geography both providing information on data type and sampling. Within Psychology, a specific statistics module exposed students to a range of techniques, including: different forms of regression, factor analysis, and linear models.

Topic	First			Second				Third	UG/PG Masters		
	Economics	Geography	Psychology	Criminology	Economics	Geography	Psychology	Economics	Economics	Geography	Psychology
Mathematics											
Maths	✓	✓[1]			✓			✓	✓	✓	
Statistical Theory											
Data Types	✓	✓[2]		✓		✓			✓	✓	
Sampling	✓			✓		✓					
Errors/Uncertainties		✓[1]									
Descriptive Statistics											
Descriptive Statistics				✓							
Difference Testing											
Hypothesis Testing	✓	✓[2]	✓				✓			✓	
Chi-Squared	✓	✓	✓				✓				
Z-test/Normal Distribution	✓	✓									
Confidence Intervals	✓										
T-Test	✓	✓	✓								✓
Correlation and Regression											
Correlation	✓	✓	✓				✓			✓	✓
Linear Regression	✓	✓					✓	✓			✓
Multiple Regression							✓	✓			
Advanced Regression							✓[4]			✓[3;4]	
Moderation/Mediation Analysis											✓
Multivariate Analysis											
Multivariate Analysis										✓	
ANOVA		✓	✓				✓				✓
Factor Analysis							✓				
Modelling											
Generalised Linear Models										✓	✓
Mixed Linear Models							✓				✓
Simple/Mixed Effects Models							✓				✓
Specialist Techniques											
Spatial Statistics										✓	
Time Series					✓			✓		✓	

Table 4.3 Content included in compulsory QM(s) undergraduate and postgraduate modules, as identified from module outlines.

[1]Content included in an optional QM(s) module; [2]Content included in a content module; [3]Logistic regression; [4]Log linear regression.

The apparent lack of QM(s) provision by Economics - who are listed as only providing content on mathematics and time series - and Geography is thought to be due to the inclusion of QM(s) material in other option modules that ran during the second year, which provided discipline specific techniques. In the case of Criminology, the leader of the course was keen to highlight that this module was not a statistics module, instead it aimed to cover data handling skills, thus explaining the focus on data types, sampling, and descriptive statistics.

In the third year, only Economics students had compulsory QM(s) teaching, which included regression, time series analysis and other mathematical content. In Geography and Psychology taught master's courses (Undergraduate and Postgraduate Master's), content spanned a broad range of subjects with overlapping content including data types, correlation, and general linear models. In Economics, compulsory content only included information on data types and mathematics. This pattern perhaps reflects the expectation that content would be mastered earlier, during an Undergraduate degree, as well as the embedding of QM(s) content in specific topic modules. Criminology did not, at the time this research was carried out, provide any Postgraduate taught courses.

At the broadest level, across disciplines similarities were observed in the structuring of undergraduate modules that included QM(s) content, with material being housed in similar weighted first and second year modules. Although there was some overlap, the content included in these modules varied widely across disciplines and years, again highlighting the multiplicity of QM(s) character. While content appeared to be repeated across years in Undergraduate Geography and Psychology degrees, in Economics much of this content was embedded within second and third year option modules. Here, then, while boxed up similarly, the specific content and placement of QM(s) within the curriculum varying across disciplines, thus while we saw a mix of agency attributed to QM(s) via participants' words, here we see QM(s) as comprising different things in different disciplines. Acknowledging this heterogeneity of QM(s) when located in the words and content included within the curriculum, we can now turn to examining the identity and relationship to QM(s) on participants' concept maps.

4.3 QM(s) on Concept Maps

In total, 33 concept maps were drawn by participants – see Table 3.1 on page 72 for a breakdown of participants by discipline - 23 of which (69.7%) included a reference to QM(s). All concept maps that included QM(s) did so on their original diagrams, i.e. no references to QM(s) were added when the concept maps were redrawn.

Overall, Geographers mentioned QM(s) less than other disciplines, see Table 4.4, with 8/14 participants (57.1%) mentioning QM(s), compared to Criminology (75.0%), Economics (85.7%), and Psychology (75.0%). Across participants, undergraduates included QM(s) on their concept maps the least (54.5%), with most staff (80.0%) and postgraduate students (75.0%) including reference to it.

Affiliation	Participants (n)	QM(s) included (%)	QM(s) not included (%)
Criminology	4	3 (75.0)	1 (25.0)
Economics	7	6 (85.7)	1 (14.3)
Geography	14	8 (57.1)	6 (42.9)
Psychology	8	6 (75.0)	2 (25.0)
Undergraduate	11	6 (54.5)	5 (45.5)
Postgraduate	12	9 (75.0)	3 (25.0)
Staff	10	8 (80.0)	2 (20.0)
Total:	33	23 (69.7)	10 (30.3)

Table 4.4 Frequency of QM(s) presence on participants' original concept maps.

Across all participants' concept maps, an average of 2-3 links were drawn to QM(s), see Table 4.5, however there was a wide range observed in the number of links drawn to QM(s). On the whole, there was little variation in the number of links drawn by different disciplines and participants to QM(s) - see Table 4.5.

Affiliation	Participants mentioned QM(s) (n)	Average links on original (redrawn)	Median links on original (redrawn)	Range of links on original (redrawn)
Criminology	3	3 (4)	2 (4)	2 (2)
Economics	6[1]	3 (3)	2 (2)	5 (5)
Geography	8	2 (3)	2 (2)	2 (2)
Psychology	6	2 (3)	1 (2)	3 (4)
Undergraduate	6	2 (3)	2 (3)	3 (4)
Postgraduate	9[1]	2 (2)	2 (2)	3 (3)
Staff	8	2 (3)	2 (3)	5 (5)
All concept maps:	23	2 (3)	2 (2)	5 (5)

Table 4.5 Descriptive statistics for the number of links to QM(s) drawn on original and redrawn concept maps (1sf).

[1]Includes one participant who listed quantitative techniques on the concept map but did not specifically identify these as quantitative methods.

However, when redrawing the concept maps often more links to QM(s) were added, shifting the distribution. This shift was expected given that concept maps were redrawn with information added from participant's verbal explanations of their concept maps. On these redrawn concept maps, Criminologists included, on average, one more link to QM(s) than the other disciplines. A smaller range, reflecting the highly networked diagrams drawn by Criminologists, accompanied this. On average, on these redrawn concept maps, undergraduates and staff members drew one more link to QM(s) than the postgraduate students. This similarity between staff and undergraduates is thought to be due to the fact that they have a greater involvement with a shared curriculum. The postgraduates, by contrast, often drew concept maps that represented their own narrow research field and less a general image of their discipline, similar to results found by Hay *et al.* (2013).

On average, QM(s) was placed two links away from the core discipline, - see Table 4.6 - with little variation between original and the redrawn concept maps, although there was a wide range of values present (from 1 to 5 links). Across all participants, postgraduates tended to draw QM(s) one link further away from their discipline, again reflecting their tendency to draw highly-specific concept maps. Looking across the disciplines, Geographers and Psychologists, on average, placed QM(s) furthest away from the centre of their concept maps – 2 or 3 links away. In contrast, Criminologists and Economists had fewer links separating QM(s) from the discipline (1 link). In particular, when the maps were redrawn to include information included from participants' verbal explanations, Criminologists had the fewest links separating QM(s). Criminologists also had, on average, the longest chain length (7 links) indicating that this closeness of QM(s) to the discipline was not simply a product of drawing smaller concept maps.

Affiliation	Participants mentioned QM(s) (n)	Average links separating on original (redrawn)	Median links separating on original (redrawn)	Range of links separating on original (redrawn)
Criminology	3	1 (1)	1 (1)	1 (1)
Economics	6[1]	1 (2)	1 (2)	1 (3)
Geography	8	3 (3)	3 (3)	4 (4)
Psychology	6	2 (2)	3 (3)	2 (2)
Undergraduate	6	2 (2)	2 (2)	2 (2)
Postgraduate	9[1]	3 (3)	3 (3)	4 (4)
Staff	8	2 (2)	2 (2)	2 (2)
All concept maps:	22	2 (3)	2 (2)	5 (5)

Table 4.6 Descriptive statistics for the number of links separating QM(s) from the discipline on original and redrawn concept maps (1sf).

[1]Includes one participant who listed quantitative techniques on the concept map but did not specifically identify these as quantitative methods.

Along with drawing fewer links to QM(s), and having a greater number of separating links, Psychology and Geography were also the only two disciplines to include the word "Science" on their concept maps. Of the Psychologists and Geographers, most (15/22) tended to include either both terms or neither term - see Table 4.7. Postgraduates were the group that exhibited this tendency most strongly.

This pattern is perhaps due to the nature of Geography and Psychology as disciplines, with both straddling the arts and sciences. As such these disciplines are perhaps engaged with a greater discussion over disciplinary boundaries and knowledge validation through appealing to a quantitative scientific method. This boundary discussion may also be a factor in Psychologists' and Geographers' lower number of links to QM(s) and greater

Affiliation	QM(s) ∩ Science (%)	QM(s) ∩ Not Science (%)	Not QM(s) ∩ Science (%)	Not QM(s) ∩ Not Science (%)	Total (%)
Undergraduate	2 (33.3)	1 (16.7)	1 (16.7)	2 (33.3)	6 (100)
Postgraduate	6 (60)	1 (10)	1 (10)	2 (20)	10 (100)
Staff	2 (33.3)	2 (33.3)	1 (16.7)	1 (16.7)	6 (100)
Geography	6 (42.9)	2 (14.3)	2 (14.3)	4 (28.6)	14 (100)
Psychology	4 (50.0)	2 (25.0)	1 (12.5)	1 (12.5)	8 (100)

Table 4.7 Co-occurrence of science and QM(s) on concept maps.

number of links separating QM(s) from their disciplines, with those identifying, or engaging with, their discipline in a more arts-based way being possibly more likely to not include QM(s), or to place it further away from the centre of the discipline. Similarly, the breadth of these disciplines may mean that different areas of the discipline are associated with different techniques, instead of a central concept of methods applying to the discipline as a whole. Thus QM(s) is placed further away from the centre of the concept map closer to different branches of disciplinary knowledge.

One reason for the low occurrence of QM(s) on Geographers' concept maps was postulated to be the stronger presence of GIS (Geographical Information Systems) within the discipline. However, GIS was not mentioned more frequently than QM(s) on participants' concept maps, and where mentioned, GIS only occurred where QM(s) was also included on the concept maps.

Another explanation for the lower rates of inclusion, the fewer links drawn to and the greater number of links separating QM(s) from the discipline by Geographers, could be due to differences in the curriculum. However, as seen in Table 4.2 on page 80, little variation was observed in the allocation of credits between disciplines. Similarly, while Economics and Psychology tended to use more exam-based assessments – either final exams or class tests – Criminology had a similar balance of coursework and exam assessment methods to Geography. Furthermore, this explanation could only be partially linked to the undergraduate concept maps, as neither the staff nor the postgraduates would be required to take these modules. In addition, interviews for this study were conducted during the term time, before undergraduates had sat their final exams.

Across disciplines, there was a difference in the number of modules, that were overtly linked to QM(s), and thus potentially Economics and Psychology students had a greater exposure (in terms of contact hours) to QM(s), which combined with the wider range of assessment methods served to make QM(s) more memorable. In comparison, within Geography, QM(s) were more hidden within modules, which were often named covertly and included other skills such as remote sensing and GIS, thus perhaps making it less likely to be mentioned on students' concept maps.

Overall, like the patterns observed in the curriculum, while a unified thing of QM(s) could be identified across participants' concept maps, the relationships that different disciplines and different participants had to QM(s) varied. For example, undergraduates tended to include QM(s) less on their concept maps, and postgraduates, Geographers, and Psychologists, were more likely to place QM(s) in more isolated, distant areas of their concept maps. In contrast, Criminologists linked QM(s) more strongly into their concept maps, suggesting a greater complexity of understanding (Kinchin, 2016; Shavelson *et al.*, 1993).

4.4 Conclusion

Despite being characterised by the literature as a unified object, this early foray into QM(s) begins to challenge this understanding. Through examining the words used by participants in conjunction with QM(s), QM(s) was shown to occupy multiple identities, each of which had different agency over the human actors/users. While QM(s) was housed in similarly structured modules, exploring these modules in detail illustrated that a range of different techniques were included in these modules across the different disciplines. Although participants often included a reference to QM(s) on their concept maps, different disciplines and participants had different relationships to QM(s). For example, Criminologists tended to present a more networked understanding of QM(s) while Geographers and Psychologists often placed QM(s) as separated from their disciplines. Equally, postgraduates' relationships to QM(s) and their discipline appeared to be different from those held by undergraduate and staff members, reflecting wider studies illustrating PhD's more specific and fluid understandings of their disciplines. Accepting this multiplicity of QM(s) we can now turn to examining the actor-networks that construct and maintain QM(s) in different settings. In the following chapter QM(s) as an actor-network constructed through classroom learning-teaching performances will be presented, before subsequently discussing QM(s) interaction with disciplinary actor-networks – Chapter 6 – and its changing identity, in Chapter 7.

5 QM(s) as Constructed

In the previous chapter, we began to problematize the notion of a unified QM(s) as characterised within the literature, instead illustrating how a multiplicity of QM(s) was found when examining QM(s) placement in actor's words, QM(s) modules, and participants' concept maps. In this chapter, we move to exploring how this multiplicity of QM(s) is played out in the performed/lived spaces of the module learning-teaching environments.

This chapter begins with a description of the learning-teaching environments, identifying and introducing the actors (both human and non-human) that were present within QM(s) learning-teaching. The chapter then goes onto assemble these actors into an actor-network that performed and maintained two beliefs about QM(s), and examines how specific actors within this actor-network performed and translated these beliefs, giving rise to alternative understandings of QM(s) character. In the final section of this chapter, the impact software had in these actor-networks and on the understandings of QM(s) character are explored (illustrating a mischievous side to QM(s)).

5.1 Inside QM(s) Formal Learning-Teaching Environments

At first glance, the learning-teaching environments of QM(s) did not look fundamentally different to any other learning-teaching environment found within Higher Education. Large group teaching occurred in lectures, where students sat in rows or tiers facing the lecturer, possibly taking notes on paper or laptops. Lecturers presented the content of the teaching aurally supported by visual aids, usually power point slides, clicking through slides, which presented explanatory text, mathematical notation, and worked examples. With momentary ideas, or key points, being written up onto whiteboards with lecturers underlining or circling elements as they saw fit.

Alongside these lectures, were practical or workshop environments where staff and students were joined by computers, software, and worksheets. Usually these learning-teaching sessions occurred within computer labs; rooms housing ordered rows of computers, each offering the same setup of software and applications. In one module observed, lectures and practicals were also supplemented with small group tutorials. These one-hour sessions were led by one PhD student and consisted of working through a series of pre-set questions. Students were expected to have attempted the questions beforehand, few did, with most taking notes during the class of the procedure. In these sessions, the seminar/tutorial leader worked through the questions, writing the steps needed to complete the problem up onto a whiteboard, asking students to provide answers or suggested next steps.

These formal learning-teaching environments were populated by a range of familiar human and non-human actors found across many Higher Education learning-teaching environment: students, lecturers, PhD students as General Teaching Assistants (GTAs) or seminar leaders, worksheets, question sheets, computers, software, whiteboards, industry characters, timetables, and curriculum. Along with these actors, QM(s) also draws several specialist actors into its performances, including: equations, statistics, data, calculators, formula sheets, answer sheets, lookup tables, and flow diagrams. Together these actors and environments form the actors in QM(s) actor-networks, however to form networks these actors must be assembled and put to work.

5.2 Performing QM(s)

Across the disciplines teaching staff and course designers were enrolled as spokespersons (Callon, 1986; Latour, 1983) by QM(s), justifying QM(s) skills by appealing to the omnipresence of numbers. They simplified QM(s), giving it two key identifying features, which gave rise to certain performances, and legitimised common concerns, such as difficulties over timetable constraints and the mixed ability of students. The first of these two key identifying features was that QM(s) was a collective of linear and fixed knowledge, as actors described:

> You know, at the start correlation and so on, going up to statistical modeling [yeah] but then there's also complimentary but different set of skills, which are quantitative skills
>
> (Staff member, Criminology - Doug)

> So the quantitative approach, so I, it's your typical like inferential stats [mhm]. So you would do things like analysis of variance and correlations, and T-tests
>
> (PhD Student, Psychology - Alex)

> Aims and scope: A full first course in statistics and data analysis from a non-mathematical viewpoint. Covering both parametric and non-parametric methods, up to and including generalized linear models.
>
> (Geography, Postgraduate Taught Student Handbook, QM(s) Module Description)

Across all the disciplines, actors were found to have this idea of starting from basic descriptive statistics and 'moving up' to regression or modeling. That there was a fixed sequence of knowledge to be followed which was 'typical' and standard. Working to the understanding that QM(s) knowledge must be acquired through a linear progression through specific material, several structures were enlisted to monitor the continuing enrolment of students into the network of learning QM(s). While students' attendance was monitored across their degree programme through sign in sheets and electronic scanners, in QM(s) modules course attendance was often closely monitored and regularly reviewed, with students that missed sessions being flagged and targeted by administrative and teaching staff. Furthermore, QM(s) courses made extensive use of various methods of continual assessment, thus ensuring students continued to progress sequentially through the standard course material. Equally, within the classroom, content was presented linearly to students, often with the steps of a procedure being outlined and emphasised through numerical bullet points. Some teaching staff choose to work through problems by hand on a whiteboard, choosing to slow the pace at which they traveled through this knowledgescape and further drawing attention to each step of the linear process of doing.

These techniques for enrolling students into, and drawing attention to, the linear and fixed character of QM(s) also served to maintain a second belief, that QM(s) must be learnt through doing, as illustrated in the following four quotes:

> The lecturer continues saying: "Chi-squared test says you've got to calculate this thing called a Chi-Squared test statistic, and this is how we do this".
>
> (Fieldnote: Geography, 1st year UG lecture, QM(s) module)

> He explains that the course is 50% coursework - the assessment of a five-week project that students are just coming to the end of now. And 50% interactive exam, which tests their ability to physically do it.
>
> (Fieldnote: Geography, 2nd year UG lecture, GIS module)

> Seminar Leader (SL) asks: How do you work out the test statistics?
> Student (S): Erm I don't know.
> SL: The formula for the 1 sample is here
> Student reads out the answer.
> SL: How do you calculate the 1 sample?
> S: P…
> SL: How do you calculate p?
> Student reads out $p = \frac{20}{250} = 0.08$ (SL writes up answer onto the whiteboard)
> They write up the confidence interval: $0.08 \pm 1.96 \times \sqrt{\frac{0.08 \times (1-0.08)}{250}}$
>
> (Fieldnote: Economics, 1st year UG tutorial, QM(s) module)

> Across from me the student raises their hands and the GTA stops talking to me to go over to them. The student explains that he's still stuck on Question 4. He draws a line on the paper at where he understood up until.
>
> (Fieldnote: Geography, 1st year UG workshop, QM(s) module)

All QM(s) courses included some element of the 'doing' of QM(s). Lecturers and seminar leaders did worked examples in lectures and seminars. In practicals/tutorials, guided by worksheets and problem questions, students enacted the doing of the techniques, joined by calculators and computers, supported by teaching staff, other worksheets, and textbooks. Doing was not limited to human actors, however, with different software packages and equations also doing QM(s):

> Seminar leader comments "I do sympathize, that's [confidence interval equations] a tough thing to memorize, that's why we get computers to do it for us".
>
> (Fiednote: Economics, 1st year UG tutorial, QM(s) module)

> We had to use SPSS, er [mhm] I don't know what that stands for, which is where you plug in sort of some details and it will come out with sort of an answer.
>
> (1st year UG student, Geography - Roxanne)

5.2.1 Worksheets and Handouts

Through these two beliefs – QM(s) as linear and fixed, and QM(s) as learnt through doing - the timetable became a powerful actor, controlling and constraining the content included in modules and the speed at which teaching staff were forced to cover it in (similar to that identified by Gorton (2012)), concerns that commonly resulted in students and staff commenting on the need for more contact hours. To mitigate these timetable constraints, and to enable students to progress though the required material at their own pace, worksheets and handouts were enrolled into the learning-teaching performances of QM(s) – see Appendix 12.8 for two examples. These worksheets were entrusted to maintain QM(s) character as a linear actor to be done, being structured around either a series of steps or numbered questions, as one student commented:

> Er we've had some lessons on the computers, so they say, "Now click this button and then click this button and you'll get the answer at the end of it"'.
>
> (1st year UG student discussing GIS worksheet, Geography – Roxanne)

These worksheets became influential actors in practical sessions with students often interacting more with them than with the teaching staff, bringing out handouts from past practical sessions to find answers to their questions instead of asking for assistance from the human actors. In these learning-teaching sessions, students developed different ways of interacting with the worksheets, as seen in the following three quotes:

> The room is relatively full, with two girls sat next to me on the back row. One of these students says, "Why don't you have that one open and I'll have that one open?" referring to the handout and the dataset open on two adjacent computers.
>
> (Fieldnote: Geography, 3rd year UG practical, Content module)

> Each of the students has a different way of remembering where they got to, ticking off sections they've done/read or drawing a line under where they've got to on the handout sheet.
>
> (Fieldnote: Geography, 3rd year UG practical, GIS module)

> Next to me a student is reading through the sheet following along the lines with her finger. *Power of the handout.* […] Students around the room are clicking away, and holding the sheet up next to the computer screen.
>
> The demonstrator is still stood with two students going through the coding of the variables, she asks if they've got their handouts from last week. […] Two students along, the lecturer is working through the same problem with another student, he turns and asks the room, "Has anyone got the handout from last week?".
>
> (Fieldnote: Criminology, 2nd year UG practical, QM(s) module)

As the final extract illustrates, worksheets often, not only enrolled students, but also staff and GTAs into their use, with staff referring back to previous handouts or carrying a copy of the handout around the classroom with them.

In addition to worksheets, in one module students were provided with a choice diagram to assist them with the doing of the tests. This choice diagram – shown in Figure 5.1 - described how to select a test statistic through asking a series of questions about the kind of variables. This diagram formed the lynchpin for the rest of the lecture series with the module's progress through the chart being highlighted and traced during each lecture. It is worth noting that this presentation style is not uncommon within QM(s) learning-teaching with similar choice diagrams being found in many textbooks, including Field (2000). These diagrams fixed the statistical techniques into certain positions, with one kind of test being applied to one kind of data. In this way, they rendered QM(s), themselves, as passive and fixed, waiting to be selected by the user as appropriate. However, this chart also fixed the students and staff into certain performances. Similar to the worksheets, outlined above, this actor served as guide for staff and students, directing the learning-teaching environment and ordering the learning-teaching into a sequence of linear steps. Through this direction, this chart, just as with the worksheets, mediated staff and students' interactions and enrolled them into fixed, linear performances.

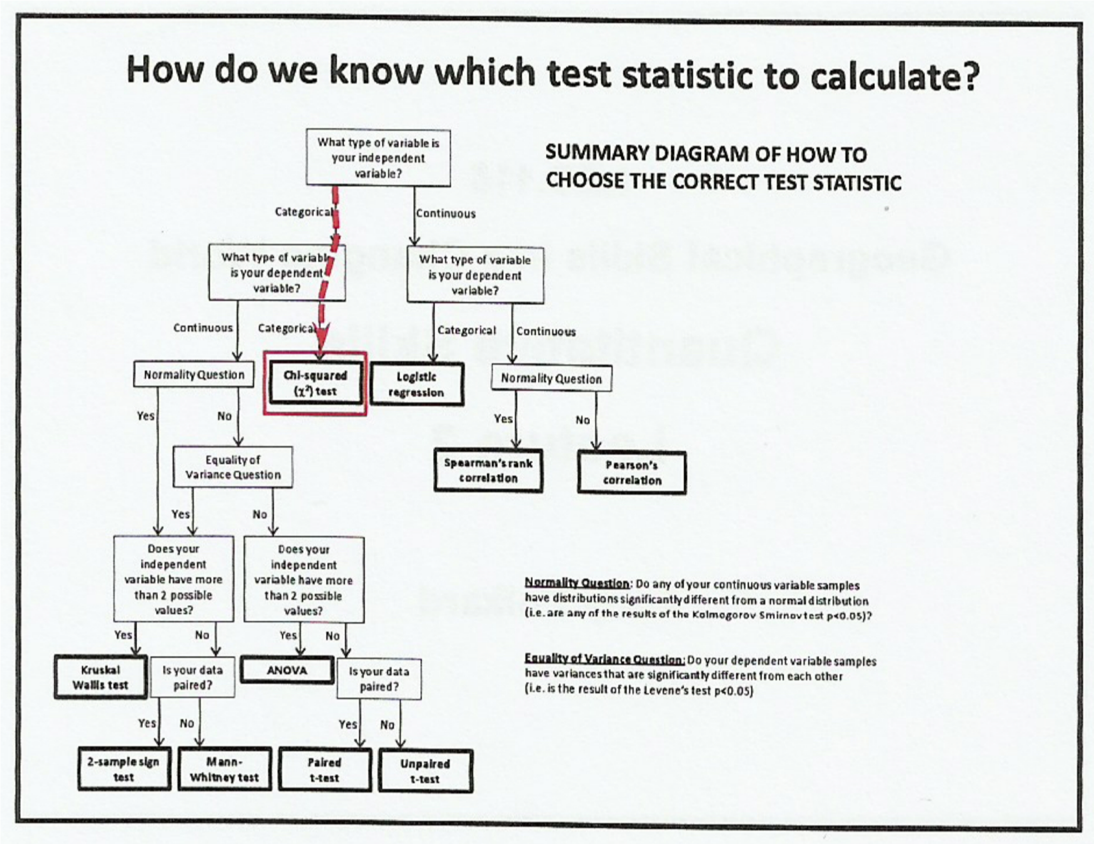


Figure 5.1 Test statistic choice diagram (taken from Geography, 1st year UG lecture slides, QM(s) module)

> He clicks forward to bring up a slide with the flowchart on it, and works through the flowchart to find the right test to perform.
>
> (Fieldnote: Geography, 1st year UG lecture, QM(s) module)

Although initially enrolled to maintain the character of QM(s) as linear and doing, these worksheets and choice diagrams served to translate QM(s) into a character to be correctly followed. While staff and courses became enrolled into following these fixed sequences, for students these worksheets and choice diagrams became instruction sheets, setting out the steps they should follow to reach the correct answer or test. Students thus became skilled at scanning through these documents to find the next step or question to be completed. As such emphasis shifted from the *doing* of the test to the *completion* of the test, the production of the output, and the correct answer. To remedy this, staff adopted different strategies to engage students with the doing of the test:

> The students next to me hit a block with a series of errors coming up, they sit in silence for a few minutes before one says, "What if we try this first", pointing to

> a section of code that is later on in the workbook. The student next to me types in the code and runs it, before saying, "Just put things in the right order!".
>
> (Fieldnote: Psychology, Master's practical, QM(s) module)

> The lecturer moves onto asking what the catch is with the tables provided. He explains that they give values for a one-tailed test, which psychologists don't often use.
>
> (Fieldnote: Psychology, 2nd year UG workshop, QM(s) module)

> We've reformatted the handouts [mm] and now […] little bits of information or reminders we pull out into little boxes at the side [mm]. So it doesn't break so much of the flow, but that information is still there [yeah] for reference. […] X was always very fond of putting different bits of text in, bold. So it actually got to the point where you could work through one of [their] handouts without reading anything other than the words in bold 'cus the name of the tools were in bold, the names of the parameters were in bold.
>
> (Staff member, Geography – Stephanie)

For students these re-orderings, blank spaces on the handout (see Appendix 12.8), and formatting changes were seen as tricks to catch them out, impeding their achievement of the correct answer, instead of being seen as a necessary part of the process of doing QM(s). In practical sessions, students enrolled another actor – GTAs – in their quest for correct answers. Unlike most of the lecturers observed, GTAs were accompanied by another actor - the answer sheet. To gain access to this answer sheet, and the associated correct answers housed within it, students carefully searched out GTAs at opportune moments in practicals to check on their own progress. As such, the GTA(s) became recast; initially enrolled to provide assistance with the doing of QM(s) here they became passive providers of correct answers, with worksheets and lecturers being understood as the key actors to assist with the doing of QM(s).

5.2.2 Correct Answers

Here then correct answers became both actors and an obligatory passage point. For staff, correct answers were employed to help monitor the enrolment of students into the network of learning QM(s):

> The seminar leader moves to the next students and says, "Can you show me your answers?" the student shows her page, he comments, [gesturing at the page] "That is correct, but that isn't, you'll have to try again" [Accepting tone].
>
> (Fieldnote: Economics, 1st year UG tutorial, QM(s) module)

However, by enrolling correct answers the 'doing' of QM(s) become focused on calculation and obtaining correct, numerical answers, as one student described:

> At A-level [Economics] was quite open and you could just argue a point with essays…whereas now, when there's set answers, you're actually looking for that answer.
>
> (1st year UG student, Economics – Ben)

Across disciplines, students performed this understanding of QM(s) as being correct, numerical answers by comparing results between one another, asking for copies of the answer sheets, and commenting on the existence of right or wrong answers. As well as being emphasised through worksheets, the importance of these numerical answers was further reinforced through the assessment methods employed. Overall, QM(s) modules employed a range of different assessment techniques:

> No statistics was very different, erm, we had weekly web-based assessments [mhm]. Erm which I think each of them were worth like 1% [yeah] and there was like 20, so it add up to quite a lot, which I'd really wish I'd realized last year, and then an exam at the end of the year.
>
> (3rd year UG student, Psychology – Tani)

As well as web-based assessments and exams, as described above, modules could also include weekly worksheets/problem questions, reports and presentations. These different techniques often involved different formatting practices and seemingly contradictory advice over collaborative working practices, as this extract exemplifies: (see next page)

> Students should fill in the worksheets on their own, but can help each other with practical skills.
>
> Work can either be handed in [redacted] or given directly to the tutors during the practical session. There is no need to complete a cover sheet.

(Criminology, 2nd year UG QM(s) module outline)

However, in comparison to other content modules QM(s) assessments stood out not because of the range of techniques used, but because of the scheme to which they were marked, as one student described:

> We get marks and everything so like with like a maths test, if you revise and you do well you get good marks, but, and you come out of the test thinking, "I did really well" [mm] and then you get a good mark for it. Or you think, "I did really badly" and you probably have done badly, whereas you might come out of an essay after handing it in going, "That was really good" [mm], you get a really bad mark, you took ages on it [yeah]. Or you could wing something the night before which I have done, and I got a really good mark for it, and it's not proportional to the amount of effort.

(1st year UG student, Geography - Roxanne)

In contrast to the perceived subjectivity of essay mark schemes, here the student ties quantitative mark schemes to an objective measure of effort. This difference of mark schemes was also commented on within handbooks, with one explaining:

> [redacted] Answers to more mathematical questions tend to be marked in proportion to the correctness of the answer, and it is thus rather easier to gain high marks (or very low marks) for such questions than in the more discursive ones.

(Geography, Postgraduate taught handbook, Coursework and marking criteria)

Marking for correctness, as the handbook phrases it, means not only that the range of marks would differ, but also the marking scale, aggregation of marks and the form of feedback provided, as these course handbooks explained: (see next page)

- The majority of assessed work is marked using letter grades and these are what you will see on returned work […]
- Assessed work which is quantitative (marked to a defined marking scheme and often largely numerical or multiple choice tests) may be marked on a percentage scale.

(University UG assessment regulations, found in Psychology and Geography student handbooks)

There are many different types of coursework and the feedback you are given will vary from one piece of work to the next. In some cases there will be written comments throughout the text, in others feedback may be written on the front or at the end of the piece of work. In the case of practical reports and other quantitative assessments, feedback may be given in

the form of a model answer attached to your work or posted on Moodle. Feedback may also be given verbally to the class in a de-briefing session.

(Geography UG student handbook, Coursework feedback)

These marking schemes and assessments, needed for the enrolment of correct answers reinforced QM(s) as a fixed, binary character, as highlighted by one student's comments:

The seminar leader goes onto describe that the standard $\mathcal{X}^2$ goodness of fit test "measures observed against the expected". He says, "You've got 5 mins to work out how all the observed and expected." Suggests it'll be a good practice for the speed they'll need to do it in in the exam.

One student comments, "I should've done maths not psychology, I was thinking about doing maths, everything's black and white not grey".

(Fieldnote: Psychology, 2^{nd} year UG practical, QM(s) module)

Here, again, then we see the influence of correct answers. When enrolled into assessments, correct answers became not a marker of ongoing progress, as initially enrolled to facilitate, but instead reinforced QM(s) characterisation as a fixed thing capable of providing correct knowledge claims - a quality that also appealed to students in Williams *et al.* (2008) report. Through handouts and correct answers, QM(s) personality is shifted and transformed through the learning-teaching environments generating different understandings of QM(s) personality to be held by different actors.

5.3 Other Sides to QM(s)

This translation of QM(s), from being an actor about doing and linear sequences to one of correctness and following, creates a tension with another side to QM(s). QM(s) itself is a data hungry actor, with each statistical technique dependent on a supply of specific kinds and quantities of data. As we met their demands for ever larger quantities of data, QM(s) became spoken for by computers and software:

> He goes onto say that before they have been dealing with 10s of observations, they're moving onto dealing with data sets that are comprised of 1000s of observations, which are "straightforward to handle in R", but not other softwares such as SPSS.
>
> (Fieldnote: Psychology, Master's workshop, QM(s) module)

Working with the impression of QM(s) as linear, staff and students were plugged into the machines. Users became removed from the systematic doing of the methods, instead 'chucking' data into the software to be crunched up and spat out as an output.

Through enrolling software, QM(s) illustrated a mischievous side in contrast to its often-passive framing:

> Whilst working through [the worksheet] students type in the code from the sheet, after hitting enter one student exclaims, "Yay!" when the final scatter plot is displayed. One student says to the other, "I keep forgetting to put quotation marks in". The students continue varying between writing line by line the code, and several lines of code before running it. Student 1 remarks: There's such a lot of code to make a decent looking plot. Student 2, after clicking enter: Oh it didn't like that…
>
> (Fieldnote: Psychology, Master's workshop, QM(s) module)

No longer was QM(s) about following the linear process. By enrolling software, the nature of doing QM(s) was transformed into an iterative process of seemingly random errors and rejections. No more were QM(s) passively selected and followed. Instead students and teaching staff were joined together in a 'dance of agency' (Pickering, 1995: p.116) with the QM(s)-software assemblage. Software had to be 'tuned' to allow QM(s) to speak out though tables of outputs. Here numbers lost their power, giving way to the

SPSS stars of significance and the commas and quotation marks of formulae and code in R.

Even without software, the doing of QM(s) was not always a simple linear sequence, where alternative pathways produce fundamentally 'wrong' answers:

> Students in the group start talking about the statistics test for another module with one saying that a friend had got 90/99% and yet she had spent time teaching her friend how to do the statistics. She continued saying that if you got the first answer wrong then the rest would also all be wrong. Another student agreed adding that she thought she might've got the wrong answer because she rounded her answer, which she wasn't sure if she was supposed to do or not.
> *Transparency of statistics, hidden knowledge needed. The idea that it has an element of luck not of understanding*
>
> (Fieldnote: Psychology, 2nd year UG practical, Qualitative module)

> Going over to another group the GTA remarks:
> "And why is that there? Rewrite it with the u^3 on the top, so to -3 and then differentiate that".
> *Why hadn't the students done it that way? Well because the lecturer didn't show it to them that way. – Less examples of different ways of doing things?*
>
> (Fieldnote: Geography, 1st year UG workshop, optional QM(s) module)

As this student's comments illustrate, the doing of QM(s) is not an unproblematic linear sequence to be followed. This following however was often interrupted by the presence of hidden knowledge, in the above example the choice to round or not.

Even when teaching staff slowed their progression, and presented steps on worksheets, steps were still skipped, with knowledge assumed to be commonly held, as expressed in the following quotes from one lecturer and fieldnote:

> Er I, I struggle quite a bit in my postgraduate [module] where I'd write out equations [saying] ,"As we know this" and they would say, "No we don't, extremely sorry but we have no idea what you're talking about". [yeah]. And to me, that seems obvious [yeah] to them it seems obvious that I'm silly.
>
> (Staff member, Economics – Rohan)

> Next to me a student raises their hand and the lecturer comes over to the group (note the same student raises their hand in the group). The students ask about Q4, the lecturer (L) stops them and says:
>
> L: Anyone else struggling with Q4? Come up and we'll do it on the board.
> The group of three students at the back get up and follow him to the front LH side of the room, slightly removed because of the alignment of the pillars. The lecturer begins working through the question, several other students get up and join the group (total of 5). He continues working through asking students for what to do next, and explaining. One student asks him "How do you work that out?" (referring to the unit change). Lecturer moves over to another board writing up: 5km/hr. He says:
> L: So if we've got 5km/hr, I'd do it one step at a time, so 5000m/hr, m/s, so divide by 5000/3600.
>
> (Fieldnote: Geography, 1st year UG workshop, QM(s) module)

This hidden knowledge echoes Garfield's (1995) principal that students may struggle with unexpected elements of the curriculum, and Cornell's (1999) and Folkard's (2004) description of students frustration and anxiety when staff provided incomplete instructions, missing out steps of the calculation. However, unlike the suggestion within Garfield, this hidden knowledge represents more than a comment about the best teaching practice. Here, we see that QM(s) are not simply a well-trodden path to be followed. The doing of QM(s) is not simply a passive following, but an active navigating of paths and choices to be taken. In lectures and seminars teaching staff act as guides, conjuring up a land of numbers, and showing students these paths. However, students can become easily lost, wandering blindly through the knowledgescape, sometimes trying to catch up, sometimes giving up. In the world of correct paths these alternative routes are looked upon with distrust, they are mistaken choices. Yet outside the safety of the QM(s) classroom - in which QM(s) and data are pacified - these meanderings are not mistakes but required actions for the doing of QM(s). After all, outside the classroom there is no back of book where answers can be checked.

As well as QM(s) being a path to navigate, the 'real' doing of QM(s) requires the ability to enroll data. Yet in learning-teaching sessions, data is a silenced, passive actor to be matched to a QM(s) that will speak for it. However, 'real' data is rarely passive:

> The problem is of course is that it's real data, so it's always messy and it never gives you the answers you want it to so you want to demonstrate what a significant result for an ANOVA test looks like and there isn't one in your data.
>
> (Staff member, Geography – Freddie)

Here, again, we see that the doings of QM(s) is not only a passive, linear fixed performance, but one that can be non-linear, requiring active navigation, and negotiating skills to enable data to be fixed down and spoken for.

5.4 Conclusion

In this chapter, the actor-networks that construct QM(s) in the module learning-teaching environments were presented. By tracing out these actor-networks, we have moved from a simple understanding of QM(s) as multiple to examining how this multiplicity is played out in the learning-teaching environments.

This chapter began by outlining the variety of actors observed in these environments – many of which were overlooked by the literature. These actors present included, the familiar students and staff, worksheets, software, curriculum, and other less familiar actors, such as equations, statistics, data, answer sheets, and choice diagrams.

These actors were subsequently assembled into an actor-network, with lecturers enrolled as spokespersons for QM(s). These actor-networks performed and maintained two key beliefs about QM(s): 1) QM(s) was a collection of linear and fixed knowledge, and 2) QM(s) must be learnt through doing. While specific actors, including worksheets and correct answers, were entrusted to support and maintain these beliefs, this chapter described how these actors transformed the character of QM(s). Through enrolling staff, students and the curriculum into linear and fixed sequenced performances, these actors translated QM(s) into a character defined by following and the search for correct answers, overshadowing the doing of QM(s). While strategies were developed by staff to interrupt this performance, students became masterful at scanning through worksheets and seeking out correct answers held within the answer sheets carried by GTAs.

Following this, this chapter commented on the role of correct answers as both an actor translating the character of QM(s) and as an obligatory passage point for students. In enrolling correct answers, QM(s) learning-teaching was marked out to students as different from other kinds of disciplinary knowledges, with different assessment methods serving to further solidify the character of QM(s) as a fixed provider of correct knowledge claims.

Finally, this chapter described how, in practical sessions where QM(s) enrolled software, this hybrid QM(s)-software actor performed a more mischievous side. This side provided a stark contrast to the fixed framing of QM(s) identified elsewhere in the learning-teaching environments. No longer linear and passive, the QM(s)-software assemblage was performed dynamically, in a process akin to Pickering's (1995) dance of agency. Here students and staff tinkered together on the quest for outputs, with numbers and data fading into the background. In this section, the absence of data as an actor was briefly commented upon. In each of these learning-teaching performances the data itself had been pacified and silenced, simply there to be matched to a QM(s). However, this silencing of data is perhaps cause for concern, given the messy, slippery nature of 'real' data.

While the implications of these performed actor-networks will be discussed in Chapter 8, it is worth noting that the features of QM(s) touched upon here echo principals of best practice outlined in the literature (Garfield & Ben-Zvi, 2007). Yet in tracing out the actor-networks which serve to maintain these features, we are forced to question the narratives of unproblematic uptake of QM that ground policy initiatives (e.g. Nuffield Foundation, 2016).

Having examined the construction of QM(s) in module learning-teaching environments we can now turn to examining how its character is constructed and performed within the actor-networks of the four Social Science disciplines included here.

6 Disciplinary Doings

After examining the learning-teaching performances that serve to construct, translate, and enrol actors into the module actor-networks of QM(s) in Chapter 5, here we explore how QM(s), as an actor itself, is enacted/positioned within different disciplinary networks. In this chapter, the qualities of QM(s) as an actor within each discipline will be presented. We will explore how QM(s) becomes enrolled into disciplinary actor-networks by performing different roles in each disciplinary actor-network. Within each of these disciplinary actor-networks, QM(s) acquire power through its ability to assist with disciplinary narratives. For clarity, each discipline has been linked to a single dominant role QM(s) plays, however it is important to note that these different roles were found, to some extent, across all disciplines. After having presented each disciplinary doing of QM(s) a comment will be made on the driving force behind these narratives.

6.1 Criminology

> Two students come in discussing how many people they think will turn up to the seminar as it's the last of the term. At 4pm two other students arrive, we all sit in silence waiting for the seminar leader to return.
>
> After passing around the sign in sheet the seminar leader asks what was found in Phase 1, a student replies "NHS?", the seminar leader agrees expanding saying "Yep, benefits and the welfare state". She continues asking:
> SL: What was going on with crime?
> Student: By 1955 it started rising by 10% *(Numbers as measures, with students making a fixed matter of fact statement)*
> SL: As it was quite stable up until then.
>
> The seminar leader moves onto Phase 2 asking what happened to crime, a student responds saying that it became a "salient wedge in the manifestos and criticizing each other.". *(In this seminar group the students are much happier to answer questions.)* The seminar leader agrees talking through that in 1981 there were the Brixton Riots and that crime was 50% higher in 1992 than it was in 1998. *(Same phrased sentence quoting the statistics as used with the previous groups).*
>
> Next to me a student has opened up the lecture slides and is clicking through them. They consist of graphs and tables as well as text. The student says:

S: I think there was 3000-4000 new offences from 2000-2008.

The seminar leader explains that New Labour redefined the landscape, with PACE aiming to balance the system by actually rebalancing in favour of the victim, the exchange continues:

SL: What happened to prison numbers?

S: Under New Labour they were they highest they'd ever been.

[Seminar leader passes around the printed question sheet]

SL: What happened to crime during the 1950s to the 1980s?

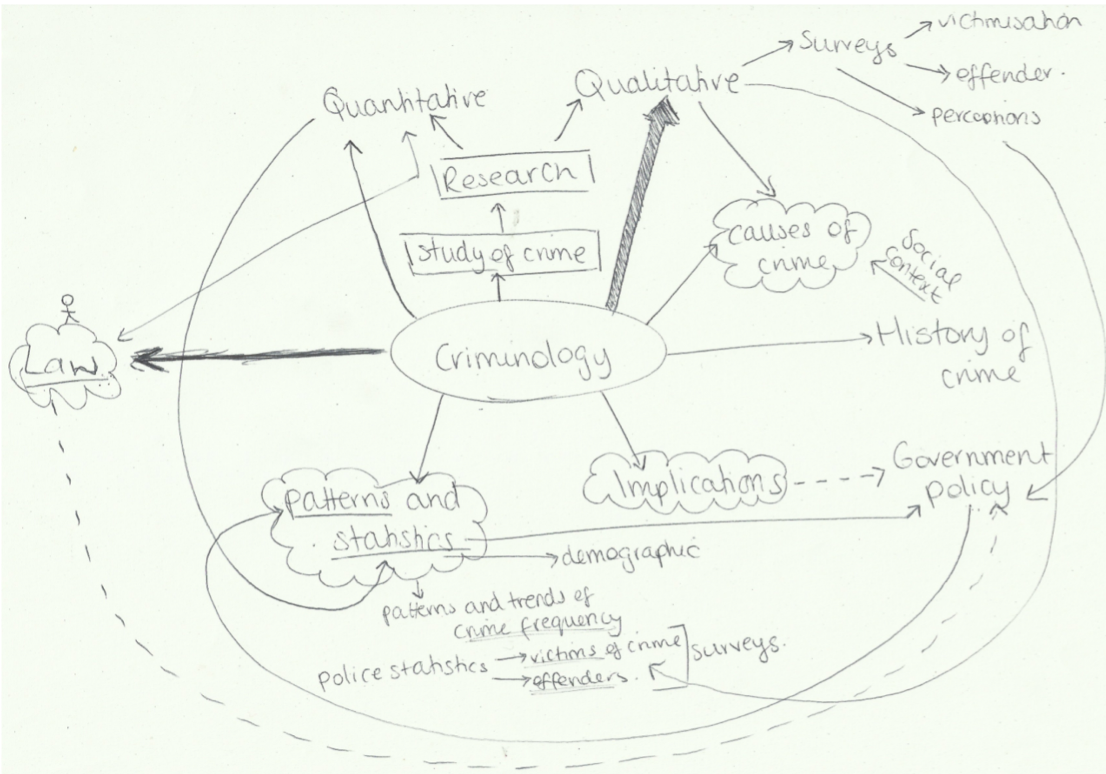
S: It rose.

SL: There was a slow increase – quantify it. During the 1980s crime shot through the roof, from the late 1990s crime decreased – why?

S: New economy and New Labour

SL: Yep, we're used to rising crime now, it's become the norm.

(Fieldnote: Criminology, 1st year UG seminar, Content module)



(2nd year UG student, Criminology – Daisy)

> Currently I'm doing another module […] and yeah that's, we get assessed on our computer labs, so how well we handle statistics, and we also have coursework, which erm, is like a lab report where we have to find trends and explain the trend in crime frequencies over 100 years for sexual offenses and then we also have an exam.
>
> (2nd year UG student describing the assessment of a 2nd year UG content module, Criminology – Daisy)

> The coursework was about change in crime rates for two particular crimes [mhm] […]. It was kind of like interpretive. We had this data [mhm] and we had to make a graph out of it and we had to say why there'd been a change in the data.
>
> (2nd year UG student describing the coursework assessment of a 2nd year UG QM(s) module, Criminology – Genevieve)

When entering the field of Criminology, it was impossible to overlook the dominance of trends of data, specifically, trends of crime rates. Numbers of victims, offenders, prisoners, or reported offences acted as lenses through which to understand patterns and trends of crime. Unlike other disciplines where conditions were controlled, tested, and repeated, here patterns were linked to policy changes (often the dominant variable changing). These trends were there to be carefully quantified, presented, and interpreted - a fact that was reinforced in the teaching practices and assessments, as seen in the quotes above.

However, instead of emphasis being placed on the process of producing 'correct' trends, students and staff were continually mindful of the ways in which statistics could be misused by the media (an issue gaining increasing attention through the growth of organisations such as Full Fact and statistical reporting courses provided by the RSS (2015)) and of the limitations inherent in crime survey data:

> We've been challenging statements made with statistics, and trying to find research to back them up and all that kind of stuff, it's impossible like, just so much of it seems to be a bit, erm, made up really. Erm, which is why I think the media is quite important, cus that's how, before learning about this stuff, that's how I got most of the information, and if the media isn't showing, erm, the true

> picture that Criminology research is finding, and it's mainly based on qual-quantitative facts because they're easier to pick out and sort of translate upwards, aren't they? So I think that's quite important.
>
> (2nd year UG student, Criminology – Sarah)

> What they do is they learn to, erm, access data [mm]. They learn to work with data of various forms, […] they're learning how to work with data, they're also, in the lectures they're getting a background as to what is, and what isn't included in these crime figures […] they're understanding where this data comes from, but then […] they're starting to use their analytical skills to maybe understand why we're seeing differences
>
> (Staff member, Criminology - Doug)

A sentiment that was reiterated by one module handbook:

Week 2 Quantitative research on crime & criminal justice

Quantitative research – that is, research that involves *numbers* – is key in finding out the *what, where, when* and *how* of crime. It is also key in persuading politicians, policymakers and the general public about what the 'problem' of crime is and what the solutions should be. Yet the utilisation of quantitative research makes certain assumptions about the nature of the world and the nature of knowledge, and the process is fraught with methodological challenges. This lecture explores some of these issues, using examples from research to illustrate.

Preparation for seminar:

Activity	Title
2.1	Based on your reading, make notes on: (a) What is the relationship between theory and research? (b) How does *quantitative research* map on to the concepts of 'ontology', 'epistemology' and 'methodology'? (c) What are the problems with using *quantitative research* when researching crime?

(Criminology, UG 2nd year research methods module handbook)

For Criminologists, these limitations, or what "isn't included" as Doug described it, is of particular importance, with the term 'dark figure' being used to describe the number of crimes that are left out of official statistics. By labelling in this way what is effectively an unquantifiable error term, Criminologists reinforced a necessary scepticism towards QM(s). This constant interrogation of QM(s) is also of importance given the overwhelming dominance of survey data and of secondary data used in their field, such as that from the Home Office, ONS, or the Crime Survey for England and Wales. With little control over the design of these surveys, emphasis shifted to the production of trends through time, descriptive statistics, and the representation of this data, through pie charts and line charts.

Although these techniques were understood by students as producing a shallower picture than qualitative methods, despite this and the aforementioned scepticism, QM(s) were still understood as valuable, as one student described:

> It's never going to give you a complete picture, but what it does give you is at least a starting point of trends. It's better for trends really. [mhmm] Erm, and what police statistics show you really are, how many crimes were reported to the police [mhmm], not how many crimes happen. So they're not completely useful, but not completely useless.
>
> (2nd year UG student, Criminology – Daisy)

While Criminology and Sociology are disciplines often characterised as having low QM(s) content (Williams *et al.*, 2016; Williams *et al.,* 2004) here QM(s) power to provide trends was relied upon across the degree. In focussing on this side of QM(s), students were taught to interrogate and cross-examine the statistics presented to them, understanding that QM(s) were used to make statements, and ultimately an argument, according to a specific dataset. As such, students acquired much higher levels of quantitative literacy (see Ben-Zvi and Garfield (2004) or Rumsey (2002)) or thinking skills (as used by delMas (2002)) than seen in other disciplines. Overall, QM(s) here were fluid and changing depending on the data, speaker, and occasion, providing partial indicators not fixed truths.

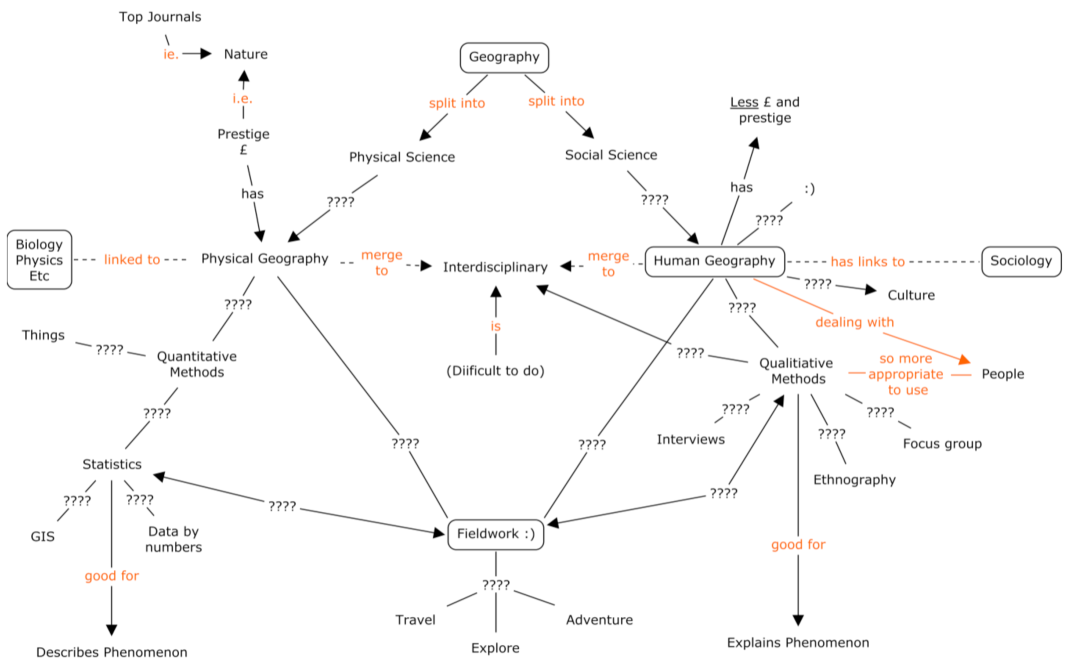
6.2 Geography

Within Geography, students were exposed to QM(s) through questionnaires, fieldwork, lab work, and maps and charts in GIS. Here QM(s) could be numerical representations of an environment, a mathematical model of a system, or outcomes of a statistical test. When stepping into Geography, the trends and patterns of crime seen in Criminology become trends and patterns across space, visualised, predominantly, through GIS. When exploring these trends and patterns, Geography had a similarly close relationship with secondary data as was observed in Criminology, with data sources including the

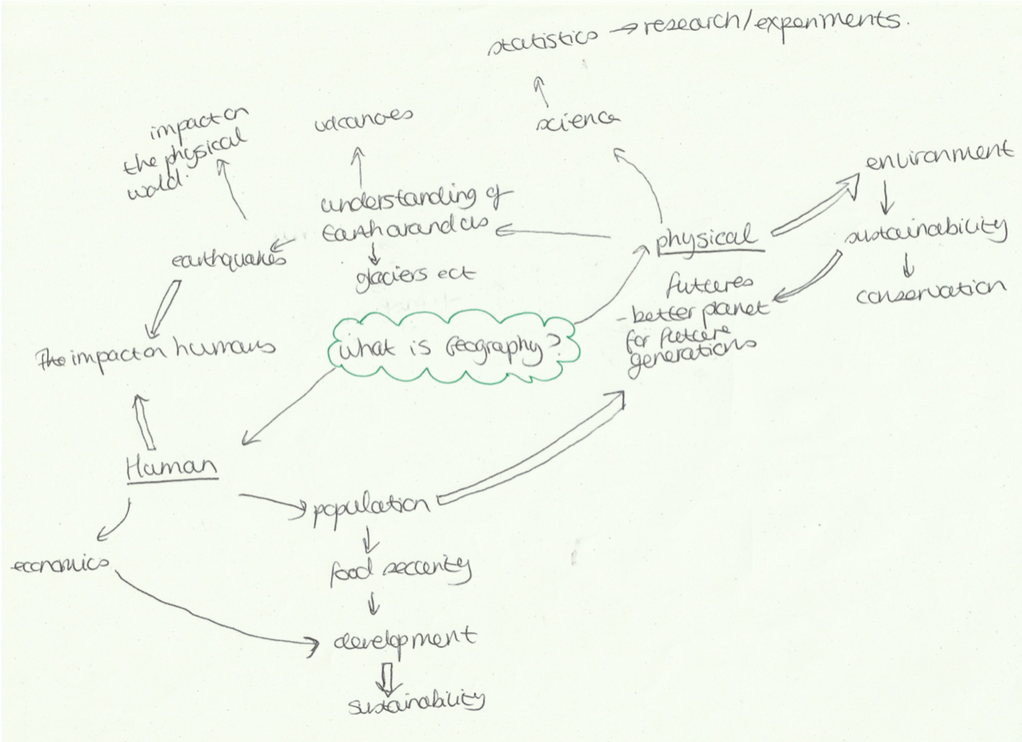
Ordinance Survey, Environmental Agency, or services such as EDINA Digimap Service, or Greenland and Antarctic Ice Sheet Model (GRANTISM). However, here the partiality and scepticism of QM(s), dominant in Criminology, was far less emphasised.

This lack of scepticism towards QM(s) is postulated to be a result of how QM(s) was positioned within the wider discipline. For many QM(s) was understood as being closely related to physical geography, as illustrated below:

> So I guess yeah, I don't know if I'd call myself a geographer any more […] I feel like, yeah, as I loose the quantitative and the physical side of my work, yeah, cus I'm drifting more.. more and more into this kind of social stuff then yeah, then I feel that that makes me less of a geographer and maybe more of a something else.
>
> (PhD student, Geography – Laura)



(PhD student, Geography – Rory)



(1st year UG student, Geography – Ella)

While QM(s) were placed within a Human Geography context in the curriculum, many still tied QM(s) to a scientific approach, as discussed in Section 4.3, a legacy perhaps of the quantitative revolution of the 60s (see Sheppard (2001) for a description of the quantitative revolution within Geography). Within the literature, this division is commonly attributed to students seeing QM(s) being more widely used by Physical Geography staff members, which has thus resulted in a call for the promotion of Human Geography applications of QM(s) (Johnston *et al.,* 2014). However, here, this link is thought to be also due to a difference in the nature of QM(s) uptake into each of the sub-disciplines.

Across much of Physical Geography, QM(s) were strongly tied to the measuring and estimation of physical parameters (speed, distance), as became apparent on a Physical Geography fieldtrip:

> On arrival the whole group walked down to the first location, a bridge over a stream in the valley. Both lecturers gave a short introduction to the day and the context of the location in relation to the wider geography of the region. The group was then split into two, down the middle of the assembled students. For the first part of the day I was placed with the lecturer delivering the hydrology

content for the trip. We all walked along the path up to the first location. Here, next to the stream, the lecturer passed out his hand-outs, and gave an overview of the activity – which was to answer several questions about the processes occurring at the site and estimating the stream parameters.

Students were given a while to think and discuss the questions in smaller groups (twos or individually) before the group was brought back together. In talking through the question sheet a very physical approach was taken, students were asked to think about an individual raindrop falling into the valley and the path it would take through the valley. A numerical element was added in the estimation of the stream parameters, which included: width, depth, cross-sectional area, velocity, discharge, and pH. Students were given no equipment to measure any of these elements. Instead the lecturer demonstrated how you could take a ballpark estimate using your body or foot, by first lying across the stream to estimate its width and then by putting his foot in the stream to estimate the depth. This provided a talking point for both students and demonstrators. He then asked the group what the cross-sectional area of the stream was, saying:

L: OK so what is 20cm in meters?

S: 0.2

L: 0.2, that's right, so 4 x 0.2 is? *(The agreed upon estimated width multiplied by the depth)*

S: 0.8

L: So that's $0.8m^2$ is our cross sectional area.

The lecturer moved onto the discharge of the river, asking what estimate of velocity the students thought the stream was moving at. To answer this the lecturer stood roughly a meter away and asked the students to think about how fast the stream was moving in that distance. They provided a guess, which was then used to estimate the discharge by multiplying by the cross-sectional area. There was a noticeable absence of calculators, with students calling out answers and the lecturer prompting "and what is that measured in? m^3/s".

The session ended with the lecturer emphasising that it was important to have ballpark estimates as sometimes you did not have precise measurements to provide exact calculations of the stream dynamics.

(Fieldnote: Geography, 2nd year UG fieldtrip, Content module)

As well as exemplifying QM(s) as a character of measures and estimates, in the above example the embodied nature of these numbers was drawn out. As measures embodied by either human bodies, or by tape measures or meters, numbers took on a kind of concrete quality that is hard obtain from the survey data of the Criminologists and, in some cases, Human Geographers. Given the apparent concreteness of these numbers, the scepticism of Criminology was hard to sustain, as one participant said:

> Erm I suppose what I like about numbers is… erm, they're definite lines in the sand, if that makes sense [mhm]. The, the number eight is not open to interpretation, [yeah] erm, whereas almost anything written in language is open to interpretation, so I suppose, I suppose it, numbers provide anchors [mm] on which you can make decisions.
>
> (Staff member, Geography - Aaron)

With this self-assuredness, QM(s) became characterised as problem solvers, providing quantified solutions that were – at least theoretically – hard to argue against. This face of QM(s) as a problem solver was further foregrounded through module descriptions, which included phrases such as:

> This module provides an introduction to the skills used by geographers to analyse problems in both human and physical geography.
>
> (Geography, 1st year UG research methods module description)

> Apply industry standard flood estimation and modelling techniques to solve real problems in the context of flood risk management and the latest legislation and policy.
>
> (Geography, PG content module description)

> At a generic level, the students will be able to critically appraise aspects of the scientific literature, formulating robust scientific arguments, using recent research data from the module convenor and others to design solutions to environmental problems.
>
> (Geography, PG content module description)

As a problem solver, QM(s) was a powerful ally, providing answers to specific questions, the results of which were understood as (reasonably) stable and reliable. While these numbers were understood as having errors associated with them, these errors were understood as being able to be constrained and quantified, thus leaving the stability of the result intact. This was exemplified by one staff member – David - who explained his research process by using the following diagram, shown in Figure 6.1. Through this he explained how samples were collected, processed, analysed, and how the numbers generated were then transferred into models and interpreted at system and world scales:

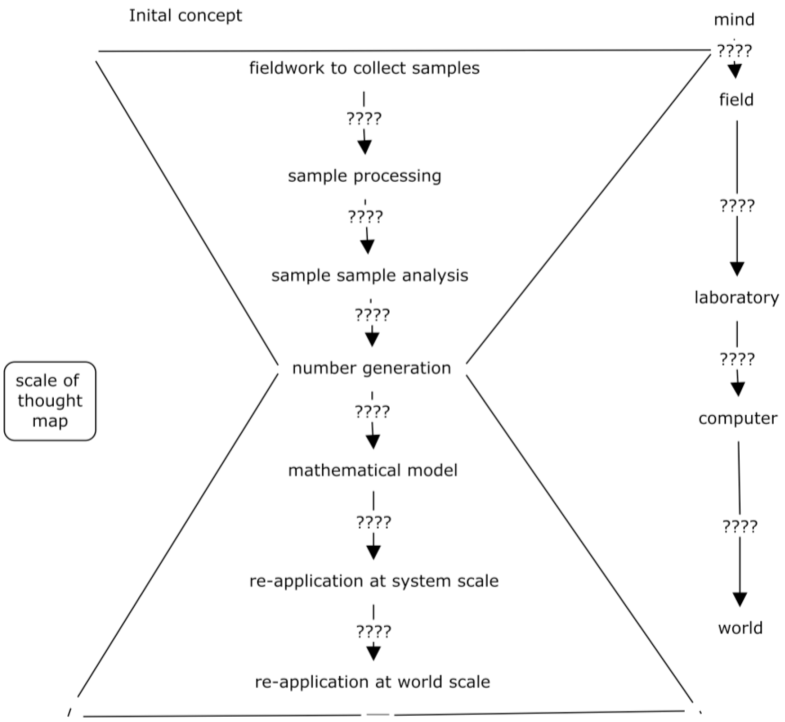


Figure 6.1 Participant's (David) scale of thought diagram describing their research process.

He went onto explain that this process could be applied to the work of Human Geographers but that their work tended to be more qualitative explaining that in that context:

> So in other words you don't have a hard and fast number [mhm] on that, on that result. Erm, they may put it into some kind of conceptual model […] which is basically saying, erm, "OK we don't put hard and fast numbers in and get hard and fast numbers out, we put ideas in, and we say how things are linked

> together and how different things happen in the world through people's perceptions".
>
> (Staff member, Geography – David)

This infallibility of numbers in Physical Geography meant that QM(s) could acquire a strength and dominance, not only providing trends but reliable answers and predictions which were vital to solving the environmental questions and problems of interest to Physical Geographers. Valorising QM(s) for their fixity and robustness however becomes problematic when placing QM(s) within a Human Geography context. Where QM(s) has thrived in Human Geography it has been in areas where numbers can be rendered with this same fixity – i.e. Transport Geography or GIS. But for those fields where "hard and fast" numbers cannot be produced, or where the underlying phenomenon studied is understood as being inherently fluid – where the data that is available more closely resembles the survey's found in Criminology – the power of QM(s) break down as a different kind of quantitative methods are employed (similar to that identified by Thrift (2002)). When compared to the highly prized fixed numbers – and world – of Physical Geography it is perhaps unsurprising that Human Geographers and Criminologists remain sceptical about QM(s) value. Overall, for Geography as a discipline this left a tension, as different kinds of data, methods, and epistemology overlaped, with QM(s) playing their part, but being kept in check by other approaches, as one student described:

> I suppose, I think the focus has been too much on quantitative generally, erm, and I think sort of things like issues like climate change won't be solved with quantitative methods. [mm] It's er, you know working out how much carbon there is in a tree trunk or whatever is not going to sort of solve the issue. It's humans living on the Earth, and the way humans live on the Earth which is the issue.
>
> (PhD student, Geography – Rory)

6.3 Psychology

> If you speak to people who never had experience of psychology they wouldn't ever think that stats would ever have anything to do with it [mm] and I think that's one of the important things, is pointing out, particularly to students who want to study it [mm] is this idea that stats without psych-, psychology without stats isn't anything [mm] it's not a subject. It's more, yeah I don't even know what that subject, like anthropology is probably what you'd want to look at [yeah] and I think a lot of people would think that psychology's more like anthropology at the start [mm].
>
> (PhD Student, Psychology - Alex)

> So it's, I think that's what people don't realized actually, that's why I put three, or two exclamation marks after SPSS, because it's unbelievably stats heavy [mm] and people that go into Psychology are not necessarily very strong in [mm] erm, statistics, but I don't think people realize that. They think it's just, well it's theoretical but obviously don't realize like how strong you have to be [yeah] in statistics. So a lot people are put off that in the beginning.
>
> (Master's student, Psychology – Flora)

For many students entering a degree in psychology QM(s) played an unexpectedly central role, in contrast to its marginal role in the A-Level curriculum within the UK. Here QM(s) were found in the lab, as measures of eye movements or test scores, as an Experimental Psychology. Like many other experimental fields, QM(s) were enrolled to provide a reliable, reproducible, and rigorous means of theory testing. Implicit references to this were found in course guidelines, shown below:

The aims of this module are to:

- Understand the concept of unconscious influences on behaviour
- Understand how both internal (e.g., cognitive) and external (e.g., environmental features) factors can shape our decision-making
- Appreciate that human preferences are not static representations, but are constructed dynamically in response to online constraints.
- To evaluate theoretical positions and select appropriate methodologies or empirical paradigms to test them
- Conduct critical evaluations of empirical studies and academic journal articles

(Psychology, PG content module course aims)

✓ The Discussion section starts off by dismissing the findings as an artefact of poor methodology. Even if you know that the failure to find an expected result is because of a methodological flaw, you must always start your discussion by giving credence to the results you actually found, discussing what they would mean for the theory under test if they were to be replicated.

(Psychology, UG dissertation assessment guidelines)

These guidelines outlined the value of theory testing and the role of methodology, which was often a quantitative approach, in this testing. This importance of theory testing was further expanded upon by one staff member when drawing their concept map (see Appendix 12.9 for Mark's original and redrawn concept maps):

> So there's a lot of I suppose, pseudoscientific stuff, magical thinking, and that's also I would say connected to er, erm, low sample, 'surprise', newsworthy research. So it looks like, it's dressed up as, dressed up as experimental but it's not really. There's a lot of that stuff that happens and it kind of connects to erm, the popular newspapers and whatnot. [writing]
>
> [Inaudible] Quantitative, qualitative. So erm.. maybe what I mean is evidence based [writes] evidence-corrected theory building, which you can do either qualitatively or quantitatively. […] You might have I think erm on this side of things [gestures to the pseudo-scientific] interesting questions [writes].. and they can come from both sides. But this side [pseudo-scientific] doesn't really care about being right or wrong.
>
> Interviewer: […] Can I just ask, when you say, this, did you say magical thinking?
>
> Interviewee: […] I guess it's explaining the world [writes] without… testable theories. [OK] Or erm. Saying things are the way they are just because [mm]… or wishful thinking.
>
> (Staff member, Psychology – Mark)

QM(s) powerful enrolment into Psychology came, in part, due to its ability to provide various markers of significance (i.e. *p*-values, *f*-values), measures of effect, and forms of proof, as two students explained: (see next page)

> Erm, I think it's very important for psychology as a discipline to be scientific [mhm]. And it's those things that make it scientific and it's those that give psychology worth [mm] because as great as sociology is [mm] it's quite easily dismissed because the the proof, and the burden of proof isn't massive [yeah]. Whereas with psychology the statistics and the research methods is what makes it concrete and what makes it solid and so now we know these things for a fact rather than speculation.
>
> (3rd year UG student, Psychology – Tani)

> This is much more exact [gesturing to the science]. The way that the psychology or the social sciences are moving. They're becoming much more defined in hard science [mhm] I don't think anyone would dispute that, and it's becoming much more exacting, they're looking for proofs all the time "Oh this happens because of this".
>
> (1st year UG student, Psychology – Alistair)

However, despite these students' ideals these proofs were built up from, not only the use of statistics, but from the associated establishment of conventions. Across the discipline there were numerous different conventions; such as conventions of formatting:

> Erm, and then Psychology is controlled by the British Psychological Society and the American Psychological Association [mhm] and as a student obviously you have to follow like their guidelines when you're you know writing assignments and [mhm] submitting erm papers and things like that.
>
> (Master's student, Psychology – Flora)

> He explains that in Psychology it is practice to present a table of co-efficient and R2s, and that "elsewhere in statistics they'll often compare to the real world and other models". *Again a comparison to 'convention' and othering of "statistics".*
>
> (Fieldnote: Psychology, PG lecture/practical, QM(s) module)

There were also conventions around accepted values of significance/effect, as were explained in one lecture:

> The lecturer gives Cramer's ϕ [Phi] or V as formula for calculating effect size. Here the equation is presented using mathematical notation:

$$\phi = \sqrt{\frac{\chi^2}{N}}$$

For a 2x2 table. V, used for larger tables is the same but divided by $N(k-1)$.

The lecturer speeds through example calculation, and then asks, "What does this mean?" Then uses Cohen's guidelines (1988) for Phi values:
0.10 = 'small'
0.3 = 'medium'
0.50 = 'large'

He suggests, "These were not values he made up in the pub", but were from mathematical modelling, as well as that their use was "tradition" in psychology."

(Fieldnote: Psychology, 2nd year UG lecture, QM(s) module)

Additionally, there were conventions guiding categories and exclusion:

He repeats again what a non-parametric test is before listing what the assumptions of the categorical tests are. He emphasises the rigor of categories by referring to researchers suggesting, "All researchers agree and can apply the category".

(Fieldnote: Psychology, 2nd year UG lecture, QM(s) module)

As one lecturer explained:

I mean you could distinguish between, how you might do data analysis in terms of erm..er.. associating a believe or a hypothesis with er, a degree of confidence, or certainty [mhm] depending on the evidence you analyze. And there are a variety of ways to do that. But erm a field, and academic field er, subject field will tend to do it in a way that is erm, reproduces itself through convention, er custom practice [mhm]. So erm, reviewers will tend to want to see an analysis done in a certain way, not because necessarily it's the right way, but because that's the way they've seen it done [mhm] or that's the way they do it.

(Staff member, Psychology – Mark)

While, as this lecturer explains, these conventions served to hold the field together and provided an easy means for valorizing QM(s), they inevitably cause problems when these conventions are overturned, as with the *p*-value crisis discussed in the Introduction, or areas where these conventions cannot be applied. For the few qualitative Psychologists, QM(s) dominance in Psychology has had noticeable effects, as one staff member explained:

> I did a little survey […] and we got a reasonable response, I think we got over 100 UK social psychologists responding to it [mm]. And there's a clear difference between quant and qual-people who are primarily identify as quantitative researchers and those who primarily identify as qualitative, in terms of their entry into the REF. [mm] If you were doing quant you were more likely to be entered into the REF than if you were doing qual.
>
> […] the effect of things like the REF is gunna be to diminish the shear number of people doing this kind of research. The value that was placed on it [qualitative psychology] within the discipline as a whole [mm].
>
> […] in environmental, you know, occupational, clinical, forensic and health psychology particularly have, qual is very healthy there [mm]. But they're not disciplines, primarily because of their applied focus [mm] that are.. likely to be rated in terms of the research outputs, not as, well in terms of the research outputs there's not going to be rated likely as 3 or 4 star.
>
> […] qual becomes allied or associated with the still slightly kind of dirty, kind of pejorative view of applied psychology [mm]. You know, it's not basic, it's not [mm] it's not knowledge generating, you're just doing something for the sake of helping people in a clinic [mm].
>
> (Staff member, Psychology – Tristan)

Unlike Geography, where QM(s) co-existed relatively amicably with qualitative methods, Psychology was the only field where QM(s) expansion was changing the kinds of knowledge valued by the discipline. QM(s') power to achieve this comes not from the infallibility of the data, nor the use of more effective methods, but through its ability to enroll actors into establishing and reinforcing conventions and recruiting external actors, such as the Research Excellence Framework (REF), to endorse the kinds of messages it can deliver. Despite the work done by these actors to maintain the actor-network in its current form, the *p*-value crisis provides a telling reminder of the fluidity of these actor-networks – a theme which will be further discussed in Chapter 7.

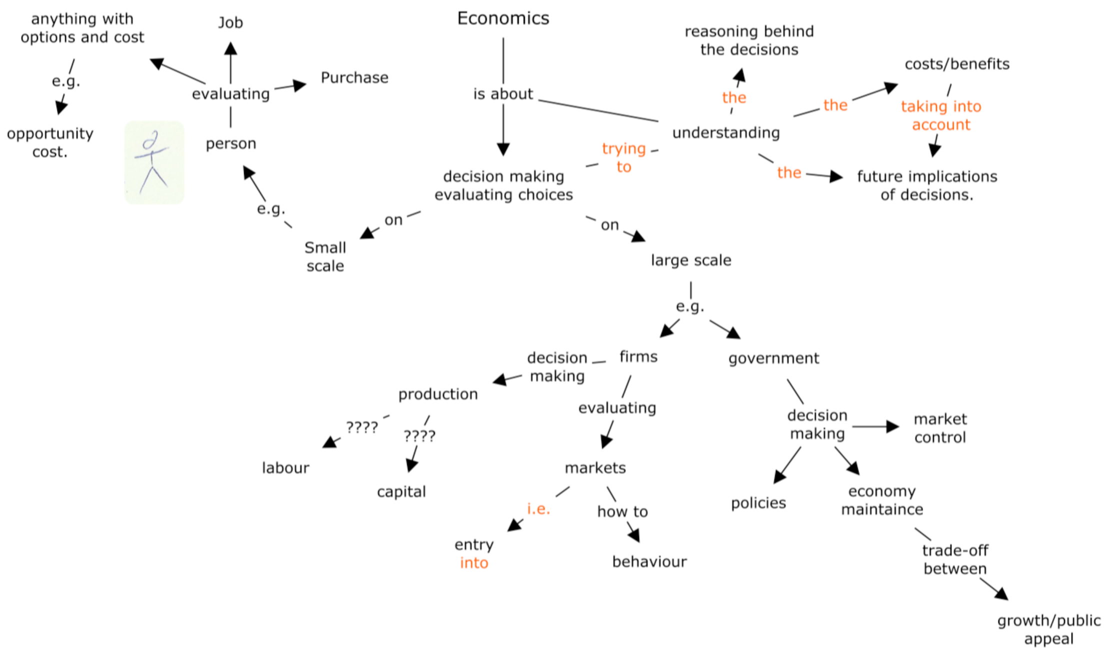
6.4 Economics

Unlike the varying visibility and skepticism found in the other disciplines, the Economists were relatively brazen about QM(s) relationship to their discipline, unapologetically and directly stating:

> The general aim is to provide students with a broad understanding of economic theory and the application of quantitative methods to economics.
>
> (Economics, UG student handbook, Programme aim)

> So, so yeah Economics is like understanding the world and quantifying it. [mhm] Erm, so yeah, we quantify, I think what Economics does neither better or, neither for the better or for the worse is we quantify things much more than some other disciplines. [mhm] I think that's a key part of Economics.
>
> (PhD student, Economics – Dan)

Here QM(s) was a blend of mathematics, modeling, and statistics, forming their own specifically termed "econometrics". For Economists, only by enrolling QM(s) and quantifying the world, could they evaluate the kinds of evidence available to them, or translate their world of numbers into predictions to aid decision-making: (see below and next page)



(1st year UG student, Economics – Ben)

> Instead of just saying what you think there's actual calculations about how you can work out the trade-off between the labor and the capital depending on the price [mhm], future expectations, things like that and so you can apply the quantitative methods to actually work out what the erm, the actual cost is of employing more labor instead of capital or vise versa and work out what the actual optimal point is [mhm] for the two as a trade-off. Erm and so then you've actually got a set position which is the best position for that firm to go into.
>
> (1st year UG student, Economics – Ben)

> He (SL) moves forward on the power point and says, "You'll always have to write something that relates these figures back to the question and the data. If you're the company you want to know if you should change or not, and you need to have the stats to back that up".
>
> (Fieldnote: Economics, 1st year UG tutorial, QM(s) module)

Here QM(s) faced little competition from other methods, which were unable to speak to the tables of numbers. It was pervasive in their thinking, spilling out into their everyday conversation and learning-teaching decision-making:

> The seminar leader comments, "So Vicky is trying to get as larger n as possible to reduce the standard error".
>
> *(Understanding my research in their terms.)*
>
> (Fieldnote: Economics, 1st year UG tutorial, QM(s) module)

> I could've chosen a more benign example but that would've come at a time cost.
>
> (Staff member explaining the choice of data in a QM(s) module, Economics – Rohan)

> Continuing with the student satisfaction example he explains that if he were to take only the responses from the best students he would likely get responses that said the module was too easy or that it was fine. He says "that kind of sampling is not going to give us the answer" and so the best kind of sampling is to randomly sample. *A theme, which is picked up elsewhere in the department with the random allocation of student into working groups.*
>
> (Fieldnote: Economics, 1st year UG lecture, QM(s) module)

But for Economists QM(s) was more than just a tool or technique to be applied, as the above quotes begin to hint at, it was a language to be spoken, in any setting. This understanding of QM(s) as a language is not an uncommon analogy, noted upon by many authors within the quantitative methods learning-teaching literature (see Malik (2015); Conners *et al.* (1998); Onwuegbuzie (1997); Chua (1996); Lalonde & Gardner (1993); or Schacht & Stewart (1990)). To facilitate the learning of this language a bilingualism was performed by teaching staff, where notation and mathematics were spoken simultaneously with English terms: (see below and next page)

> He asks the class why it might be difficult to get data on past debt crisis'? He explains that not many countries have defaulted on their loans, and that each country is different anyway, and you can't just run an experiment and ask countries to default on their loans.
>
> He says that despite that there's a "model which can try and quantify this". On the whiteboard he writes:
>
> $$B_t - B_{t-1} = rB_{t-1} + (G_t - T_t)$$
>
> He asks students what each of the terms are – "what is B_t?"
> Student: Debt.
> Lecturer: What is $B_t - B_{t-1}$?
> Student: Deficit.
> Lecturer tells the students that G_t is government spending.
>
> (Fieldnote: Economics, 2nd year UG lecture, Content module)

> The lecturer goes onto talk about the Calvo model – a model of price rigidity – which uses a probability of the proportion of firms that are unable to change their prices in a given period (w). He says that to keep it simple they use 1 as the total number of firms, meaning that $(1 - w) =$ the number of firms able to change their prices.
>
> *In each case the lecturer explains in words the situation and then shows the equation. Different to other disciplines, where the equation is shown first and then an explanation given.*

$$\hat{p}_t = (1 - \beta\omega)\hat{p}_1 + \beta\omega E_t\hat{p}_{t+1}$$

Price at t	Myopic price	Desired price at $t + 1$

> After writing up the above equation, the lecturer explains that as it has the last term it offers a dynamic model of price setting as the future affects today. So, the price is dependent not only just the marginal costs today but also by the fact that marginal prices in the future as hard to change.
>
> (Fieldnote: Economics, 3rd year UG lecture, Content module)

As the above quotes demonstrate, in Economics emphasis was placed on the constant translation of variables from spoken words to notation. This translation, however, differs from the method of translation usually encouraged by mathematics educational research where each term is translated into everyday language (e.g. Karam & Krey, 2015; Dobni & Links, 2008; Folkard, 2004; Rumsey, 2002). To use a language analogy, broadly, in doing this Economists emphasised the speaking of QM(s') language, not of the translation of each individual word used. Furthermore, the above quotes highlight how instead of presenting students with equations, staff and students constructed in real time the equations through a logical working through of the problem. In tutorials, this process of working through a problem was further highlighted through teaching staff using different coloured whiteboard pens to write up different parts of the equations, or where numbers were substituted into the equations. When discussing this with the teaching staff they commented how this process helped slow their teaching, meaning they were forced to explain more fully the equations to students. However, this action also served to enroll students into the problem solving through students actively taking notes, or being asked to complete calculations and answers. Through this real-time doing, correct answers lost the power they achieved elsewhere – as discussed in Section 5.2.2 – instead in Economics performances of QM(s) were filled with mistakes made by both students and staff, becoming an accepted part of the doing of QM(s). In this way, instead of correct answers enrolling other actors, here mistakes enrolled both staff and students into a doing of QM(s) that involved collaborative problem solving, where attention was drawn away from obtaining correct answers to knowing how to do, through the ability to speak the language of QM(s).

Mastering this language of QM(s) was vital for the Economists, perhaps more so than other essay writing and aural presentations skills valued in the other disciplines. In contrast to other disciplines, where theoretical frameworks can be slow to change, in Economics the speed of theory change was so great that QM(s) were believed to offer more stability than theory, and thus were understood as more important, as one student explained:

> So it's more like studying how to understand a model and how to create a new one because studying the, the, what we think now of the economy may be wrong, or inaccurate. So it's more like how to understand economics than studying like, for example if you study history you just learn the facts and that's it, it won't change because it's fixed, but economics we still don't know how does it work properly.
>
> (2nd year UG student, Economics – Antonio)

Despite this pervasiveness and valorisation of QM(s), and although Economists strived for the optimality of their models, a pragmatism was upheld:

> Yeah cus a lot about what we do is like about optimality. Like trying to make things as good as they can possibly can be [mhm] which we get criticized a lot for but that's what we are trying to do so.
>
> (PhD student, Economics – Dan)

> Lecturer begins again saying, "To develop as a successful economist you have to be aware of areas of problems in the model often more aware than of the model itself." He asks the class if they'd prefer him to explain the model as if it was the

> way the world was or if it was just one of many models none of which were accurate, the students pick the second.
>
> (Fieldnote: Economics, 2nd year UG lecture, Content module)

Across Economics, staff and students recognised that their models would never be complete, that there would always be an error term, or adjustments to be made. This pragmatism echoes the sentiments made by Kennedy (2002), who provided a list of ten commandments for econometrics. While this paper includes several commandments on general good principals of data analysis (such as, 'Thou shalt inspect the data' (2002: p.582), 'Thou shall look long and hard at thy results' (Ibid.), and 'Thou shalt not confuse significance with substance' (2002: p.583)), Kennedy's list also includes commandments on using common sense, not worshiping complexity (or not speaking Greek without knowing the English translation), being willing to compromise, and anticipating criticism. In both these commandments and in the comments made by Economics staff and students, the acceptance and reinforcement of pragmatism brings a quality of humbleness to QM(s) character. In a land where QM(s) had little, or no competition, QM(s) fluidity and limitations were drawn out instead of hidden away:

> This module aims to provide a foundation in key optimisation methods, and to illustrate their strengths and weaknesses as tools for modelling and solving real-world problems.
>
> (Economics, PG module course description)

> He summarizes the course in a paragraph: That you have to relax the assumption of perfect competition and price flexibility of the real business model for the New Keynesian model.
>
> (Fieldnote: Economics, 3rd year UG lecture, Content module)

Unlike other disciplines, here QM(s) were not understood as having to provide the best answer, or to be the best approach; they simply were the only way to provide an answer. Acknowledging this, and the reliance of modelling, Economics emphasised QM(s) as something to be constructed, or worked with, similar to a favoured colleague, not simply something to be applied or sold to users.

6.5 Conclusion

In each disciplinary network QM(s) were enrolled to perform and assist with different roles: to provide trends; solve problems; test theories; or evaluate and aid decision-making. These roles were not mutually exclusive to each discipline, but each was distinguishable in different disciplinary networks.

For Criminologists, QM(s) provided a way to understand trends and patterns of crime data, which were viewed upon with a necessary skepticism. While the content of modules was narrower than in other disciplines – see Section 4.2 – here students were taught to cross-examine both the datasets, which were often secondary data, and the statistics produced from analyses, developing strong quantitative literacy skills. Although Geographers used similar secondary datasets (i.e. in GIS) and produced some information on trends across space, QM(s) were used more extensively as a means to solve environmental problems. QM(s) were often associated with Physical Geographers, whose conception of QM(s) rested in infallible measures and associated robust predictions and models, where errors could be controlled and quantified. While this served to valorize QM(s) position within Physical Geography and in fields of Human Geography where similar "hard and fast" numbers could be produced, in areas of Human Geography where datasets of similar kinds to Criminologists were used, QM(s') power diminished, as it appeared to offer little value in comparison to other methodologies.

Similar to Physical Geography, in Psychology QM(s) had acquired a robustness and served to facilitate the testing of theories. However, while this robustness was in part drawn from to the datasets of embodied measures – similar to Geography - QM(s) character was also strengthened through the creation, and upholding, of disciplinary conventions. These conventions, similar to the performances of scientists described by Latour and Woolgar (1979), helped to unify the disciplinary doings of QM(s) within Psychology.

In contrast to the above disciplines, where QM(s) were positioned and argued for against other kinds of methods, in Economics QM(s) were constructed as the only method through which to evaluate data and provide adequate decision-making. Akin to framings in the literature (Malik, 2015; Conners *et al.*, 1998; Chua, 1996; Lalonde & Gardner, 1993;

Schacht & Stewart, 1990), here, QM(s') identity as a language to be spoken was strongly enacted, with a bilingualism performed. While QM(s) clearly occupied a position of power within Economics, framing almost all aspects of users thinking, QM(s) were still viewed as partial, as indicated in their quest for optimality of constructed models, not one of correctness.

Much of this variation between disciplines can be understood as stemming from the different kinds of data disciplines accessed and cultivated. In those disciplines, or sub-disciplines, where datasets were comprised of embodied measures QM(s) acquired a strength and power – sometimes at the detriment of other kinds of knowledge. However, in cases where datasets were more fluid and changeable QM(s) were greeted with skepticism or a partiality. While different disciplines did predominantly make use of one of these two forms of data, both could still be found within different areas of the discipline. For disciplines where a wide variety of data was encountered a tension between these different characters of QM(s) often emerged. These characterisations also lead to tensions between QM(s) and other kinds of data, i.e. qualitative data, with differing relationships observed across the disciplines, from one of pluralism, to one where qualitative data was devalued, to another where qualitative data had been silenced and was viewed upon with the same curiosity as given to an endangered species.

While these roles are not fixed in time, as Chapter 7 will explore, they do highlight a limitation of the quest for universal best practice that the statistics education literature has begun, as identified in Section 2.2 of the Literature Review. By boxing up QM(s), the literature is at a risk of ignoring these differences, which are vital to the performances of QM(s), as captured by one lecturer's remarks:

> Er, I did that [use humor and interactive classroom techniques] when I first er teach, taught probability and erm, it almost always falls flat [mm]. I don't know why, my theory is the students find it too simplistic and too high school [yeah]. So they, they find it a bit patronizing [yeah] so they don't like it.
>
> (Staff member, Economics – Rohan)

7 QM(s) as a Changing Actor-Network

In the preceding chapters, we have explored QM(s) as multiple and as a constructed actor-network, whose characteristics are enacted through module and disciplinary actor-networks. Across each of these chapters, the concept of QM(s) as simply techniques to be learnt/taught by students and staff has been challenged, instead QM(s) have been presented as a multi-faceted object, constructed, and performed across different physical and conceptual space(-times). In this final chapter, we turn our attention away from space(-times) to consider QM(s) as an actor performed over time(-spaces). In doing this, this chapter reflects on how QM(s') identity is changing, and considers how it may continue to change in the future, as well as how this study may contribute to changes in learning-teaching performances.

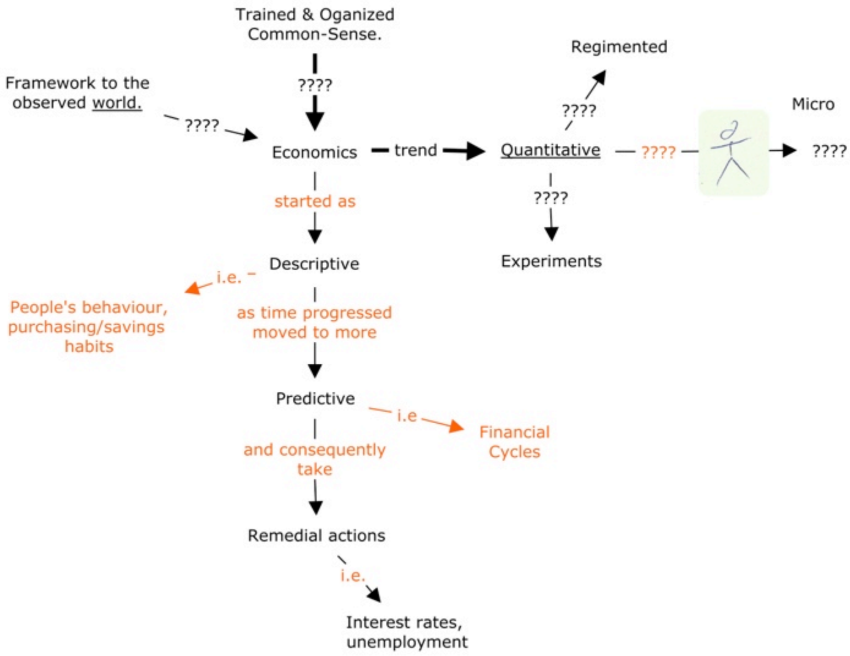
7.1 An Actor Under Threat

While we saw in the previous chapter how QM(s') character adapted to each disciplinary actor-network, these positionings and characters are not fixed in time. Returning to the literature surrounding QM(s), here five threats to QM(s) current characterisation are identified: 1) the skills deficit, 2) a lack of public trust in science and numbers, 3) the *p*-value crisis, 4) the big data revolution and the changing character of data, and 5) the changing nature of Higher Education. This list is not designed to be all-inclusive, instead it offers an initial introduction to some of the threats to QM(s) that are of particular relevance to this research.

Firstly, in the Introduction, we saw how nationally there is a lack of employees that are quantitatively-skilled (Mason *et al.,* 2015), and that this deficit is a problem that can be related, at least in part, to poor GCSE performance and low A-Level uptake numbers, which serve as a measure for the quantitative skill set of the future workforce (Vorderman *et al.*, 2011). Whilst there are structural changes being made to remedy this problem, it is nonetheless a threat to QM(s). The decline in students' quantitative skills, compared to those of the older generations (Mason *et al.*, 2015; Mulhern & Wylie, 2004) represents a threat to QM(s) both in terms of numbers currently doing, and in potential numbers able to do. To use the language analogy, discussed in Section 6.4, QM(s) is under threat as fewer are able to speak its language, and to translate its sayings to increasingly distanced audiences.

This turning-off of students to QM(s) is not only a matter of teaching or skills provision, as is commonly identified within the policy literature. Within the wider socio-cultural environment, the centuries old valuing of quantitative information (Hald, 2003; Crosby, 1999; Porter, 1995) has come under threat – the second threat to QM(s). Science and Technology Studies scholars have challenged QM(s), and science's, ability to access objective truths (Feyerabend, 1975). For several years (Achterberg *et al.*, 2015; RSS, 2014), the general publics' trust in science in general, and numbers, has declined. Whilst this is not perhaps something completely new - scientists have always had to argue their case for new knowledge (Shapin & Schaffer, 1985) - the general distrust of experts/scientific institutions (Edelman, 2017; Achterberg *et al.,* 2015) and the heralding of the "post-truth" era (Flood, 2016) is creating a new wider cultural sensibility towards QM(s). Though online media, public(s) have access to greater amounts of information than ever before, aiding the fracturing of truth. This backdrop of attitudes presents a second serious challenge to QM(s), whose value in recent times has been tied to the production of objective truths (Porter, 1995). Not only is QM(s) facing an audience who is unable to talk its language, but it is an audience that is increasingly resistant to its most common method of enrolment – the claim of objective, universal truths.

This mistrust of the public is not only a factor generated from socio-cultural innovation. Within quantitative fields the techniques, which have served as the foundation, and gold standard for many disciplines, have commonly come under attack. Looking at Economics, Psychology, and Geography, we can see that each has undergone various quantitative revolutions, moving from qualitative description to quantitative description to quantitative modeling and prediction (Barnes, 2014; 2002; 2001; Porter, 1995) - a transition drawn by one participant onto their concept map of their discipline, see next page. More recently, however, these disciplines, and science more generally, has faced a third threat in the form of the *p*-value crisis – as described in Section 1.2.1 - whereby the reliance on hypothesis testing and *p*-values for the production of reproducible, objective deductions has come under criticism.



(Staff member, Economics – Rohan)

However, the *p*-value crisis represents more than a crisis for science. Just like previous quantitative revolutions, it is placing increasing strain upon QM(s). At its broadest, this third threat to QM(s) represents a significant challenge to the positioning of QM(s), and the scientific method more generally, as providers of objective answers (a role of quantification as described in Porter (1995). More specifically, the crisis poses a serious threat to QM(s') long standing identity as frequentist statistics - the assumed curriculum of QM(s) discussed in Chapter 4 – as well as QM(s) common characterisation as a search for $p<0.05$.

Fourthly, QM(s) has come under threat from the big data revolution. As described in Section 1.2.2, big data is heralded as having the potential to offer increasingly accurate answers to powerful stakeholders (Davies, 2017). Sidestepping the implications and problems of the big data revolution for policy makers and other key stakeholders, big data has drawn attention away from QM(s), personifying the call to let the data talk for itself.

This emphasis on data presents an interesting juxtaposition given the silencing of data in the QM(s) classroom, observed in Chapter 5. The big data revolution is not about giving increasing attention to all data, but a different kind of data. As previously mentioned in

Section 1.2.2, the size of big datasets means that data moves from being stored within visible tables to being stored across computers, interacted with as disparate flows of data. This shift means an increasing emphasis is placed on programing, mathematical modeling, and algorithms, as opposed to frequentist statistics. While it remains unlikely that Social Science programmes will be redesigned to produce graduates to fill these emerging data analyst positions, the increasing presence of this information in our everyday lives means that to continue to fulfill their role in providing data-literate citizens Social Science programmes will have to begin to accommodate this kind of information into degrees and QM(s) modules in some form.

Although big data is clearly an extreme case, the impact of which remains to be seen, similar, smaller-scale, changes can be observed in the kinds of data that QM(s) courses are expected to interact with. Across disciplines there is a growing emphasis in students interacting with real, secondary datasets (Homer, 2016; Williams *et al.,* 2016). While these datasets allow the same kind of statistical tests to be used, they are already far larger than students' own primary datasets, and thus draw attention different aspects of QM(s), such as those activities related to data handling and cleaning, instead of simply the doing of the tests.

As well as challenges from cultural attitudes towards QM(s), the *p*-value crisis, and the changing character of data, QM(s) within Higher Education also face a fifth threat: the changing character of Higher Education. Within the UK, as a sector, Higher Education is experiencing growth (Universities UK, 2016; British Council, 2012) and increasing commercialisation (Wang *et al.*, 2011; Drummond, 2004) both of which are placing additional strains onto QM(s). Growing student enrolment numbers pose a general challenge to traditional classroom learning-teaching methods (Kreber, 2007; Macfarlane, 2004; McInnis, 2000). For QM(s), specifically, growing class sizes represent a challenge to the methods currently used to enroll actors into its network – outlined in Section 5.2 - with best practices, such as small one-to-one tutoring becoming increasingly impractical to achieve (Fox, 2005).

Alongside the issue of growing cohort numbers, the issue of the commercialisation and commodification of Higher Education are also influencing the nature of content included in QM(s) modules. Through initiatives such as the Teaching Excellence

Framework (TEF) institutions are under increasing pressure to maintain their advantage, or keep up with, other institutions to attract essential student numbers. In one department, the QM(s) course had been specifically designed with reference to changes that were going on at other institutions:

> We've got to think about our competitors, so as well as the fact that I want to do this […] and it'll compliment other modules very well [mm]. Erm, we need to compete […] there's a Q-Step centre where, the undergraduates […] are getting placements, they're getting formal statistical training […] I have to have my competitive head on to a certain extent [yeah], it's great that this is happening because we're getting, it- it's contributing towards the, the base of, or the knowledge base of Criminologists, and the ability to work with this kind of data [mm] more generally so that's erm, it's great that it's happening. Erm, but yeah, like I say, if.. my thinking behind creating this […] module [mm] erm, is not to just compete [yeah] but you know because it will also be contributing towards this movement.
>
> (Staff member, Criminology - Doug)

In addition, across Higher Education, increasing emphasis is being placed on graduate employability and the linking of academia with the wider world of work (i.e. Harvey, 2000). For many graduate employers and in policy reports, QM(s) - often referred to as numeracy - are identified as transferable skills which the ideal employee should have (Tu *et al.*, 2016; Archer & Davidson, 2008; Mistry *et al.*, 2009; CBI, 2008; Dearing, 1997). In a survey by the Institute of Directors (2007), employers ranked numeracy as the sixth most important skill from a list of 28 employability skills. Whilst referred to as numeracy, in another survey, the two numerical topics most employers expected graduates to be competent in were calculating percentages (88%, $n = 165$) and data interpretation (85%) (Durrani & Tariq, 2011). These topics encompass both basic numerical skills and more advanced skills, such as statistical reasoning and statistical thinking (delMas, 2002), required for data interpretation (Garfield, 2002) hence illustrating that although referred to as numeracy employers expect a broad range of quantitative skills. Despite this importance, these transferable skills are not always those skills desired by academia (Mistry *et al.,* 2009), and tutors often have low confidence in students' skills (Tariq & Durrani, 2009).

7.2 QM(s) as a Responsive Actor-Network

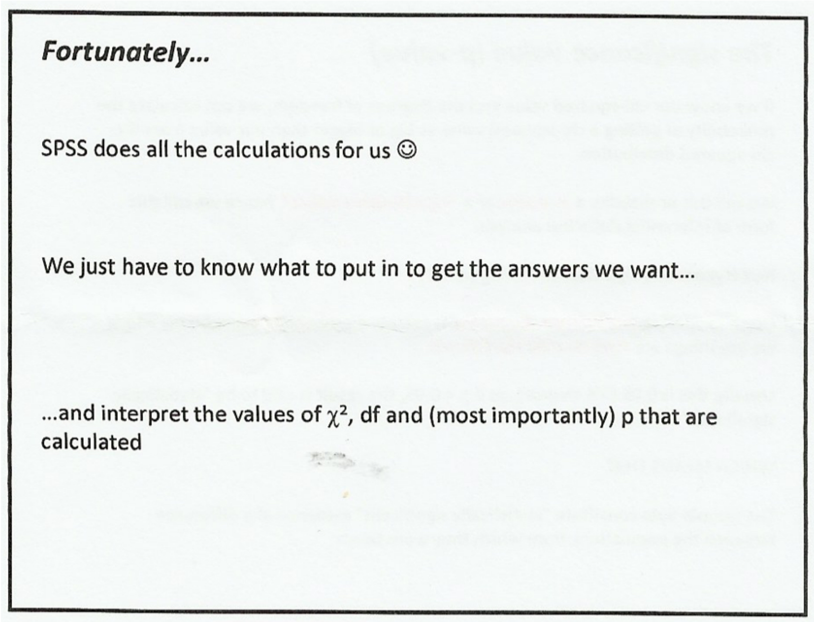
Each of the dangers outlined above - the skills deficit, public trust in numbers, the *p*-value crisis, the changing character of data, and the changing nature of Higher Education - can be thought of as a threatening QM(s') existence, killing off QM(s) as we know it. However, despite outlining QM(s') common features in the preceding chapters, just like any actor-network, QM(s) should not be understood as being a static entity. Acknowledging its dynamic nature, we move away from conceiving of QM(s) as something that needs to be conserved and protected from these threats, towards imagining QM(s) as an entity changing in response to these pressures. For example, instead of understanding the skills deficit as a matter of enrolling more spokespersons and actors into the wider QM(s) actor-network, we can instead think of this as a driver of change/evolution of the QM(s) actor-networks, and an associated change in characteristics of QM(s).

Murmurings of how QM(s) may change can be seen in the literature (e.g. Johnston *et al.,* 2014; O'Sullivan, 2014), however this literature rarely considers how QM(s) is already changing in learning-teaching environments. In this study, several glimpses were observed as to how QM(s) is already changing - the rise of new software, new statistical approaches, new learning-teaching environments, and a fracturing of courses. As well as discussing each of these individually below, attention will be given to considering how these changing activities embody and highlight different characteristics of QM(s).

7.2.1 <u>New/Changing/Expanding Software</u>

For many years, software has been understood as essential for completing real data analysis, providing a means to engage students in QM(s) learning-teaching by providing hands-on experience, and an alternative means for visualizing QM(s) theoretical knowledge (e.g. Chance *et al.* (2007)). As commented briefly upon in Chapter 5, software played a considerable role in all QM(s) modules observed here, including the many content modules where QM(s) was embedded. In one discipline, software had become so tightly bound to the doing of QM(s) that students were required not only to present the results of their analysis for their dissertations, but also copies of their data analysis files.

Across disciplines, software within modules was often black-boxed, understood as a passive mechanism or container for the doing of QM(s): (see next page)



Student: I found that [statistics] quite hard to do because..erm, it was about data that we'd taken from questionnaire […and] the lecturer had put it on, as like a, put all the data on the…

Interviewer: Software?

S: Software, and we just had to erm use it. But I found that quite difficult because erm, it told you what to do, so I didn't really know how to talk about the methods cus it had already said all the things about the methods that I could think of.

(1st year UG student, Geography – Rose)

(Geography, 1st year UG lecture slide, QM(s) module)

Although software was presented as a black box, in Section 5.3 it was reported that software could interrupt and fracture the linear doings of QM(s), drawing out a mischievous side to QM(s). As well as affecting the doing of QM(s), software also added its own language to QM(s) performances:

He adds that in SPSS, which they'll be using later in the term, it's called CrossTabs, which he doesn't like but that's what the software uses.
TECHNOLOGY terms creeping in.

(Fieldnote: Psychology, 1st year UG lecture, QM(s) module)

> The lecturer continues typing "=mean (cell:cell)" into the relevant cell. An error message comes up, the lecturer looks at the cells for a moment before explaining that in Excel it uses the word average, not mean. He retypes the equation "=AVERAGE (cell:cell)". A value of average salary appears.
>
> (Fieldnote: Economics, 1st year UG workshop, QM(s) module)

Through developing their own language, different to that used by QM(s), each software enrolled actors into its own way of doing QM(s). For both Excel and SPSS – the two most common QM(s) software packages observed here – the doings of QM(s) became focused around navigating data tables and selecting correct functions from either manually entered formulas or dropdown menus (examples of which can been seen in Figure 7.1 and 7.2).

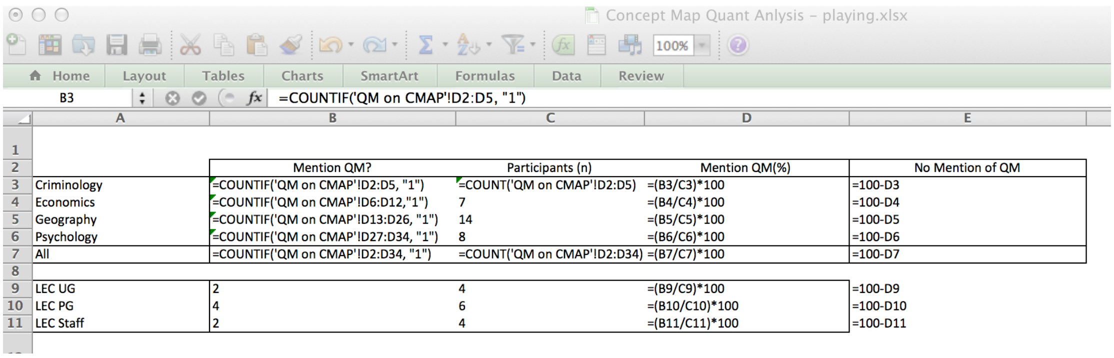


Figure 7.1 Screenshot of Excel (Microsoft Corp., 2011) user interface, showing the use of manually entered formulas (taken by author).

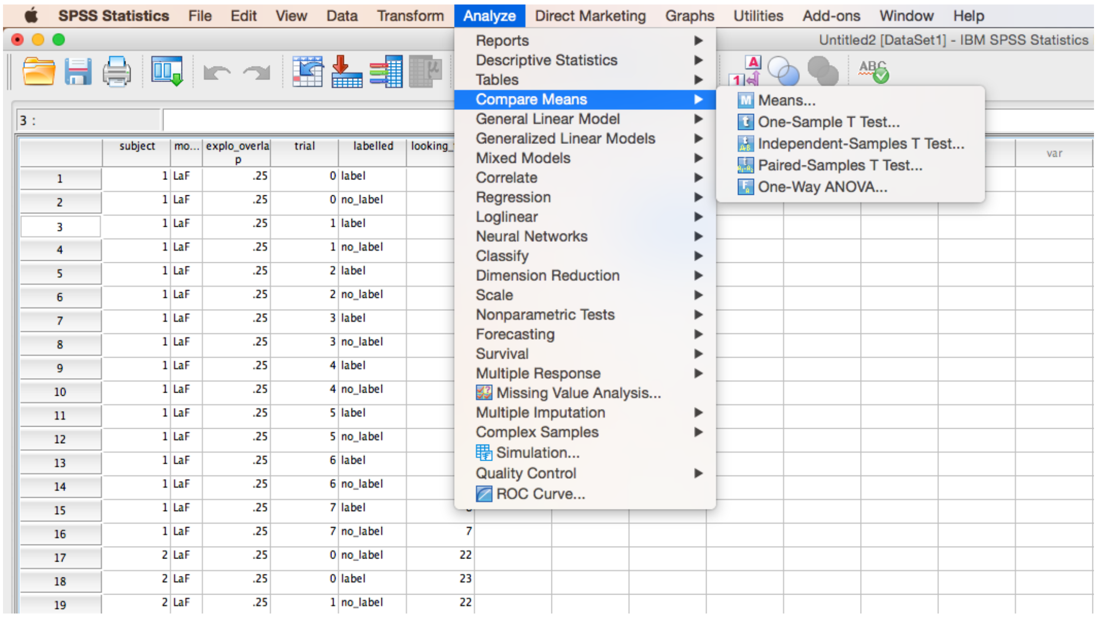


Figure 7.2 Screenshot of IBM SPSS (IBM Corp., 2015) user interface, showing dropdown menu of tests (taken by author).

For staff, the choice to work with Excel or SPSS was often based around their user-friendliness, as one staff member – Doug - explained:

> Erm, in any other module in any other criminology degree [not those taught at Q-Step centers] that might use any of this [mm] any data like this I would almost guarantee that they'd use Excel and SPSS […]. I, I think it's that SPSS is so widely used, and out of all of the soft-pieces of software, cus there are others, [yeah] there's things like STATA and what have you, it's probably the easiest [mm] to use. [yeah] And less frightening to use. I say the easiest.. it's, it's for someone who has never used [mm] a piece of software like that before [yeah] erm it's it's, I think it's the best.
>
> (Staff member, Criminology - Doug)

Despite this user-friendliness, as touched on in the above quote, there was growing interest towards the introduction of another software program, R - a statistical programming language and software application. While many of the staff interviewed used R for their own research, at the time of the study only one module observed, a postgraduate module, presented R content to students. The choice to adopt R was explained, during a learning-teaching session and by the teaching staff member, as follows: (see next page)

> As a group they discuss errors in R and the difference between R and SPSS, the lecturer stressing that R can handle much bigger datasets than SPSS, but that errors in R are generally tiny mistakes that can mean you take a long time to find them. However once you do find them you know you're getting better, it's time well spent, i.e. the more time you spend doing it the better you get, whereas for SPSS that's not true.
>
> (Fieldnote: Psychology, Master's lecture/practical, QM(s) module)

> Interviewer: In that module you were specifically teaching R [mm] over SPSS, can I ask why?
>
> Interviewee: Erm. Well there are a number of reasons. People that use R earn more money it seems [mhm] erm, R is free, SPSS costs money [mm] erm, R is associated with community that provides erm, helpful resources [mm]. SPSS also does but I don't find the resources that helpful. Erm, R is open, SPSS is closed [mm]. .. Oh yeah R erm, SPSS is ugly, the plots are ugly in their new systems [mm] clumsy. […] For example the SPSS menu system has multiple erm, er menus for doing regressions. It's a single technique it shouldn't have multiple different places to do the same thing [mm].
>
> (Staff member, Psychology – Mark)

As previously mentioned, QM(s), in its frequentist form, is a data hungry actor. As increasing amounts of data is collected to fulfill QM(s) demands, software packages have become increasingly valued for their ability to handle the data and not simply their ability to perform the necessary computations. As outlined above, R represents the latest software offering new abilities to successful handle and manipulate the ever-growing datasets, as well as offering additional benefits of its free and open source qualities. Whilst often thought of as simply a different statistical software, in the postgraduate learning-teaching environment observed R produced a different kind of doing of QM(s):

> Whilst working through the exercise, students type in the code from the sheet, after hitting enter one student exclaims "yay!" when the final scatter plot is displayed. One student says to the other "I keep forgetting to put quotation marks in". *A common error made by students when using* R *- focuses attention on specifics of the code.* The students continue, varying between writing line by line the code,

> and several lines of code before running it. After typing that code in the students run into another error, having an issue running the corstarsl function – which was linked to the above error. A series of error messages come up, they call the lecturer over and ask what the ♯ means, he looks at it and says that he usually just copies and pastes the code, ignoring the annotations explaining what each piece does. He looks through their codes and explains that they are missing part of the function. He adds in the missing bit, saying that it's good that they're trying to understand what each bit of the code does [not that that was what they were doing]. The student next to me exclaims: It's not red!
>
> (Fieldnote: Psychology, Master's lecture/practical, QM(s) module)

As illustrated above, by working with R students and staff became engaged in directly talking to the QM(s)-software hybrid actor. Through its design and focus on coding, instead of the selection of fixed, boxed functions, R shifted attention to the commas and quotations marks of lines of code. Instead of searching for SPSS's stars of significance users became engaged in a battle of red error messages.

In addition to the dominance of red error messages in the learning-teaching performances, the visual environment of R cultivated a different relationship to the raw data to that found with users interacting with SPSS or Excel - see Figure 7.3 for an example screenshot of R and Figure 7.4 for a screenshot of SPSS.

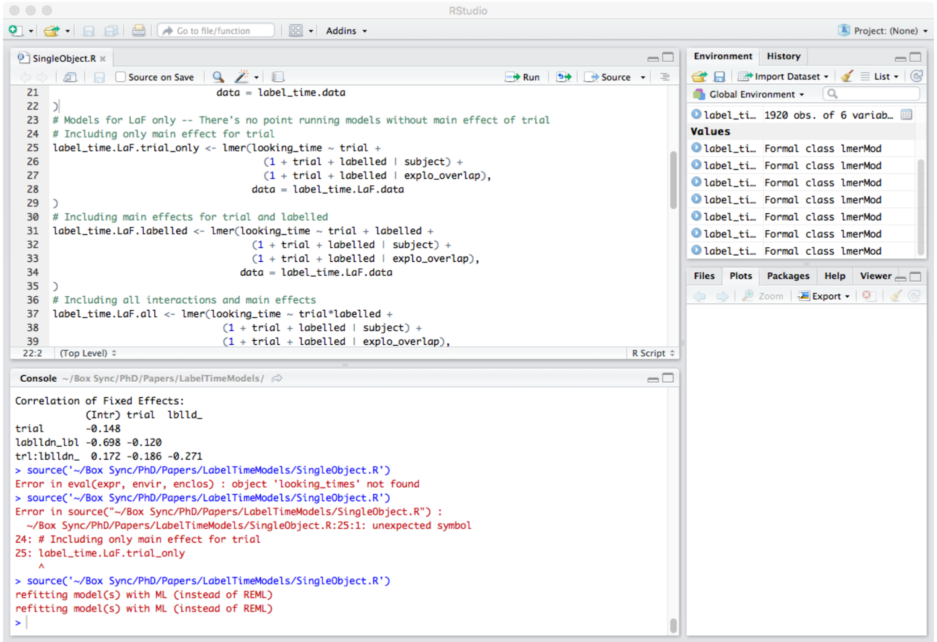


Figure 7.3 Screenshot of RStudio (RStudio Team, 2014) user interface, with example errors (taken by author).

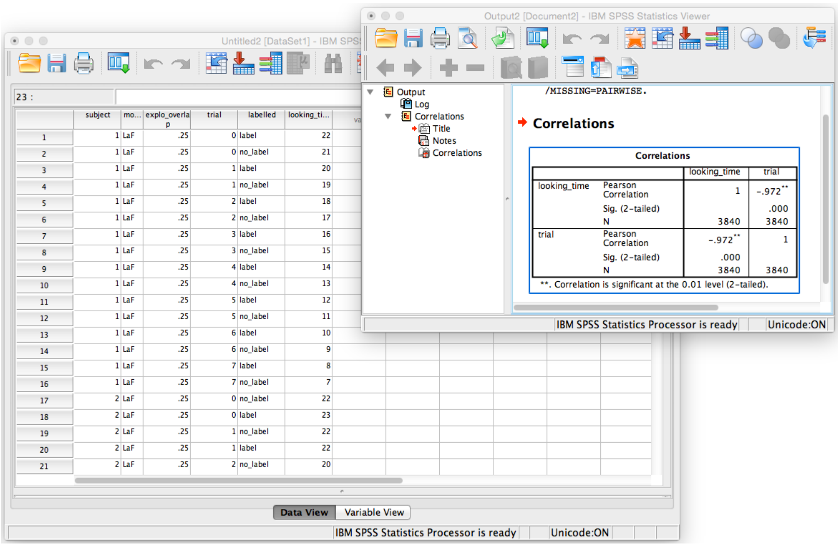


Figure 7.4 Screenshot of IBM SPSS (IBM Corp., 2015) user interface, showing data table and asterisks denoting significance (taken by author).

Instead of presented data tables, as found in Excel and SPSS, R hid the data away, with users having to specifically ask R to display the data. In doing this emphasis shifted from interacting with the individual data points, for example an individual participant's survey responses, or the labeling of variable types – essential for SPSS – to the construction of code. This hiding away of the data and emphasis on coding gave R a sublime character, with participants viewing R with equal wonder and terror, as captured by the following PhD students' remarks:

> I'll be using R, which requires coding [mm]. So when I'm speaking to my friend […] he's found that when coding you might make a tiny little error [mm] and it'll ruin the entire dataset. It might not necessarily be the dataset it's just because it's a more malleable form [mm] of erm analyzing the data. But of course with it being a rawer erm, with it being a rawer software where you can put in, it's not as rigid as SPSS [mm], it becomes very hard to actually, to actually produce something. It takes a lot longer to produce something for that reason.
>
> (Master's student, Geography – Edward)

> Although you have to learn coding and it's quite an uphill struggle […], a lot of Ecologists have built packages for, for specific things so it kind of makes sense to sort of make use of it's awesome power.
>
> (PhD student, Geography – Francesca)

While R's use of coding allowed users a greater control over the analysis, contrasting to the fixity of SPSS, R's expansion into the social sciences relied on its networking with packages. These packages – prewritten code for specific functions – as highlighted in the last quote, enabled R not only to become more user-friendly, reducing the fear associated with coding, but also to tailor itself to different disciplines, both of which served to enroll new users into its actor-network, increasing its power.

Although SPSS, Excel and R, all include an element of the following capabilities – manual coding in some form, selection of predesigned formulae, and the presentation of data tables – the growing popularity of R hints at a shift towards a new emphasis on the fluidity of QM(s). By boxing away the data, instead of the quantitative operations, R drew users into a greater interaction, specifically, with the construction and manipulation of QM(s). In doing this, as the PhD student quoted above described, data analysis was characterised as more malleable, with data analysis akin to a fluid process of controlling and shaping data.

Overall, while software is acknowledged as an important component of QM(s) learning-teaching (as argued for by Chance *et al.* (2007)), it is often characterised as a passive actor in the doing of QM(s). This passivity was initially challenged in Section 5.3. However, by examining the rise of R here, it is clear that not only does all software interrupt the common performances of QM(s) learning-teaching, but that different software creates different ways of doing QM(s). While all software enrolls actors with their own languages, Excel and SPSS offered distinctly different relations to data than found within R. Through their different performances, different conceptions of QM(s) were created which hint towards a potential shift in the understanding of QM(s), moving from one of fixity to one of construction and fluidity.

7.2.2 New Quantitative Approaches

While software offered the potential to change how users interacted with data another factor with potential to change the face of QM(s) is the rising popularity of new approaches and techniques. As illustrated in Chapter 4, disciplines focused on techniques that can often be characterised as relying on frequentist inference. One of several different kinds of statistical inference, frequentist techniques produce probabilities based on expected long-term frequencies of an event occurring. Frequentist approaches understand the population mean as a real entity, fixed but unknown, whose value can only be estimated from the sample data, using the central limit theorem. However, as the population mean is understood as fixed, with no distribution, frequentist statistics cannot estimate the probability of the mean being within a sample confidence interval (as it is either present, or not present). Instead the probability calculated is a measure of the chance of a group of similar confidence intervals containing the true mean.

Given this shared, frequentist philosophy, QM(s) as presented within these modules appears unified. As one lecturer commented to their class:

> "In ANOVAs and T-Tests we're doing the same work just in different clothing'. *Different clothing – nice metaphor. Psychology almost like stats in a straight jacket.*
>
> (Fieldnote: Psychology, PG lecture/practical, QM(s) module)

The result/output of this 'same work' done by frequentist techniques is a true or false statement about either a null hypothesis or a confidence interval. For one student this output represented a step towards seeking further information about why a significant/true result was obtained: (see next page)

> So we say, that if it's above that [mhm] then it's significant. If it's below ch-that, it's only a chance happening. […] you're never seeking proofs, you're always seeking knowledge, you're always seeking "well why is that significant, what's the next step to that significance? Well why does that show that?".
>
> (1st year UG student, Psychology – Alistair)

However, for most students this output was characterised as follows:

> Whereas with quantitative it's just, well of course you have to put all the data in the computer, but it's just a click of a few buttons and you get really sound results.
>
> (PhD student, Psychology – Erica).

Here, then, we see that the fixed, correct character of QM(s) is not only produced through the linear doings and learning-teaching practices – outlined in Chapter 5 - but also as an effect of being enrolled into using certain kinds of techniques. As a discipline, Psychology offered the greatest insight into these different mindsets. While undergraduates understanding of QM(s) character was dominated by the characterisations presented above, postgraduates who used different techniques, exhibited a different understanding:

> Then you run these really complicated data analysis techniques, you get to the end and there's something that might confirm your hypothesis but there's no like threshold for that any more [mm]. So it's good because you have to think much more about what you're showing and how to improve it [mm] because at the moment [using conventional techniques] if you get $p < 0.05$ that's it, you're done. I mean people say you might want to replicate but even then all you're replicating is a $p < 0.05$ and that's quite straightforward. [mm] Whereas now it's so much more complicate you need to think about what all these different variables are doing informing this massive huge model that nobody except the person that's run it will probably understand.
>
> (PhD Student, Psychology - Alex)

As a field, Psychologists have adopted a variety of different strategies to respond to the *p*-value crisis including: reducing the publication of *p*-values, focusing on effect sizes, or moving towards increasingly sophisticated modeling techniques. Just as in Economics, these models shift QM(s) character to one of fluidity, where construction and improvement become valued over application and significance. As this same student – Alex - went onto explain, these methods have had a noticeable impact on the kinds of knowledge generated:

> For years and years and years psychology was so held back by limitations on the stats we could do [mhm]. And now that we've got much better computing power and all these things, and technology, the stats has evolved to a state where we can really begin to.. answer much more fundamental questions […]. Erm and that means that we're then able to explore these things now that we weren't able to before [mm]. So it's not that stats is the means to an end it's that stats is the end point because we're so reliant on it [mm] and that's how we understand everything.
>
> (PhD Student, Psychology - Alex)

However, many of these modeling approaches still relied on a frequentist positioning, even if they gave rise to a more fluid and dynamic version of QM(s). However, accompanying this rise of modeling, and growing popularity of R, was the rise of Bayesian statistics (Homer, 2016; Andrews & Baguley, 2013; Zellner, 2008; Poirier, 2006; Jackman, 2004; Davies Withers, 2002). In contrast to frequentist approaches, Bayesian statistics understands only the sample data as a real entity, with the population mean instead characterised as an abstract entity whose probability relies both on the sample data and prior beliefs held by the researcher. Most importantly, it allows the probability of a confidence interval containing the population mean - the probability of an event given some evidence – to be calculated. Unlike frequentist statistical approaches, Bayesian statistics allow the researcher some position of subjectivity, as they decide the values entered. Furthermore, it allows these views and values to be updated given further analysis. This direct focus on generating probabilities, theoretically, could offer potential for a new emphasis on QM(s) as a partial actor, with the researcher's judgment valued, instead of downplayed, similar to that found within qualitative methods. While not presented within any of the modules observed, staff and several postgraduate students in Psychology and Economics mentioned Bayesian statistics during the interviews. If these Bayesian approaches continue to grow in popularity as a response to the *p*-value crisis, then it is possible QM(s') fixed character will continue to be fractured, allowing researchers and other actors new roles in the actor-networks.

7.2.3 Learning-Teaching Environments

In addition to software and techniques changing the character of QM(s) in response to the growing quantities of data, criticisms from qualitative methods, and the *p*-value crisis, QM(s) also faces threats from increasing intake numbers. While across most of the modules studied here, growing student numbers were mitigated by running repeated workshops and tutorials, retaining the small group teaching recommended by the teaching literature (e.g. Folkard, 2004; Jolliffe, 1976), two modules adopted different approaches.

In the first, a first year module, lectures were supplemented by online worksheets which students were expected to complete in their own time to assist with their coursework. Such an approach maintained the understanding that QM(s) learning-teaching was an individual, embodied endeavour, whilst serving to lower staff workloads. Overall, this approach can be understood as creating the same effect as discussed in Chapter 5, where worksheets become the primary means through which students construct their understandings of QM(s), translating its character into one of linear sequences and correct answers. However, in this approach, we see a shift in the learning-teaching environments of QM(s), with the doing performances of QM(s) moving out of the formal learning-teaching spaces of the workshop and into greater use of informal learning-teaching spaces.

In contrast to this, the second approach adopted to mitigate increasing student numbers observed as part of the study retained QM(s) in the formal learning-teaching environments, but was forced to re-purpose the space. Overall, most of the workshops associated with QM(s) were performed within computer laboratories. In these environments, students were plugged into standardised set-ups, using the same operating system and software types. Nevertheless, despite this standardisation, as one participant commented, different spatial arrangements of computers could still produce different performances and understandings of students and staff:

> [We] didn't have a great opinion of the the group [when in the first room], they didn't seem to interact and, but as soon as […] we swapped into [the other] lab all of a sudden we realized that was actually the strong group. But we'd had a worse perception of them largely because of the room and so when we got into the room where we could actually move around the class and interact erm, it

> was, it turned out to be probably the stronger of the two practical sessions […] But, there's not many labs on campus that have got enough space […] with computers so packed in tight that you can't actually easily move behind students and come and stand next to them and discuss stuff. Cus that's the way we like to teach, we like to wander up and down, we like to actually spend time explaining things and getting students thinking about it and yeah, in the other lab it was more or less of stand at the front and if someone was really stuck they'd ask for help and beyond that you couldn't, [so the room does matter].
>
> (Staff member, Geography – Stephanie)

Here, the rows of computers served to restrict or accommodate performances of smaller-group learning-teaching, generating a different perception of the students from the staff member. In the second approach adopted to mitigate growing student numbers, workshops were transferred out of the computer lab and into the lecture theatre and supplemented by repeated tutorials. In doing this, workshops could be run once, instead of repeated, as all students could be housed within the lecture theatre. In this workshop, students were expected to bring their own laptops on which they would complete the exercises. Just as above, the interaction between students and staff changed, here students became more mobile, moving and carrying their laptops to other students and to the lecturer, not simply sitting in a fixed position waiting for help to come to them. However, the use of laptops, as detailed below, also meant students used a range of different software types and versions:

> The lecturer then talks the students through adding the Analysis Toolpack add-in. A student raises his hand saying he doesn't have the analysis toolpack. The lecturer goes over, and looks at the screen before saying "I'm not sure how it works on numbers, you can have Microsoft Excel on Mac. I'll try to find out how it works on Numbers and I'll post it up onto Moodle". He continues asking "Anyone else not using a Mac?". *Instantly those using a Mac are phased out, or left to explore on their own.*
>
> (Fieldnote: Economics, 1st year UG workshop, QM(s) module)

In leaving the standardised labs, different software packages were quick to move in and colonise the learning-teaching of QM(s), requiring students and staff to fall into different groups of users, iteratively exploring their functionalities – which were not always suitable for completing the exercise in question. While through this approach the teaching staff reduced their contact hours, they found themselves writing worksheets and user guides for multiple software packages.

Although rising student numbers pose a threat to the small group teaching advocated by much of the QM(s) learning-teaching literature, these two strategies observed gave rise to different learning-teaching performances of QM(s). In the first, by being housed within a worksheet, the doing of QM(s) was transferred out of the formal learning-teaching environments into informal learning-teaching environments focused on the individual. Here the power of the worksheet was maintained, if not increased, similar to that observed within the workshops discussed in Chapter 5. In contrast, in the second approach, by re-purposing a leaning-teaching environment through the use of personal laptops, different software packages problematised the standard linear learning-teaching performances, instead giving rise to heterogeneous environments demonstrating QM(s') iterative and mischievous character.

7.2.4 Fracturing of Courses

Finally, as well as the changes to the software, techniques taught, and learning-teaching spaces, disciplines hinted at a fracturing of QM(s) courses. Across all disciplines included in this study, staff often commented on the difficulties of teaching students of mixed abilities and with different prior knowledge:

> We are now stuck in, in a point where erm, we are making a transition from being a qualitative descriptive discipline [mm] to a quantitative predictive discipline [yeah] and erm, we can't let go of either because our students are, they do not expect a full qualitative treatment of stuff, that would bore them quite a lot [yeah]. However if you give them the full quantitative rigor [mm] er all of them would struggle [yeah].
>
> (Staff member, Economics – Rohan)

> I think one of the most interesting challenges we've maybe come across is, we tend to assume a basic level of ability to navigate in Excel [mhm]. And that tends to be lacking [mm] and I don't know where that needs to, to come in but even just the concept of using a formula to, do some basic maths across a few

> columns [yeah] we're not, not advanced excel [yeah]. Erm, those kind of very basic, data handling skills sometimes I think can be missing.
>
> (Staff member, Geography – Stephanie)

> Especially and I think students with A-Level maths, erm, will cope with pretty well anything in a geography degree, students without A-Level maths, erm are likely to be, avoiding more quantitative modules [mm] which is why it's useful that we, and why we provide a kind of [mm] background support [yeah] for first years.
>
> (Staff member, Geography - Aaron)

As this last participant remarked, to remedy this situation often disciplines provided extra modules for those students who required more assistance. Across disciplines this, usually, mathematical content was provided in either compulsory or supplementary modules or through faculty peer-to-peer mentoring. While changes to the A-level and GCSE curricula offer potential to narrow this distribution of students' abilities, currently the courses provided within Higher Education hint at a potential fracturing of QM(s) into modules concentrating on critical data handling, descriptive statistics, and algebra skills, and those modules covering inferential statistics and other advanced techniques. If QM(s) courses continue to be housed within smaller and smaller modules, choices over the aims and content of modules will become increasingly important, with the current broad understanding of QM(s), including anything from basic to advanced techniques, becoming narrowed and fractured. While these modules may remain compulsory, this fracturing of courses could increase emphasis on students' abilities to evaluate their own QM(s) knowledge independently, as one student handbook described:

> Students should also be able to realize when the analysis that they need to perform is beyond the materials covered in the course, and that they should therefore consult a statistician.
>
> (Geography, PG student handbook, Research methods module description)

However, no pattern of such a response could be observed here, and it is likely that each discipline would adopt different strategies according to the varying skill sets characterised as essential by their disciplines.

7.3 Conclusion

To conclude, this chapter has summarised some of the threats currently facing QM(s). Changes to attitudes surrounding quantitative information, rising student numbers and increasing use of big data have each challenged QM(s) character. However, as discussed in the second half of the chapter, QM(s) appeared to be responding to these challenges in a number of ways. Increasingly, QM(s) was being comprised of different software packages and techniques in response to the *p*-value crisis and to the rise of big data. Similarly, new learning-teaching environments – both physical spaces and conceptual module spaces - were being colonised to mitigate problems of rising student numbers and mixed abilities. While the extent to which these murmurings of change will be adopted by disciplines remains to be seen, they hint towards the potential for a shift in the characterisation of QM(s) from an actor of fixity and linearity to one of multiplicity and fluidity.

8 Re-Packaging QM(s): Implications

In the preceding chapters, the different sides of QM(s) have each been traced out, individually recasting QM(s) as multiple, constructed within classroom and disciplinary actor-networks, and as a changing, responsive actor. In this final chapter, these sides are brought together to consider how QM(s) is unified and the impact this has on the understandings of the relationship between QM(s), theory, and data. It ends asking how QM(s) may be repackaged within Higher Education Social Science subjects to mitigate these issues and facilitate enrolment into QM(s) actor-networks.

8.1 QM(s) as Different

Throughout this thesis we have seen how QM(s) is itself inherently multiple, yet this begs the question: How can something multiple cultivate an appearance of singularity? After all, although the details of QM(s) character are varied, this shared thing, QM(s), still appears to exist across disciplines and sectors.

When embarking upon the project it was assumed that this unity was a product of similar techniques being included across all disciplines. However, after mapping the content of QM(s), included in Chapter 4, little evidence was found of this assumed corpus of unified QM(s) techniques. While – as seen in Chapter 5 – similar learning-teaching performances were observed across many of the disciplines these performances did not produce similar narratives of QM(s) across disciplines – as discussed in Chapter 6. Instead of being unified through similarities of techniques or performances, QM(s) appeared to unify itself, and be unified by others, through a process of othering (Said, 1985).

Across disciplines extensive boundary work was done to reinforce QM(s) as different to other kinds of knowledge. Most obvious to newcomers was the different language developed and spoken by QM(s). While regional dialects existed, the overarching mathematical language spoken was continually empahsised as different to common or even disciplinary languages used:

> The seminar leader comments that, “The complete name is statistically significantly different”, saying that “because in statistics” different has a special meaning. He reinforces this by writing up:

"X + Y are said to be statistically significantly different if μ_x is consistently bigger/smaller than μ_y"

He continues asking the group that as they have the "knowledge of statistically significant in statistics, should they replace the thermometers?"

S: No.

SL: Why?

S: As there's no difference.

SL: Yes in statistics.

(Fieldnote: Economics, 1st year UG tutorial, QM(s) module)

This special meaning of "significance" in QM(s) language, as exemplified in the above quote, was constantly repeated and reinforced across the disciplines observed. Alongside this, QM(s) also presented their own different framework for doing, through concepts such as representativeness or bias/impartiality - which students often easily translated to a qualitative methods context (a problem for qualitative methods learning-teaching as described in Glesne and Webb (1993)). For QM(s) results were evaluated using different mechanisms to those used in everyday logic or decision-making (Garfield & Ahlgren, 1998), with new rules developed and applied. This difference in language was reinforced through notation, which served as a means to both represent, and to communicate with, QM(s). Just as the spoken language of QM(s) must be learnt, so too must this notation, with both having to be translated into everyday language for students. Together this notation and language served as an obligatory passage point for those wishing to work with QM(s) independently, without the use of a translator.

As well as the different language serving to unify QM(s), when transferred into Higher Education learning-teaching environments QM(s') difference was further magnified by curriculum and module structures. As presented in Chapter 4, in all disciplines QM(s) were boxed up in 15-20 credit modules separated from other disciplinary modules. While in all these modules QM(s) were presented through relevant disciplinary examples, the doing of these modules remained distinctly different to other forms of knowledge. As presented in Section 5.2.1, the doing of QM(s) through worksheets and exercises reinforced QM(s) as a different kind of knowledge. This was knowledge that required the support of extra actors and learning-teaching environments, with workshops and surgeries playing host to a multitude of software packages and teaching assistants.

Furthermore, these modules adopted assessment methods and marking schemes that were strikingly different to those used in other modules. As explained in Section 5.2.2, while these assessments and mark schemes were enrolled to respond to QM(s) language and doing requirements, they served to translate QM(s) character, and distance QM(s) from wider disciplinary knowledge forms.

While this boxing up and othering of QM(s) serves to maintain QM(s) status as a single, unified actor, cultivating an identity based on difference creates difficulties when (re-)integrating QM(s) with disciplinary knowledges. As discussed in Chapter 4, when examining student concept maps, QM(s) was often represented as distanced and separated from the various theoretical contributions of their field. This separation of QM(s) mirrored not only the boxing up of QM(s) within methods modules, which is often emphasised within the literature (e.g. Williams *et al.*, 2016; Buckley *et al.*, 2015), but also the other boundary work described above which served to differentiate QM(s) from other kinds of knowledge.

Furthermore, for students the relationship of QM(s) to theory was often understood as one directional, as one student explained:

> [Economics is] made up of the theory, but the theory must be confirmed through like statistics and research [mhm]. And basically erm, the only thing that came up in my mind for this is like er a weird ring, in the sense that theory is then confirmed by research, therefore theory again.
>
> (2nd year UG student, Economics – Antonio)

Although the student describes the relationship of QM(s) to theory as cyclical, this ring represents a linear sequence of steps followed to test theory and not a reciprocal relationship of influence from theory to method and method to theory. As one handbook summarised it, students should "understand the link between data and substantive psychological questions, and how one can answer such questions using statistical methods." (Psychology, PG module information, QM(s) module description). This characterisation of the relationship between theory and methods can be understood as one directional/dimensional as here methods simply serve to passively generate or test theory, with little consideration given to how theories and methods actively influence one another.

In contrast, many staff included a representation of QM(s) (and research methods in general) link to theory, see Figure 8.1 for extract, full concept map show in Appendix 12.11. Although staff did not draw more links to QM(s) (average = 2) than students (undergraduate average = 2; postgraduate average = 2), Figure 8.1 illustrates that staff held a more complex understanding of QM(s) relationship to theory. As explained by the staff member, the cyclical nature of this link represented the following:

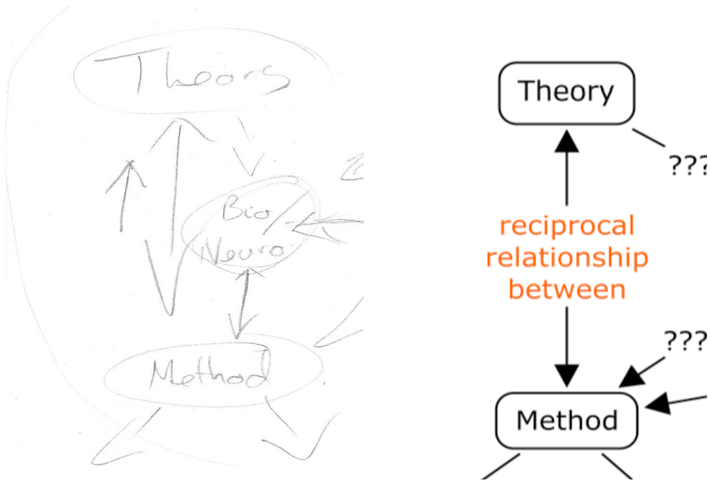


Figure 8.1 Extract of Psychology staff member's concept map - Tristan

> What tends to happen is the method takes priority over theory. So it's certain advances in psychology, particularly neuro-scientific are primarily technological advances in terms of what it is we can detect. In terms of brain activation and in response to a particular stimuli without necessarily there being any er prior theory as to what those things might represent [mhm]. [...] Erm and you know if you read people like Danziger, erm Danziger will say actually it's method that predominates and it's particular forms of methods, primarily quantification, experimentation and measurement that predominate and that they are what now drives theory.
>
> (Staff member, Psychology – Tristan)

As such, instead of theoretical approaches guiding methodological choice – as often described by students – staff also acknowledged the role methods played in driving and shaping the kinds of theories that a discipline produced. For staff, QM(s) was not characterised as distinctly different set of knowledge separate from the discipline. Instead QM(s) was understood as part of a collective of methods, which together formed a key component of all knowledge. Here then, instead of an identity of difference, for staff QM(s) was understood through an identity of similarity.

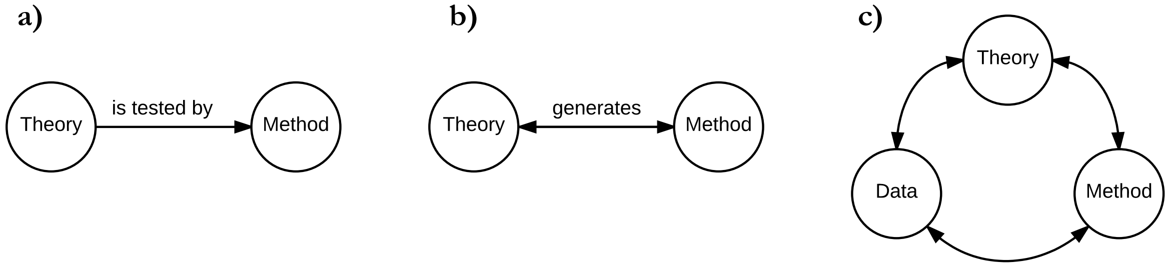


Figure 8.2 A figurative representation of student (a) and staff (b) understandings of the relationship between theory and method, and a proposed alternative (c).

These different understandings held by students and staff are represented in Figure 8.1.a) and b). Noticeably absent from both staff and students' representations is the actor Data, whose relationship to QM(s) and theory is illustrated in Figure 8.1.c). When examining the actor-networks in the learning-teaching environments in Chapter 5, here too Data, as an actor, appeared to be silenced. Yet without data QM(s) is powerless. Moreover, as observed in Chapter 6, disciplinary differences in the character of QM(s) can be understood as an effect of the different kinds of data used by, and available to, different disciplines. For those disciplines working with data in the form of absolute measures, QM(s) acquired a character of stability and reliability. Whereas for disciplines working with data in more complex forms the characterisation of QM(s) remained partial. Understood in this way it was the data type, not the techniques chosen that controlled the identities of QM(s) in disciplinary actor-networks.

8.2 New/Changing Actor-Networks

Having outlined a theoretical alternative to current structures of student and staff thinking about the relationship of theory, method, and data, in the following section attention is given to the ways in which the actor-networks presented in this account could be altered to cultivate this different understanding. Here two broad areas for change will be discussed: strategies for enrolling data into these actor-networks, and secondly, approaches to strengthen QM(s) link to theory.

In order to change impressions of QM(s), ANT would suggest the building of new links and networks. However, enrolling the missing actor, data, into these networks represents more than simply bringing data into the learning-teaching environments.

Getting students' hands on with data has long been framed as a way of engaging students with QM(s) (Neumann *et al.*, 2013; Mvududu, 2005). In all the modules observed as part of this study students were 'hands on' with data, which in many cases was real, gathered data not example datasets, yet students often commented that qualitative methods were more 'hands on' with the data than QM(s). This closeness of qualitative methods is often justified by appealing to methodological differences – with QM(s) acting as stronger mediators and making use of greater abstraction – and the assumed interaction qualitative researchers have with research participants. However, differences can also be observed when examining the performances present within the learning-teaching environments.

In many of QM(s) learning-teaching environments data was pacified, pre-selected to generate results, and pre-packaged to be fed to QM(s) by students. Across the modules observed students and staff spent little time getting to know a dataset. Two notable exceptions to this were a second year Criminology module – where a series of lectures covered in detail the background of the survey data used in the workshops - and a first year Economics module – where students were exposed to large datasets which required cleaning before analysing. In one of these workshops, where students were cleaning the data, the lecturer explained the value of getting to know the data as follows: (see next page)

> The lecturer asks if there is anything else that the student's have noticed about the data set. No one says anything. The lecturer points out that the salary is just called salary, but whose salary is it? As that would make a difference to what it means. He explains that in this case it's CEOs salaries.
>
> (Fieldnote: Economics, 1st year UG workshop, QM(s) module)

In current learning-teaching environments the voice of the QM(s) techniques dominates. Lectures are arranged around a sequence of different techniques being covered each week, with students assessed on their ability to do these techniques. To begin to get students more 'hands on' and closer to the dataset the voice of Data needs to be brought into the learning-teaching environments, as it is only through the hybrid QM(s)-Data actor that meaning about the world is solicited.

In addition to repositioning data, the second area for change lies in strengthening QM(s) link to theory in the learning-teaching environments. As explained earlier this link is vital for integrating QM(s) into disciplinary knowledge structures. However, as well as relating to disciplinary themes, understanding the philosophical foundations of QM(s) is likely to become increasingly important as different approaches, outlined in Section 7.2.2, gain popularity. Cultivating an understanding that QM(s) draws on different philosophies and are used differently by different theories, however, is not simple. This is the kind of problem usually faced by qualitative methods modules (Hein, 2004). In this study, as described in one handbook, different qualitative approaches were presented to students as different ways of addressing specific research questions:

> This lecture concentrates on the role of 'asking questions' in qualitative research. Using case studies from research, the lecture will explore the different ways in which qualitative research questions can be used, and identify similarities and differences to the types of questions that generate quantitative forms of data.
>
> (Geography, 1st year UG research methods module handbook, qualitative lecture description)

In the one qualitative methods module observed as part of this study, a similar approach was taken, with different qualitative approaches being presented as different ways of addressing a central research question, which was used and adapted throughout the module: (see next page)

> The lecturer describes the thematic analysis as reducing and making sense of the interview. He clicks forward to a slide with the research question they're investigating on and a description of the aim to today's session as being to identify an answer to that question. […] He continues defining epistemology, and explains that it has a greater importance in qualitative research than in quantitative research. He describes there as being a continuum from social constructivist perspective to a realist perspective, and that the position you take affects what can be said from the data. […] The lecturer refers back to the research question and says that it adopts a realist position assuming what people say can be taken to refer to what they feel/think.
>
> (Fieldnote: Psychology, 2nd year UG lecture/practical, Qualitative methods)

Here, then, it was not just that method provided translations of data, it was emphasised that each method provided its *own* translations. In this setting, qualitative methods were not valorised based on their role as transferable employment skills or by emphasising the presence of words all about us (common justifications provided within QM(s) classrooms (i.e. Paxton, 2006)), instead they were valued through their specific abilities to provide answers to certain questions.

Applying this to QM(s) learning-teaching, in strengthening QM(s) link to theory, QM(s) become another method, not a different set of techniques that are more valuable if applied (as argued for by Onwuegbuzie & Leech (2005)). Through encouraging an appreciation for the multiplicity of QM(s) – not just inferential testing – and the value of QM(s) as answering a variety of research questions the adoption of QM(s) by new users may be encouraged.

Strengthening this link could be achieved in various ways, including increasing attention on research questions not null hypotheses (as remarked upon by Andrews and Baguley (2013), embedding QM(s) into content modules, to enable a greater variety of QM(s) to be introduced to students, or through problem-based learning where discussion over the contributions of QM(s) is encouraged (similar to solutions advocated by Dobni and Links (2008) and Folkard (2004)).

8.3 Conclusion

In this chapter, the various sides of QM(s) characterised in each of the proceeding chapters have been brought together. Here it was suggested that QM(s') unified character, present within the literature, is achieved not through the similar techniques or narratives within modules or disciplines, but through boundary work that served to unify QM(s) based on reinforcing its difference to other kinds of knowledge. Through cultivating its own language, notation, module structures, and assessments, QM(s) were able to enrol actors into its own actor-networks.

However, while this process of differentiating QM(s) served to unify its character and enrol users, it created problems when attempting to integrate QM(s) with disciplinary knowledge. For students, QM(s) was characterised as having a one-way relationship to theory, where QM(s) was broadly understood as a way to test theory. In contrast, for staff, this relationship was represented as two-way, with theories generating methods, and vice versa. For staff, QM(s) was understood not as distinctly separate from the discipline knowledge, but as a fundamental part of it, occupying a position of similarity to other methods.

Having discussed student and staff representations, an alternative representation of the relationship between theory and method was proposed. Given the importance of data in controlling QM(s) character, identified within Chapters 5 and 6, this alternative representation included data as key part of this relationship.

This chapter ended by outlining some of the ways in which the actor-networks presented in this thesis could be manipulated by reinforcing QM(s) link to data and theory. Overall, the drive to raise QM(s) standards should not become the key reason for valuing QM(s). While research is needed on how to learn/teach these concepts increased attention should given to understanding how to value the research questions that QM(s) are skilled at answering, and how to foster an appreciation for QM(s) ability to transform data in different ways. Furthermore, instead of framing the problem as students not being engaged with QM(s), greater attention should be given to considering why certain topics, such as representative and bias, appear to be more easily taken up by students and transferred to other methodological approaches.

9 Evaluation

Having presented and discussed the four faces of QM(s) and the implications of these faces, we can now turn to evaluating the study and outlining its limitations. Here specific attention will be given to providing a relatable account of working with ANT. This will be followed by a comment on using concept maps - both generally and as a tool to be used with ANT. Finally, several specific limitations of the study will be presented.

9.1 ANT as a Colleague

Throughout this account emphasis has been placed on 'working with', not 'using' ANT, this linguistic tendency was chosen to acknowledge ANT's role as an actor itself within the research. For me, working with ANT involved two distinct stages of interaction – labelling/identifying, and mapping power/action – both of which I would suggest is vital for successful co-authorship with ANT.

9.1.1 Stage 1: Labelling/Identifying

Like Latour and Woolgar's 'observer' (1979: p.41) or anthropologist (Latour, 1999b), I went out into the field, equipped with a notebook, coloured pens, dictaphone, and identification key in the form of ANT. In these early stages, ANT had told me what I should be trying to spot, and, at least theoretically, how to spot these things. Furthermore, work by Fox (2009) seemed to make it clear that these actor-networks were in the learning-teaching environments to be seen, traced, or followed.

I had my starting point, my way into, this network: the courses taught that contained quantitative methods. I began identifying key teaching staff and struggling to recruit participants through email lists (Meho, 2006), meeting those actors who I would later identify as spokespersons for QM(s), and attending the sites of performance of quantitative methods. Yet all I was able to see were the interactions described by the very authors whose work I was so critical of. I could not see actors. I could just see lecturers and students.

I began interviewing staff and students, hoping that they would provide me with a fleeting image of these actors, or networks - I did not care which - through their spoken words or concept maps. In the majority of interactions with participants, I choose not to declare that I was working with ANT. During the pilot study I had become aware of the difficulties of explaining ANT to my participants, by trialing diary methods (Latham, 2003) with a staff member I discovered that while I could focus on the materiality of a learning-teaching environment, the teaching staff often were more comfortable and familiar with keeping reflexive accounts of their teaching practice. These accounts often had very little reference to any materiality, instead focusing solely on evaluating the student-teacher interactions. Having tried, and failed, to explain ANT to a participant with whom I had developed a good working relationship, I began the main study somewhat wary of wasting the limited time of the interviews explaining my theoretical positioning, a positioning that seemed to me to be of little importance to my participants and one that I was still struggling to explain to myself.

I quickly gave up talking about my research in ANT terms with my participants. I was already having trouble selling my research to participants, who were often critical of my choice of qualitative methods, wary of my role as observer, and presumptive of my underlying aims for choosing to research this area - was I secretly reporting on their performance? Adding to that, that, yes, I did genuinely believe that the t-test, the whiteboard, or the handout in that week's class had as much, if not more, power or agency over the learning-teaching environment as they did, seemed stretching their faith too far. Instead I chose to explain my research in general terms, with the normalised goal of seeking to improve the learning-teaching of QM(s), emphasising that my research aimed to understand the conceptions and performances of QM(s). In essence, this was what my research was about; however, in deciding to characterise my research in that way I became forced to constantly translate between the everyday world and the ANT world. This pragmatic decision appeared to have little impact on the relationship I had with my participants, and allowed me to stay close to their language (as emphasised by Latour, (2005)) instead of imposing ANT's theoretical language onto my participants.

After struggling to communicate my research to participants – a common issue within research studies – I also experienced problems seeing/finding the actors that supposedly inhabited and constructed the learning-teaching environment. Both while conducting my fieldwork and when focusing on my analysis, the easiest place to start had always seemed to be the actors. After all, so many studies had provided lists of them in educational research contexts (i.e. Fox, 2009), and in classic texts readers were advised to simply 'follow the network…or to follow the actors' (Ruming, 2009: p.453). Nonetheless, my participants' narratives, just as in my pilot study, tended to be human centered with gentle probing sometimes being needed to encourage them to reflect on the materiality involved in the learning-teaching of QM(s).

In contrast to these other studies, my research had never sought to follow the central actor (QM(s)) through time, instead I aimed to travel across disciplinary space(-times). In doing this, instead of gaining insight into the interactions occurring between actors I found myself surrounded by ever-growing lists of actors found within disciplines, skeptical of the power any of these actors really had in performances of quantitative methods. It did just seem to be teachers teaching, and students learning.

9.1.2 Learning the Language

At this point, ANT seemed like an inappropriate theory to apply in an Educational Research setting, after all it was developed to study the activities of science, not education. My research had none of the usual STS accessories; there were no new or failed cyborg technologies in these lecture theatres. Apart from labeling things as actors and drawing sketches of possible ways these actors could be arranged in networks I had little to show for the glorious insights I had thought ANT was going to give me.

Of course, these early problems were not just a result of my choice of theoretical framework. Researchers have long called attention to the difficulties of building rapport with participants (Clarke, 2006), of being an insider/outsider (Dwyer & Buckle, 2009), of acting the researcher (Mulhall, 2003), and of conducting research with more powerful elites (Campbell, 2003). In working with ANT, however, you yourself have to become enrolled into its network. You have to displace your own prior understandings of the world to see and think not in terms of people, but of actors. You have to learn to follow its orderings of the world, to use its labels, to learn to translate into its language.

During this stage, we, as researchers, are ANT's researchers. To use ANT terms, we must become enrolled into its actor-network. ANT exerts power over us by providing a language and theoretical model of the world. But simply labeling the world as ANT sees it is not *doing* ANT. At this point ANT was simply a tool for describing the world, but ANT is not just about describing the things in the world according to labels. After all, as

Latour says, 'a good ANT account is one where all the actors do something' (2005: p.128).

9.1.3 Stage 2: Mapping Power/Action

As the research progressed I became more aware of what ANT was doing for me, I became more able to speak ANT-ish to my participants. Not necessarily using all of the typical key terms, but starting to talk to participants in terms of networks and flows and enrolment, enabling me to member check the narratives that I was beginning to form. By this point I had begun to identify human, and more importantly, non-human actors. Yet I felt I was simply reproducing stories that had already been told. In starting to analyse my data ANT became something I had to work to, to use, or stick with. While in the early stages ANT had been a way of viewing the research environment, here it became a series of abstract narratives that the research appeared to need to be slotted into.

For example, as commented on in Section 8.2, when justifying quantitative methods, lecturers tended to emphasis the ubiquity of numbers, a marked contrast to the justification given by those leading qualitative research methods, who focused on the research questions that could be answered with qualitative methods, instead of emphasising the frequent appearance/value of words in the world. When first considering this situation with ANT, it was all too easy to assume that the lecturers were in control; after all they were the actor putting forward the justification.

Similarly, when in lecture environments, lecturers seemed to be the actors in control, both of the students and of QM(s). They were directing, choosing the slides, communicating, while students passively sat taking notes, occasionally answering questions. ANT had promised to tell me something about the other actors, yet here it seemed to be telling me things about the actors already popularised in the literature. Here it was telling me stories of a passive QM(s), tightly controlled, with barely a life of its own.

I felt sure these moments should be saying more than these framings were presenting. In one meeting when asked by my supervisors how I felt about the piece I had written I could only comment that it still 'wasn't ANT enough'. To try to remedy this, I started, in desperation, retracing my steps through the literature searching for what *was* ANT enough.

It was at this point, roughly two and a half years in that I found other researchers uttering discontent with ANT (Hitchings & Jones, 2004). They clarified what I had begun to suspect while re-reading classic ANT texts, namely that these accounts were presented with almost no reference to methodology - in Laboratory Life (Latour & Woolgar, 1979) the reader is furnished with two paragraphs on the subject. But in contrast to those trying to critique ANT, Hitchings and Jones went further to hypothesize reasons for this methodological silence. Reasons included: a greater interest in the theoretical or philosophical contributions of the work; the use of ethnographic methods, which were commonly methodologically underdeveloped; and a favouring of narrative styles of reconstruction which foregrounded new entities and backgrounded the author.

Revisiting my own data, I saw that the accounts I was producing were not 'ANT enough' because they were reproducing pre-existing understandings of the power dynamics within quantitative methods teaching. I was ticking things off from the identification chart but doing no more. I was not translating, or enrolling, ANT into my own research.

In focusing on what actors and networks there were, I had overlooked the power dynamics of these networks, or to use Latour's phrasing, I had overlooked, 'The sort of action that is flowing from one [actor] to the other' (2004, p.64). I had been simply applying a standard understanding of the power dynamics instead of interrogating this framing and considering QM(s) as an active actor. Although, the nature of QM(s) could have been that it was a passive actor, rendered so by the lecturers, these narratives were so common that I began to consider that the power lay in a different direction. Nonetheless, framing these narratives in a way that challenged the position of power the lecturers are often placed in was difficult and uncomfortable.

Nevertheless, over time, I began to trust and believe that these actors did have equal potential agency over one another, and more importantly that non-humans could have more power than human actors. That QM(s) was not always a passive actor there to be learnt. That, in certain situations QM(s) was enrolling lecturers to talk about it in specific ways, while in others, worksheets were enrolling both lecturers and students into shared performances of doing quantitative methods (not simply learning), and that different disciplinary learning-teaching performances were (re-)producing different research ontologies.

9.1.4 Learning to Think in Different Directions

This shift was not, as is often presented in the literature, a clear seeing of the actor-networks. It involved developing a sensitivity to, and acknowledging the possible presence of power in all objects around us. Equally, it required developing confidence/ belief to attribute this power to those objects, and not transfer power back to the humans. This proved to be difficult, given the prevalence of student-teacher narratives within the literature, as discussed in Section 2.2.

This shift involved a messy process of looking at my data in different directions. If we consider everything to be interconnected in a network of relations it becomes theoretically possible to start from different positions in that network and draw out different pathways. In my early writing/thinking, I had started from the point of those actors that drew the most attention – the lecturing staff, the students, the computers – and worked my way around network diagrams linking actors together. But as Laurier and Philo explain, ANT is about bringing other entities out from a 'shadowy domain' (1999: p.1056). It is about making all the actors work, not just those that are the most visible.

One of my first moments of getting ANT to work for me was realising that in the narratives I was producing, little reference was made by staff, students or in the learning-teaching interactions to the raw data that these quantitative techniques were applied to. The techniques themselves were controlling the learning-teaching environments and enrolling staff and students into producing understandings that these techniques were what QM(s) was all about. Similarly, in considering that, as for Latour's (1993) Pasteur, actors often enrolled other actors as spokespersons, I began to retrace my understanding of power in the classroom asking: What if teaching staff were not the ones in control? What if they were simply spokespersons for other actors, namely the quantitative methods?

In doing this, the lecturer shifted from a position of power to simply being a mediator in QM(s') attempts to create a network. As already mentioned, this learning to see was not an easy process. Although ANT is seemingly straightforward to grasp as a theory, applying it to the field, deciding which strand to follow, which actors to listen to, and what story is worth telling, is not. As with any research, judgments have been made by the researcher to tell certain stories, given the research questions. Here decisions were taken to foreground QM(s) and not the staff/ students.

In re-assigning power in the networks I had mapped, I enrolled ANT into my research setting. After struggling to learn the language I was now able to translate ANT into my own actor-networks, and to create an engaging narrative (Latour, 1988) that met my aims instead of reproducing the narratives of surrounding quantitative methods learning-teaching literature or the narratives of ANT about the world around us.

Overall, ANT did offer useful and valuable insights in an Educational Research context. However, these insights were not produced through a simple seeing or tracing process, in contrast to the styles of presentation ANT accounts are often characterised by. Here a two-stage process of working with ANT was identified whereby I, the researcher, had to become enrolled into the actor-network of ANT, along with enrolling ANT into my research actor-network. While, for the novice researcher working with ANT for the first time, this poses a challenge it should not detract from the potential benefits of applying ANT in Educational Research contexts, and hopefully this account will encourage more discussion around the doing of ANT.

9.2 Problems of Concept Mapping

Having provided an account of the process of working with ANT, this chapter will now turn to discussing the method of concept mapping.

Along with working with ANT, difficulties in this study were also faced when using concept mapping. Here these difficulties are separated into two sections – those associated with the initial drawing of the concept maps, and secondly, those associated with the redrawing of concept maps using the CmapTools software. Following this, as described in Section 2.5, a comment will be made on the use of concept mapping with ANT.

9.2.1 Drawing

As discussed in Section 3.2.3, concept mapping was used to gain an understanding of participants' conceptions of QM(s) in relation to their disciplines, as housed within relational space. During the interviews, all participants were asked to draw a concept map answering the question, 'What is [their discipline]?'. During this initial drawing, three specific difficulties were faced - the diversity of concept maps produced; the broad focus question; and putting participants at ease – each of which are discussed separately below.

Firstly, although specific instructions were provided to participants about how to draw the concept maps, the resulting concept maps were reasonably diverse. For those that had drawn mind maps previously many defaulted to drawing such diagrams – i.e. ideas spiralling out from the central concept – which, as outlined in the Methodology, is a different type of mapping method. For those that drew maps that were closer to the guidelines provided, many often left out descriptions of the drawn links – which in the strictest application of concept mapping should be understood as incomplete knowledge (Novak & Gowin, 1984).

Variation was also seen in the amount of content included on the maps, for some very few nodes were drawn onto the map (see Appendix 12.10), while others drew denser diagrams – see Appendix 12.11. Others tended to include paragraphs of information in nodes, consisting of different points, instead of separating the keywords out to form short sentences comprising single word nodes and links.

This variation is perhaps due to the nature of using them in an interview, with time pressures limiting the participants' willingness to invest time in drawing the concept map, instead filling out the structuring in the subsequent discussion. This variation could also be due to the relative freedom given to participants in this study over the structuring of their concept maps (Kinchin, 2016).

Secondly, while time was given to developing a suitable 'focus question', here the focus question used was very broad. Questions used by researchers elsewhere typically asked, "What is a plant?" (Novak & Cañas, 2008), "What is sustainable development?" (Lourdel *et al.*, 2007), whereas here the question "What is [their discipline]?" was chosen. Some participants did ask further questions to narrow down this question, specifically if I was interested in the staff member's view or the students' view of what the discipline was, while others asked explicitly what I was interested in.

Thirdly, participants often required reassurance while drawing their maps: Was the content they had included right? Were their maps detailed enough? Many participants were also defensive about their handwriting - apologising, as I would not be able to read the concept map - or the neatness of concept map as a whole, commenting on the "messiness" of their final diagram. In each of these situations I was quick to reassure participants that messiness was inherent in the method, and that they could redraw if they wished. Despite the concerns, none of the participants did redraw their concept maps. A move, which suggests that this was simply a way of dispelling the discomfort felt by participants when drawing.

For some drawing a concept map without much time to prepare was felt to be uncomfortable. Undoubtedly, for these participants the one-to-one environment with me, at points, observing them did not help their unease – despite my emphasis to not look at what they were drawing if they seemed on edge or defensive.

On the whole, these concerns led to some participants remarking that the concept maps were "hard". However, many participants did respond positively to the concept mapping approach, despite the initial unease and uncertainty, they enjoyed the concept map method, remarking that it was "fun". This supports work by Asan (2007), who described how students in a science class found the experience of drawing concept maps fun and enjoyable.

In this research, participants' enjoyment of the concept mapping technique was related to a number of different factors. For some, they enjoyed the visual nature of the concept maps, often commenting that they were visual learners. Goodnough and Woods (2002) reported a similar reaction from students using mind mapping in a science class, describing how, while most students enjoyed the technique, their enjoyment was related to the students' own preferred learning style.

For other participants, they enjoyed the creative approach, commenting that usually they did not get to use coloured pens/pencils in their discipline/work. Moreover, for others, they commented that drawing the concept map had helped them to understand their discipline better, providing a way to reflect on their own position within the discipline, along with an opportunity to reflect on what they did not like about the discipline, and showing them things that they had forgotten. For staff, specifically, it offered a way to talk through those elements that were considered to be the popular aspects of their discipline, and those that were the academic. While, for those students further in their studies it gave them an opportunity to reflect on how their understanding of the discipline had changed through their degree.

Despite these problems in the doing of the method, concept mapping did provide a useful way of stimulating discussion with participants about their discipline without specifically mentioning quantitative methods. However, their analysis proved challenging. Give the small number produced here they were unable to be quantitatively compared (as was originally planned and usually included in other studies). Other qualitative methods of analysis, such as analysing the shapes and the specific words included on the concept map seemed to provide a very shallow characterisation of the concept maps as a whole. The heterogeneity of the mix gathered here also did not help analysis. Concept maps were redrawn in an attempt to provide some homogeneity to allow for analysis, but such information did not always generate new insights.

If concept maps were used again in the future, to alleviate the unease felt by some participants and to encourage a greater uniformity, example concept maps could be drawn during the interview, instead of talking through a sheet of pre-drawn examples. In doing that, participants would see that mess, poor handwriting, uncertainty, are all part of the method of drawing a concept map, whilst allowing the interviewer to stress more clearly the importance of describing links and separating nodes.

9.2.2 Concept Maps and CmapTools Software

Along with drawing out the concept maps by hand in the interviews, here the concept maps were subsequently reproduced using CmapTools software (Novak & Cañas, 2006; Nouwens *et al.,* 2007). As described in the Methodology, given the heterogeneity of the concept maps drawn by participants redrawing them was seen as a way to provide more uniformity, and to allow information provided by the participants in the later discussion to be incorporated onto the maps.

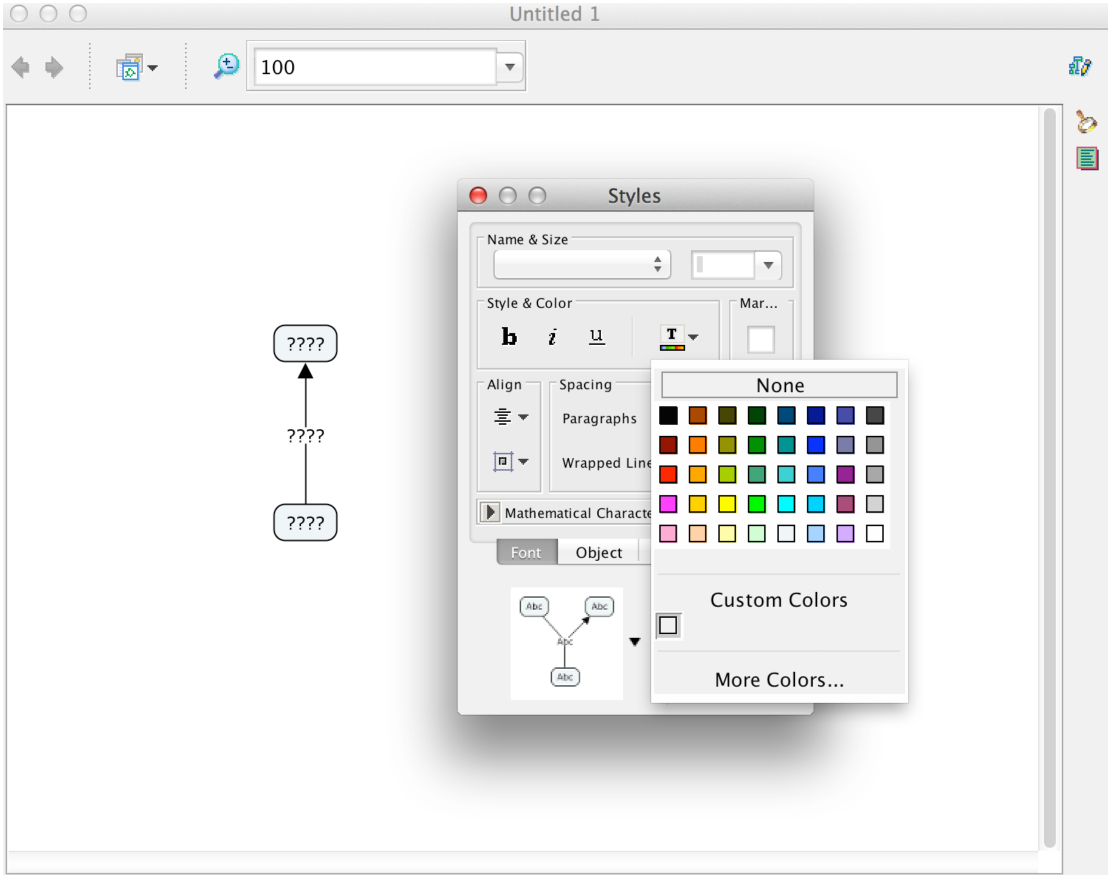


Figure 9.1 Screenshot of CMapTools illustrating the range of colours and automatically inserted "????" labels (taken by author).

However, through redrawing, the software became an actor imposing its own framework onto the concept maps. As shown in Figure 9.1, the software had a limited number of shapes and colour options available, stripping away some of the originality of participants' concept maps. More importantly, the software automatically included "????" over any links that were not described, again shown in Figure 9.1. When re-drawing the concept maps this meant that instead of passively copying participants concept maps, I became actively engaged in considering what descriptions could be added, given participants explanations of their concept maps, and adding these described links. Through this prompting, CmapTools assumed and reinforced broader theoretical assumptions over what concept maps should look like, and what was counted as knowledge or correct knowledge – i.e. knowledge that was corrected described and integrated into the network (Novak & Gowin, 1984).

If the study were to be repeated with more emphasis placed on the quantitative analysis of the concept maps produced, then asking participants to draw their concept maps using CmapTools would be beneficial to encourage a greater uniformity across the concept maps – enabling easier comparison - and to save time redrawing them. This would give participants control over where blanks were included and may have prompted them to include greater detail and to follow more closely the concept mapping method than when they were drawing them out on paper by hand.

However, given that the primary aim of the concept maps here was to stimulate discussion around an abstract topic, and the small sample size limiting the potential for quantitative analysis, introducing the software to participants offered little benefit. While the software was intuitive to use, its relative inflexibility may have impacted on participants enjoyment of the activity, as often it was the freedom and creativity in drawing out the concept maps that participants enjoyed. Similarly, for some, there may have been unease about using a new software for the first time, however, this unease is unlikely to have been any greater than that expressed over the quality of their handwriting.

Furthermore, in giving participants a blank piece of paper it enabled them to align with the method as much as they wished to. There was space for a resistance to the research (hooks, 1990), as well as a freedom to express their discipline in ways that the CmapTools software would not have allowed them to do. Equally, the variation in visual styles here was a useful way to allow an expression of the participant's own personality, and drawing by hand enabled the inclusion of different images.

Despite the problems of the software and the interesting heterogeneity of the concept maps produced, redrawing of the concept maps, I would argue, remained beneficial. Using the software offered a way to re-engaging with the material after the interview has been completed, similar to the process of transcription (Tilley, 2003; Lapadat & Lindsay, 1999). Here similar decisions were made about what to add in, what to change, how to decipher handwriting, where to position the diagram, which elements to split and which to leave together, that are comparable to issues of deciding on words spoken, where to include pauses, full stops, or new paragraphs in transcripts. This process of re-writing/ re-drawing enabled the researcher to become familiar with the data, as well as allowing participants to re-engage with the material themselves after the interview has been completed.

9.2.3 Concept Mapping and ANT

To my awareness, ANT scholars have rarely used concept mapping, as a method, with network analysis proving a more popular way to represent the actor-network (i.e. Martin 2000). While Galofaro (2016) criticises the use of concept maps as a representation for actor-networks, as they provide little or no representation of the dynamism and mobility of the network, here concept mapping paired well with ANT, mirroring its network analogy.

Through the study concept maps were used in a variety of ways to capture some of the multitude of networks that could be observed. During the pilot study concept mapping was trialled as a way to represent and analyse the structure of lectures – which gave little insight into the formalised Power Point linear narratives, which often dominated the learning-teaching environments. As already mentioned, concept mapping served as a way to gain insight into participants' understandings of the discipline, and as a stimulus for discussion within the interviews. Alongside this, concept maps were used throughout the study to consider the relations between actors and to plan draft writings. In training myself to think in networks, concept mapping offered a quick and easy way to represent these ideas to consider sections of the actor-network as a whole, instead of becoming lost in never-ending associations.

In particular, concept mapping proved invaluable when analysing the codes developed from the initial data analysis, similar to Wright's (2014) study who used network diagrams to represent the actor-networks of competition beer judging. In this study, hierarchical methods - specifically thematic analysis - were initially trialled, however the reduction and grouping of codes proved difficult. While the initial number of codes developed was high (~200), with the frequency of occurrence of each code varying widely (a negative according to Friese (2014)), codes appeared to cluster together in their role creating a certain characteristic, instead of being based on their similarity to one another. Once it was acknowledged that it was the links between codes that were important, and not expressly the codes themselves, concept maps became key to allowing these interrelations between codes to be mapped out (see Appendix 12.4).

Applying concept mapping as an analytical approach, offers numerous benefits to ANT scholars. Firstly, it serves as a useful way to present and discuss the methodology adopted in ANT accounts. As commented on in Section 2.3.3 in Chapter 2, ANT accounts have often been criticised for their tendency to produce grand narratives devoid of methodological description or discussion (Hitchings & Jones, 2004; Lee & Brown, 1994). Concept mapping hence offers a way to help visualize how these accounts are constructed, acting as a shorthand version of Latour's (2005) writing trials, which can be referred to after the final account has been written.

Furthermore given its relative simplicity as a technique to learn, and its visual nature, concept mapping, I would argue, does offer potential as a tool to help new ANT researchers to think "ANT-ish" (Fenwick & Edwards, 2010). It offers a structure that helps to foreground the links between things, helping the researcher to move from the initial identification of actors and moments of interest, to considering the flows of power around the actor-network as a whole system. Although not working with ANT, Butler-Kisber (2010) similarly argue that concept mapping offers a way for researchers to quickly note things down and to produce initial conceptual understandings of the phenomena, which draws specific attention to the relations.

In addition, through applying methods of concept map analysis, these diagrams can also help researchers identify early narratives that may be of interest, i.e. through examining the location and number of links an individual node has (with concepts with a greater number of links being understood as more central concepts (Bradley *et al.,* 2006)). This can help to provide some initial structure to thoughts and observations gathered from the field. For larger studies, these early ideas could then be used as points for further data gathering in the field. Additionally, for researchers working as part of a team, this method facilitates the communication of ideas, as the process of drawing concept maps, as shown in the interviews, acts as an effective stimulus for discussion. Extending this, if concept maps were drawn on software such as CmapTools they could be easily shared and accessed by researchers across the world (Nouwens *et al.*, 2007).

Despite offering numerous benefits for ANT scholars, concept mapping however should still be seen as a tool to be used *with* ANT, not as a method for doing ANT. While benefitting from concept mapping, the account here has been produced through an assemblage of methods, to follow Law (2004), that have been used together, with many of the key moments of the study being accessed through ANT's traditional ethnographic methods. Similarly, concept mapping cannot replace the process of mastering ANT oneself. Skill is needed to transfer the networked representations of the actor-network into the linear accounts of a written narrative, a process that only writing trails (Latour, 2005) can really assist with. Finally, there is a need to train oneself to think in different directions, to enrol ANT into the specific research settings.

9.3 Limitations of the Account

As well as evaluating ANT, as a theoretical framework, and the methodology of concept mapping, a brief comment must also be made on the specific limitations of the study reported here.

Firstly, the account presented is drawn from data gathered from just one institution. Whilst this enabled different disciplines to be explored, the identification and effect of institutional actors was limited. Similarly, the extent to which the performances outlined in this account are found elsewhere was unable to be discussed.

Secondly, whilst attempts were made to view QM(s) in as many different module settings as possible gaining access to these modules, and timetabling observation sessions, proved challenging. As courses were accessed across departments learning-teaching sessions of different modules did sometimes occur simultaneously, meaning that not all specific teaching sessions were able to be observed – for example all modules' first lectures. This limited the amount of direct cross-comparison possible between departments and modules. This issue could only have been avoided if another researcher were also working on the project, allowing simultaneous sessions to be observed, as not all of the teaching sessions at the institution were video recorded.

Similarly, unfortunately, not all core research methods modules could be accessed. Accessing learning-teaching sessions was particularly problematic for modules involving team teaching where relevant staff members could not always be identified and whose course conveyors were similarly illusive (as information was not always up to date on accessible course documentation). Whilst in any study there are difficulties in recruiting participants, had this problem with team teaching been known from the start of the study extra time could have been allocated to identifying staff on those modules, and snowball sampling applied to find the key staff members.

Fourthly, along with issues identifying and contacting relevant staff members, there were also problems of recruiting student participants. Initially, concept maps produced were going to be quantitatively compared across departments and participant type. However, in no department were adequate numbers achieved. Recruiting undergraduate Psychologists and Economists was particularly problematic; staff from both departments were surprised when I said I was not offering any financial incentive, a practice common within their respective departments. Whilst snowball sampling did have some success amongst Economics students, it had little impact with Psychology students. Recruitment of Psychology students may have been further complicated by the fact that within the department students were required to participate in Psychology experiments for credits towards their degree (a practice relatively common (Sharp *et al.*, 2006)), given this it is perhaps unsurprising Psychology students were unwilling to sacrifice more of their time for a study that appeared to offer little direct benefit/incentive to them. While financial incentives may have increased the numbers recruited for interviews the cost of this would have been prohibitive here. Beginning recruitment earlier in the academic year may have increased numbers, however this would have had implications, as students may not have been exposed to any quantitative methods learning-teaching at that point in the academic year. Carrying out concept mapping with classes within modules, as often done in studies evaluating concept mapping (Murtonen, 2015; Hay & Kinchin, 2008; Hay *et al.,* 2008), may have offered a way to increase the data generated. However, it is unlikely module leaders would have been able to sacrifice the time for this in lectures. While perhaps students could have drawn concept maps online, at home, the ethical implications of embedding a study into a module and recruiting staff members work with to achieve this would remain problematic.

10 Conclusions

When setting out, this thesis aimed to challenge assumptions made by the literature surrounding quantitative methods learning-teaching. Policy initiatives attempting to solve the skills deficit present the learning-teaching of QM(s) as an unproblematic transfer of knowledge from staff to students. Whilst the academic literature has challenged this model of the unproblematic transfer of knowledge through identifying a series of obstacles faced by students and staff, it nevertheless remains routed in a series of its own assumptions. Firstly, frequently the learning-teaching of QM(s) is understood as being an activity involving only human actors, specifically staff and students (as seen in Garfield's, 1995 principals). Secondly, much of the literature focuses only on the activities occurring within a single module (Strangfeld, 2013; Becker *et al.*, 2006; Folkard, 2004), characterising these interactions through reference to predominantly abstract space(-time) (i.e. Meletiou-mavrotheris, 2004; Onwuegbuzie & Wilson, 2003; Garfield, 1995). Finally, little cross disciplinary discussion occurs (Parker, 2011; Wagner *et al.*, 2011), despite the literature's quest for universal best practice (Garfield & Ben-Zvi, 2007). These assumptions are pervasive across the quantitative methods learning-teaching literature, and highlight a gap in the literature for research challenging these assumptions, which offer the potential to provide new insights into quantitative methods learning-teaching.

To begin to challenge these assumptions and address this gap in the literature, an ANT sensibility, supplemented by Harvey's three spaces, was selected through which to re-examine the nature of QM(s) within Higher Education Social Science disciplines. The thesis sought to answer three specific research questions:
1) What were the actor-networks that made up QM(s)?
2) How were these networks performed, conceptualised, and created by actors?
3) How did these performed actor-networks vary across disciplines?

Providing an initial step towards answering the second and third research questions, Chapter 4 began by presented the conceptions of QM(s) as located within actors' words, the curriculums, and on participants' concept maps. Here, in contrast to the literature, a multiplicity of QM(s) character was reported. While QM(s) were often found housed within similar skills modules, the kinds of techniques found within these modules varied across disciplines, particularly after the first year of undergraduate study. Similarly, although most participants did include reference to QM(s) on their concept maps, variations emerged according to level of study and discipline. Furthermore, when examining the variety of words used in association with QM(s), QM(s) was found to occupy multiple positions of agency, ranging from a passive tool to a mysterious beast. Working with this assumption of QM(s) as having an inherently multiple character, Chapter 5 and 6 mapped out the actor-networks that performed QM(s) within modules and disciplines, together answering the first and second research questions. Within classroom learning-teaching environments, actor-networks were assembled to perform two key beliefs about the nature of QM(s): that QM(s) was a linear and fixed sequence of knowledge and that QM(s) were learnt through doing. Worksheets and handouts were enrolled by staff into these actor-networks to reinforce these beliefs, however these actors, as well as correct answers, served to translate these beliefs into a characterisation of QM(s) as a passive, linear activity of completing tests. Alongside this, the role of software was also examined. Through forming a hybrid actor with software, QM(s) exhibited a mischievous side, fracturing the linear performances found elsewhere into an iterative process of errors, whereby users engaged in a process of tuning to allow QM(s) to speak out through tables of outputs. Unlike the unproblematic transfer of knowledge characterised within policy strategies, the performances of doing QM(s) here were non-linear, interrupted by errors and the hidden knowledge of staff and students.

From these performances, Chapter 6 presented a detailed account of how these actor-networks varied across disciplines – answering the third research question – supplementing comments made throughout the proceeding chapters. For Criminology, QM(s) was found as trends of crime data, and while valued, was viewed with scepticism and caution. In Geography, along with providing trends of data through space, QM(s) was tied to measures, which were often embodied physically. Working with these infallible numbers, QM(s) in Physical Geography grew in strength, valued for its ability to provide reliable answers and predictions to environmental questions. Valorising QM(s) for these qualities of fixity and robustness however proved problematic when transferred into Human Geography. While QM(s) was successfully enrolled into sub-disciplines that could provide similarly infallible numbers – such as transport geography – for those where data resembled the surveys used by Criminologists, QM(s) was regarded warily. For Psychology students, QM(s) strong presence was often a surprise; nevertheless QM(s) was highly valued by the discipline given its ability to provide various markers of significance. Although QM(s) occupied a similarly powerful position to that found within

Physical Geography, here this power was drawn not from the numbers used, but from the conventions built up and maintained by the discipline. Furthermore, while QM(s) corresponded amicably with other methods in Geography, in Psychology, QM(s) was expanding, changing the kinds of knowledge valued by the discipline, pushing qualitative research methods to the boundary of the discipline. Finally, in Economics, QM(s) was found to be a blend of mathematics and econometrics, serving a vital role in decision-making. Unlike the other disciplines, here QM(s) was not sold as the best method; instead it was understood as the only method through which their quantified world could be translated. Given this, and the techniques used, although valued, QM(s) was understood as partial, with optimality, not significant results, being the goal.

Having outlined these actor-networks, Chapter 7 turned to considering QM(s) as an actor responding to change. Across the disciplines studied, QM(s) face a number of threats to its current characterisation, in this chapter new software and new techniques emerging in response to these threats were examined. The growth of R and Bayesian statistics was presented as representing a potential shift in the characterisation of QM(s), from one of fixity to one of fluidity, where the researcher occupied an increasing position of power. In addition, this chapter also outlined two responses to growing student numbers, and the associated mixed abilities/backgrounds of students. In the first, QM(s) moved out of the learning-teaching environments it had been observed within here and colonised new informal space(-times), or repurposed current formal space(-times). In the second, the future of broad QM(s) modules was questioned, with a potential fracturing of modules occurring, with new modules emerging to house different groups of content. Although the extent to which these murmurings of change will come true is unknown, they draw attention to QM(s) position as a changing actor-network, not simply one whose identity remains fixed.

Drawing these characterisations together Chapter 8 reflected on the implications of these characterisations for learning-teaching. In this chapter, it was discussed how a unity to QM(s) character was achieved through a process of othering. Although adopting its own language, notation and module design, served to protect and cultivate QM(s) identity as singular, being boxed up in this way had repercussions when attempting to integrate QM(s) with disciplinary knowledge and theory. For students, QM(s) was understood as having a one directional relationship with theory – passively testing and generating theory. For staff, however, QM(s) was understood in relation to other methodologies. Together these methods were understood as actively shaping the kinds of knowledges that were valued and produced, and vice versa. Given the actor-networks presented in the proceeding chapters, a missing actor in these representations was identified – Data. This chapter commented that re-packaging QM(s) relied upon restoring the voice of data (whose power was seen in Chapter 6), as well as strengthening the link to theory. It ended by suggesting that the uptake of QM(s) relied not on the selling of the methods, but instead a valuing of the kinds of insights QM(s) could give.

Given the limited use of ANT within educational research, in Chapter 9 a reflection was provided on the process of working with ANT here. This process was characterised by two stages, the first where the researcher becomes enrolled into ANT, and the second where the researcher enrols ANT into their own research setting. In addition to this, the use of concept maps was evaluated, with specific attention given to examining their potential for working with ANT.

While this project has provided a first step in reimagining QM(s) learning-teaching, the actor-networks presented here are partial representations. Further research, both within and outside of a UK setting, is needed to gain an understanding of the role of the institution and wider cultural conceptions in these actor-networks. In addition, while four Social Science disciplines were investigated here, studying additional disciplines, particularly across Arts and Sciences, would enable these actor-networks, particularly the enrolment mechanisms and characterisation of QM(s), to be compared. Similarly, while this would give an understanding of QM(s) within Higher Education settings, further research could also use this approach to examine the performances associated with QM(s) at different educational levels – particularly of interest given the introduction of new syllabuses at GCSE and A-Level – allowing the nature of QM(s) to be understood through educational time(-spaces). Equally, further research is needed to identify those concepts, i.e. representativeness or bias, that are easily taken up by students that form their QM(s) mindset, which is transferred onto other kind of research methods. In drawing attention to this, QM(s) power in education and research settings can begin to be traced out. Finally – as touched up on Chapter 8 – by manipulating the actor-networks described here further studies could evaluate the potential for new configurations of QM(s) learning-teaching, and their abilities to offer new ways of enrolling students in valuing the questions QM(s) are able to assist with.

Overall, this thesis has made an empirical contribution to the field of quantitative methods learning-teaching working with ANT to examine the everyday performances of QM(s) across four Social Science disciplines. By examining these performances, this research has brought to light new non-human actors, such as worksheets, choice diagrams, correct answers, that have been previously overlooked within the literature – see Section 2.2. These actors serve to translate the character of QM(s) into one associated with passive following and obtaining correct answers, shifting attention away from the process of doing QM(s). Furthermore, through comparing different disciplines, data was found to be a powerful actor in controlling disciplinary narratives of the character and role of QM(s), with the use of survey data giving rise to a more partial and sceptical characterisation of QM(s). This account of the role of non-human actors within QM(s) learning-teaching provides a contribution to the growing body of research in educational contexts (Gorur, 2013; Fox, 2009; McGregor, 2004) arguing for the importance of studying these often overlooked, non-human actors.

Furthermore, through comparing the performances of QM(s) learning-teaching this research provides a response to calls for greater cross-disciplinary discussion of research methods (Wagner *et al.*, 2011), and exploration of interactions across, and outside of, module boundaries (Parker, 2011). In particular, the account of disciplinary differences in the characterisation of QM(s) presented within this thesis represents a serious challenge to the drive to identify, and implement, a universal best practice of QM(s) learning-teaching pedagogy. Acknowledging that, this thesis provides empirical evidence to support the calls for greater national and international cross-disciplinary discussion.

In addition to tracing through actors and their roles in QM(s) learning-teaching networks, this thesis also began to consider how the character of QM(s) is currently changing – a theme overlooked by the literature - and responding to attitudes towards quantitative material, rising student numbers and the growth of new techniques and data, and how the traced actor-networks may be manipulated to produced new understandings of QM(s), through reinforcing the link between QM(s), data, and theory.

Finally, this thesis contributes to methodological discussions surrounding the doing of ANT, illustrating how ANT can be successfully combined with Harvey's three spaces. Moreover, this thesis also provides a relatable account of working with ANT in an educational research setting, helping to, somewhat, demystify the process and provide strategies for the novice ANT researcher. On the whole, by challenging the assumptions made by the literature over the actors involved within QM(s) learning-teaching, the characterisation of space, the popularity of quantitative methodologies, and the lack of cross disciplinary analysis, this thesis provides an initial step in getting to know QM(s).

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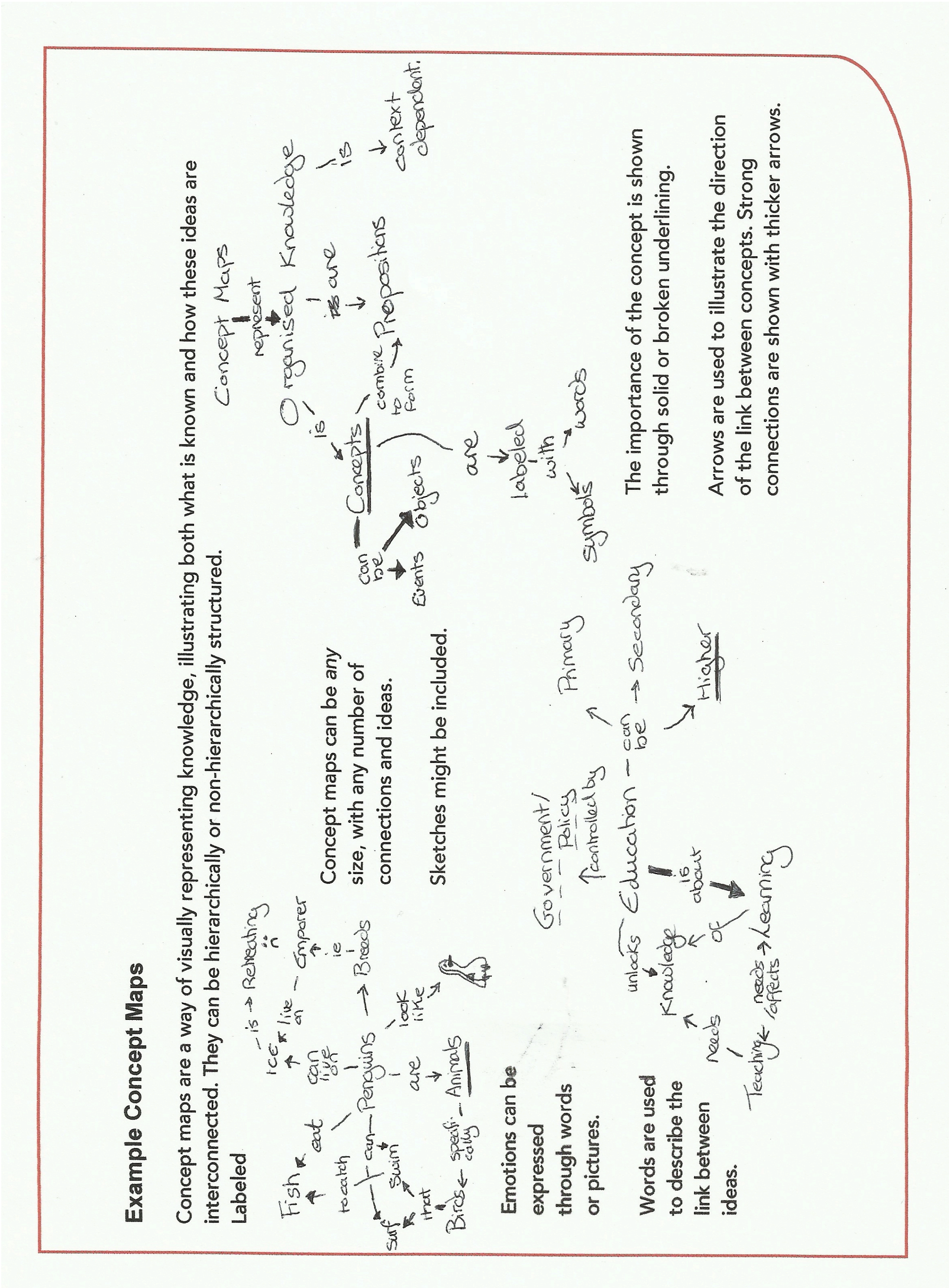
12 Appendices

12.1 Instruction sheet with example concept maps



Example Concept Maps

Concept maps are a way of visually representing knowledge, illustrating both what is known and how these ideas are interconnected. They can be hierarchically or non-hierarchically structured.

Labeled

Concept maps can be *any* size, with any number of connections and ideas.

Sketches might be included.

Emotions can be expressed through words or pictures.

Words are used to describe the link between ideas.

The importance of the concept is shown through solid or broken underlining.

Arrows are used to illustrate the direction of the link between concepts. Strong connections are shown with thicker arrows.

12.2 Interview Schedule

Lancaster University

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Interview Schedule

Initial Briefing:

- Description of what will occur within the session (background, drawing, concept map, unstructured chat around learning their discipline)
- Opportunity for any questions to be asked about the project.

Background:

- What is the specific degree program you're registered on?
- What modules have you taken as part of your degree?

Concept map:

- Explain use of concept map – gain an insight into their understanding
- Talk through of example concept map:
    - Anything can be included: concepts, applications/examples, emotions, textbooks.
    - Arrows & use of bold.
    - Not just words, so symbols can be included – sketches?
    - Use of connecting prepositions on arrows where needed, i.e. to explain link.
- Opportunity to ask any questions, clarify any issues.
- Hand out sheet and pen/pencil.
- 20 mins to draw concept map

Draw → talk / Draw → talk.

Unstructured discussion:

UG & PG

- "Can you talk me through the concept map?" Asking for clarity/further info where needed. If not included ask about:
    - What are the methods commonly used in this discipline?
    - What is the nature of this link? How strong is the link between quantitative methods (QM) and their discipline? What is the the relationship between them?
    - What is the role they play? How are they used?
    - Link to technology?
    - What are your experiences of learning/teaching QM? Encourage description of teaching/learning experiences.
    - What are you hoping QM will give you? How did you come to teach/study QM?
    - How has your thinking about QM changed since starting your degree?
- Brief summary of key points, to allow member checking.
- Turn off recorder
- "Is there anything else you want to bring up or ask about the interview?"

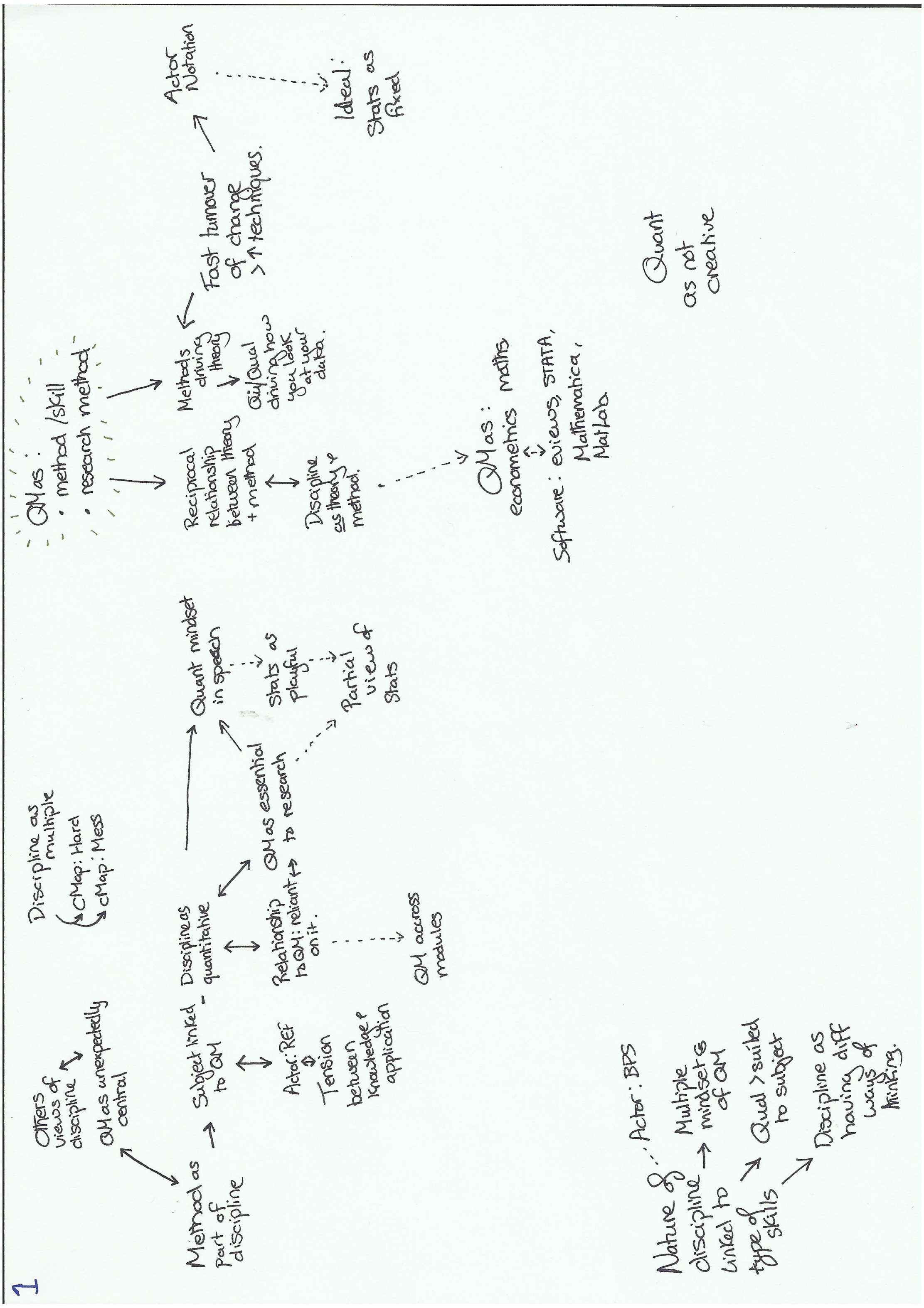
→ Kinds of methods
→ Where was QM in degree?
→ Other modules
→ Specific module: Structure/ Assessment/ Class size/ Notes/ Activities
→ Self

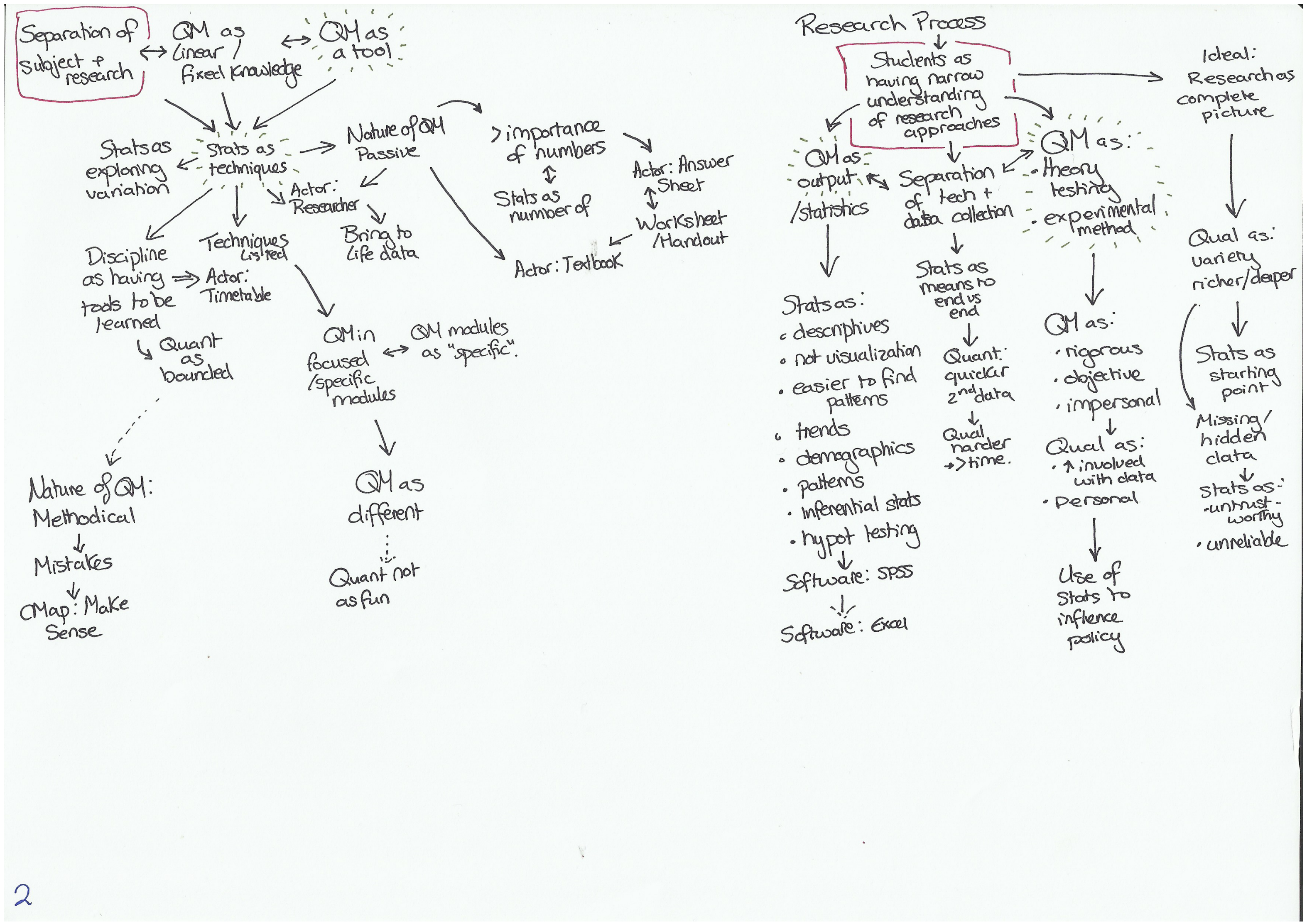
PhD
- Strength of link
- Experience
- Background
- Changes

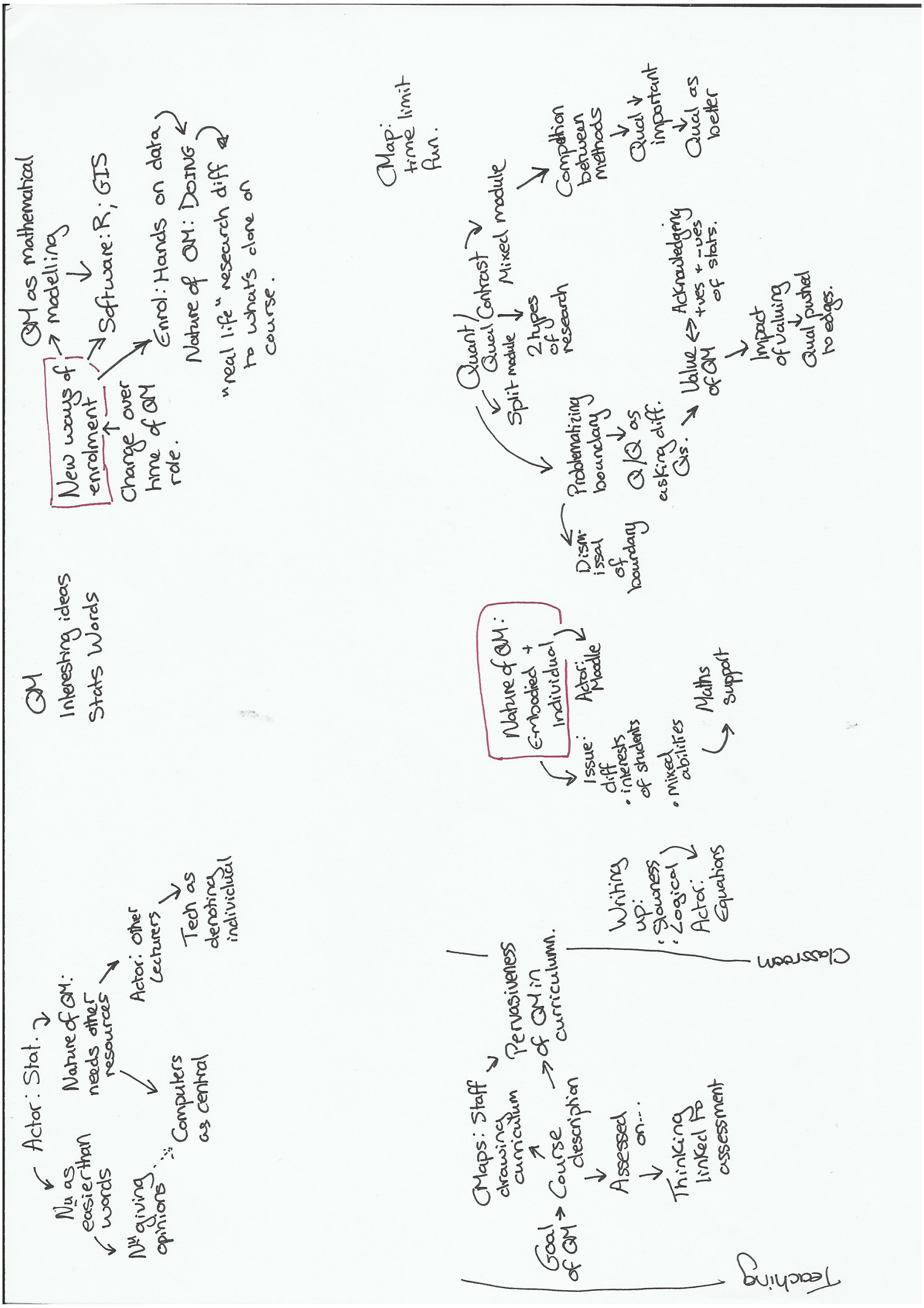
Staff
- Modules
- Observation Qs
- Nature of link & attitude towards QM.

Ask if any further questions. Highlight that any questions can be emailed to the researcher. Provide overview of study. Sign consent form. Thank them for their time.

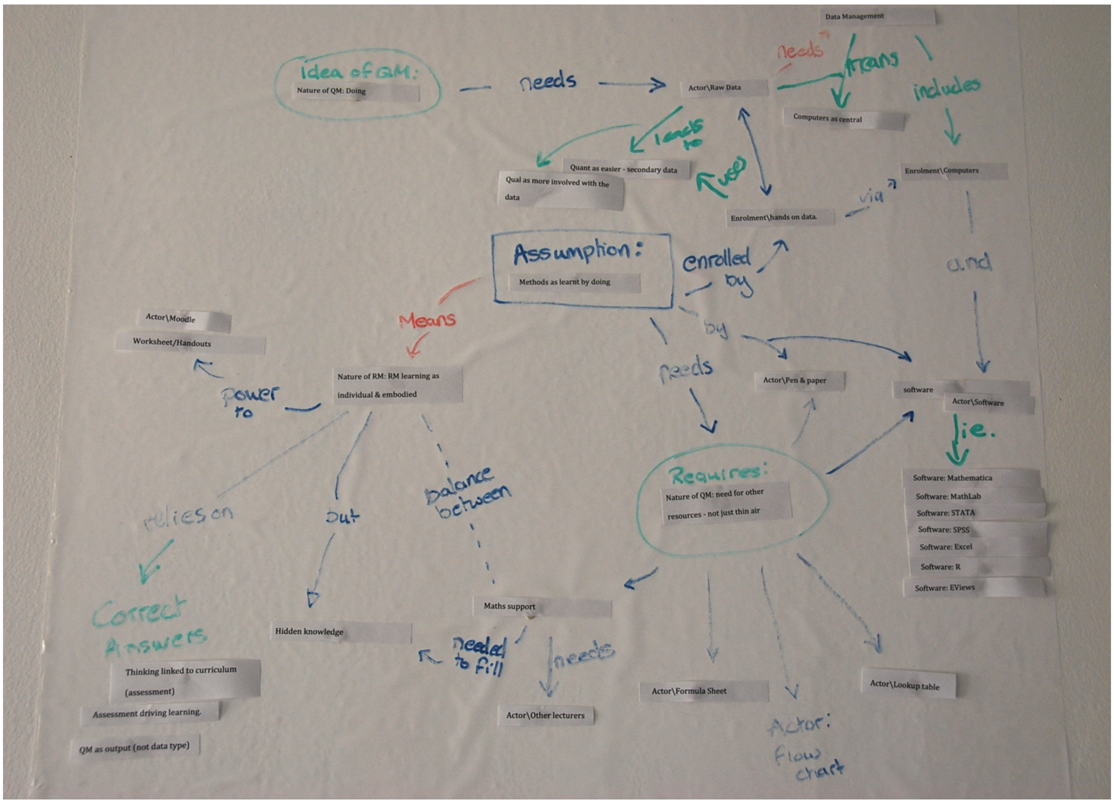
12.3 Initial trial overview diagrams constructed from early codes

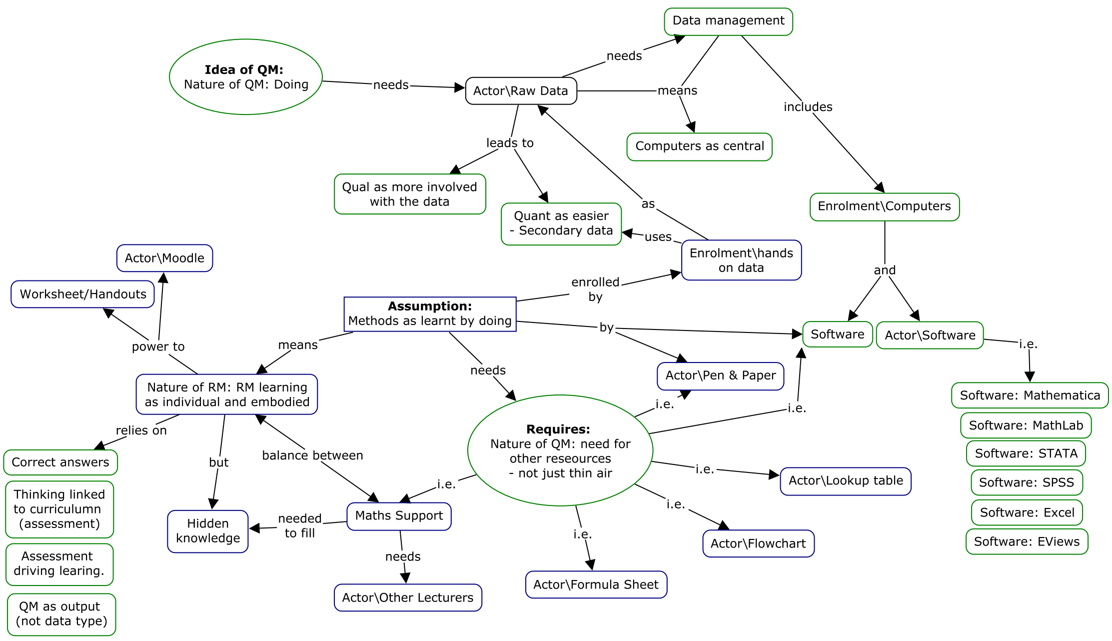


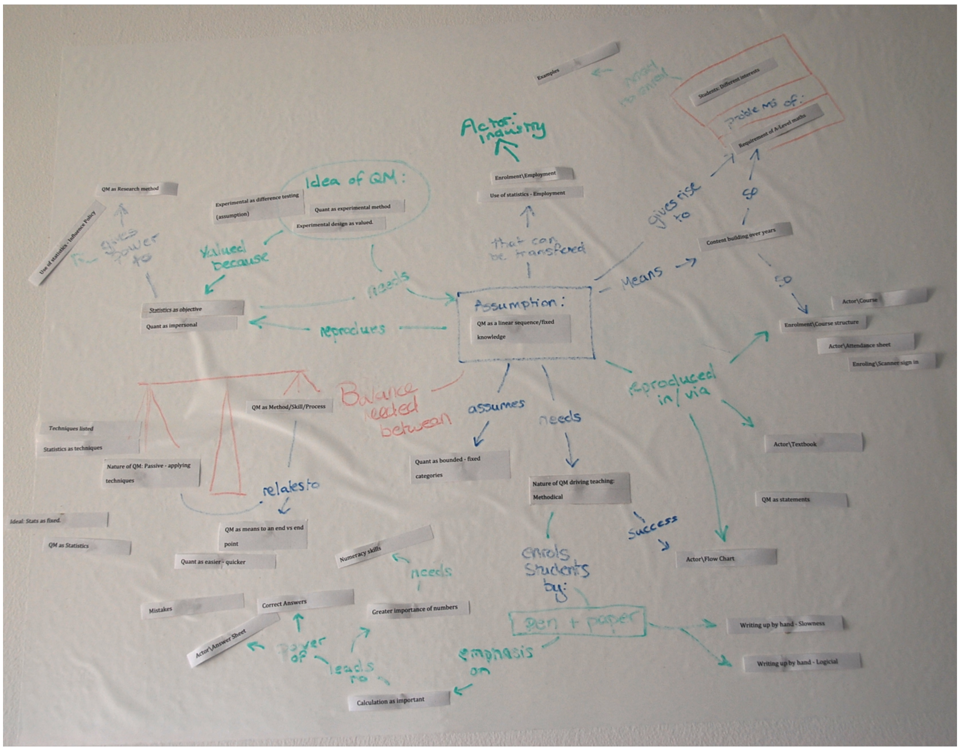

Separation of subject + research
QM as linear / fixed knowledge
QM as a tool
Stats as exploring variation
Stats as techniques
Nature of QM Passive
> importance of numbers
Stats as number of
Actor: Answer Sheet
Worksheet /Handout
Actor: Textbook
Actor: Researcher
Bring to life data
Techniques listed
Discipline as having tools to be learned
Actor: Timetable
Quant as bounded
QM in focused /specific modules
QM modules as "specific".
QM as different
Quant not as fun
Nature of QM: Methodical
Mistakes
CMap: Make Sense
Research Process
Students as having narrow understanding of research approaches
Ideal: Research as complete picture
QM as output /statistics
Separation of tech + data collection
QM as: theory testing - experimental method
Stats as: descriptives
not visualization
easier to find patterns
trends
demographics
patterns
inferential stats
hypot testing
Software: SPSS
Software: Excel
Stats as means to end vs end
Quant: quicker 2nd data
Qual harder > time.
QM as: rigorous
objective
impersonal
Qual as: ↑ involved with data
Personal
Use of Stats to influence policy
Qual as: variety richer/deeper
Stats as starting point
Missing/ hidden data
Stats as: untrustworthy
unreliable
2

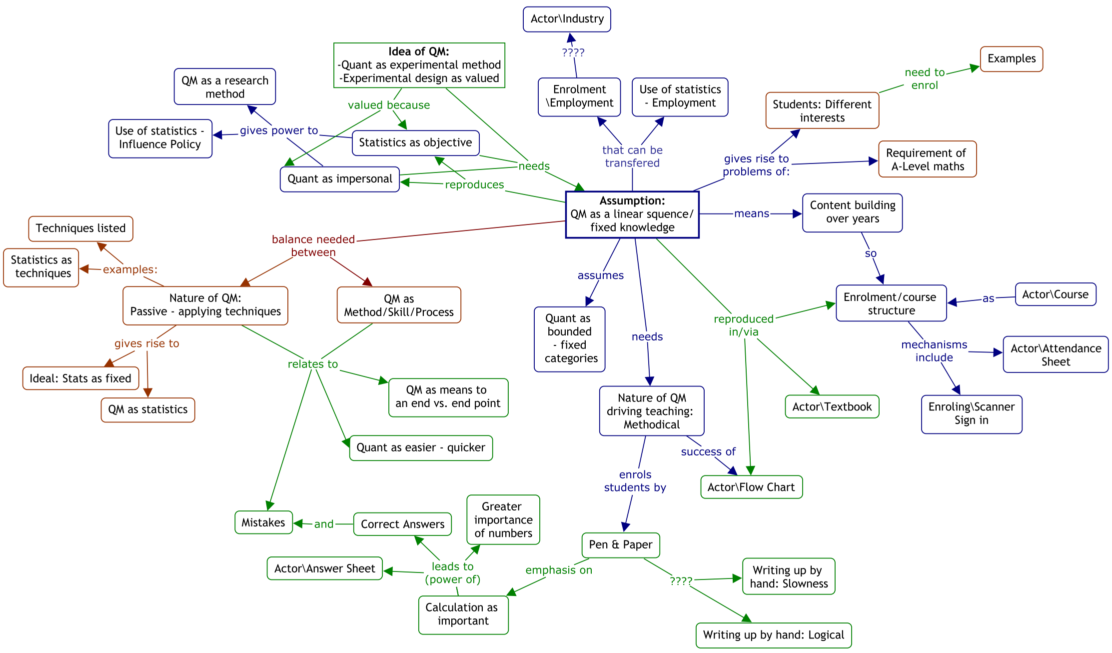

QM
Interesting ideas
Stats Words
QM as mathematical modelling
Software: R; GIS
New ways of enrolment
Change over time of QM role.
Enrol: Hands on data
Nature of QM: DOING
"real life" research diff to what's done on course.
Map: time limit fun.
Actor: Stat.
Nos as easier than words
No giving opinions
Nature of QM: needs other resources
Computers as central
Actor: other Lecturers
Tech as denoting individual
Nature of QM: Embodied + Individual
Actor: Moodle
Issue: diff
• interests of students
• mixed abilities
Maths support
Quant/Qual Contrast
Split module
Mixed module
2 types of research
Competition between methods
Qual important
Qual as better
Problematizing boundary
Q/Q as asking diff. Qs.
Dismissal of boundary
Value of QM
Acknowledging +ves + -ves of stats.
Impact of valuing
Qual pushed to edges.
CMaps: Staff drawing curriculum
Goal of QM
Course description
Assessed on...
Thinking linked to assessment
Pervasiveness of QM in curriculum.
Writing up: Slowness, Logical
Actor: Equations
Classroom
Teaching

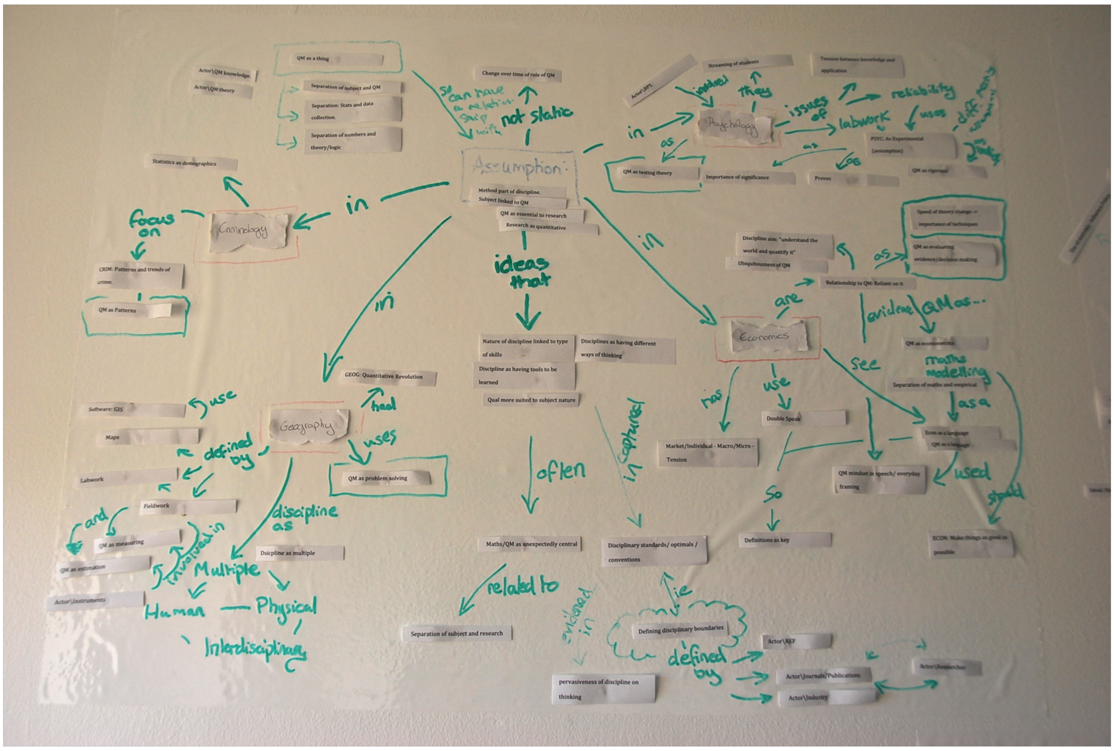
12.4 Concept maps developed from full list of codes



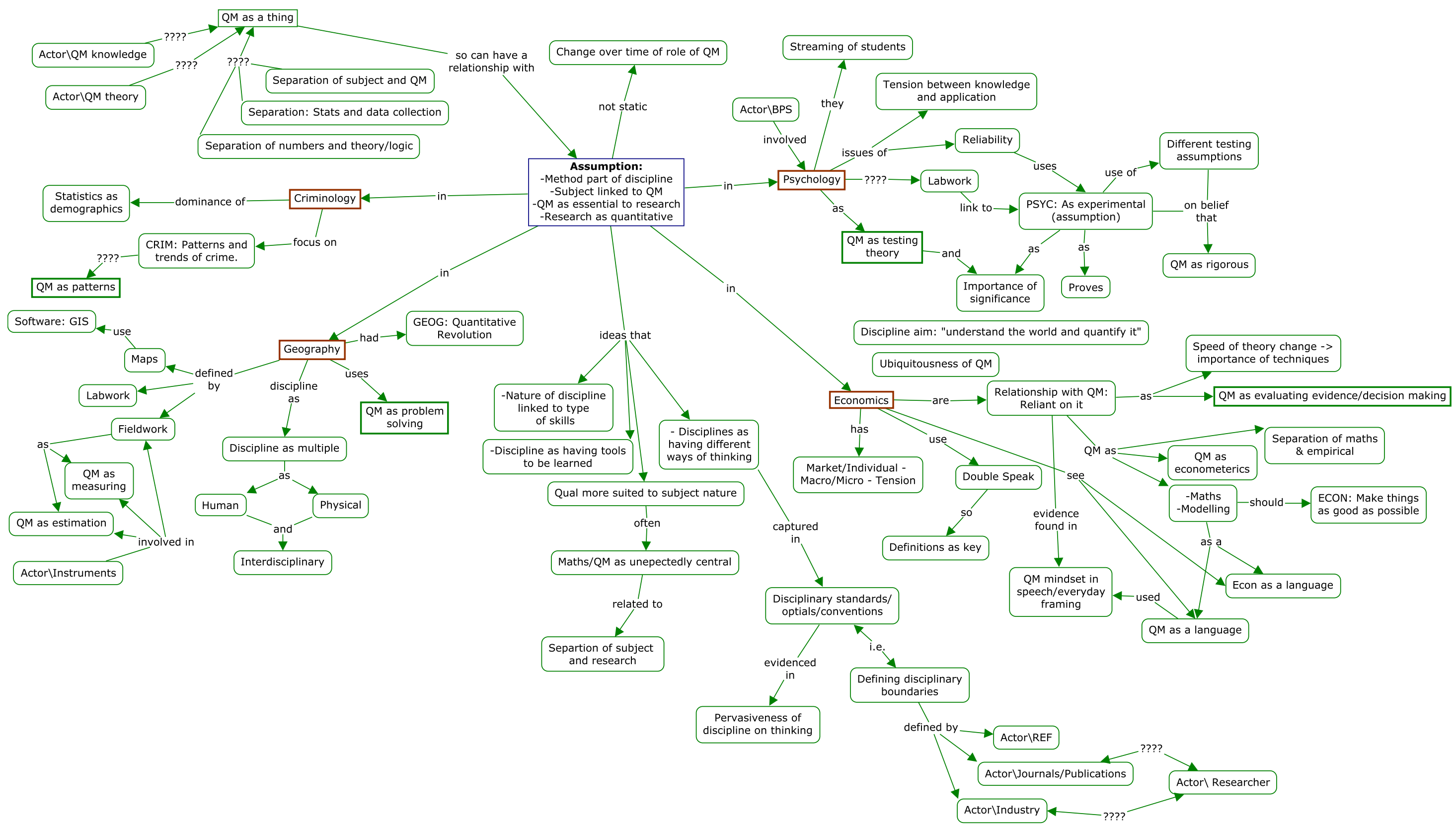


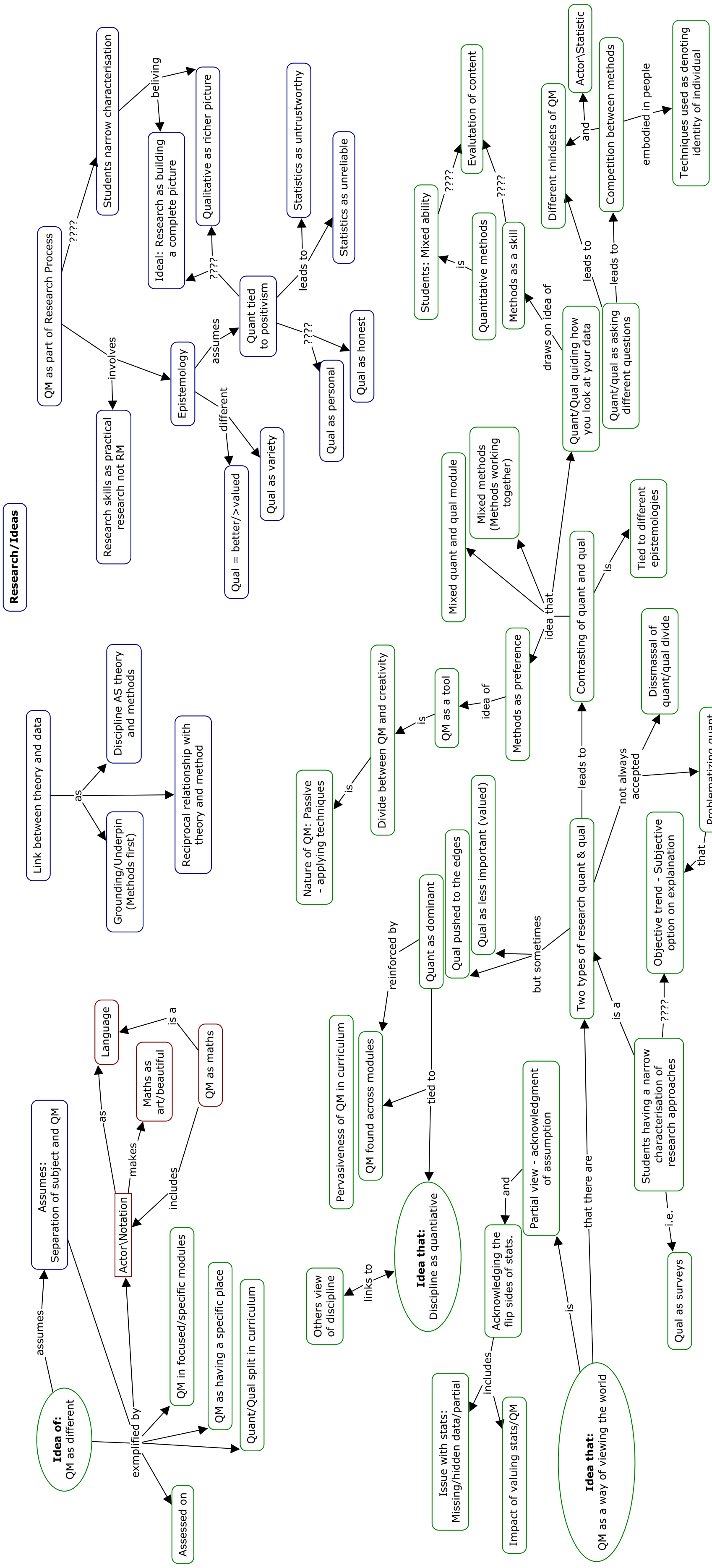



Actor\Industry
????
Idea of QM:
-Quant as experimental method
-Experimental design as valued
QM as a research method
Use of statistics - Influence Policy
gives power to
valued because
Statistics as objective
Quant as impersonal
needs
reproduces
Enrolment \Employment
Use of statistics - Employment
that can be transfered
Examples
need to enrol
Students: Different interests
gives rise to problems of:
Requirement of A-Level maths
Assumption:
QM as a linear squence/ fixed knowledge
means
Content building over years
so
Techniques listed
Statistics as techniques
examples:
balance needed between
Nature of QM: Passive - applying techniques
QM as Method/Skill/Process
gives rise to
Ideal: Stats as fixed
QM as statistics
relates to
QM as means to an end vs. end point
Quant as easier - quicker
Mistakes
and
Correct Answers
Greater importance of numbers
Actor\Answer Sheet
leads to (power of)
Calculation as important
emphasis on
assumes
Quant as bounded - fixed categories
needs
Nature of QM driving teaching: Methodical
enrols students by
Pen & Paper
????
Writing up by hand: Slowness
Writing up by hand: Logical
success of
Actor\Flow Chart
reproduced in/via
Actor\Textbook
Enrolment/course structure
as
Actor\Course
mechanisms include
Actor\Attendance Sheet
Enroling\Scanner Sign in

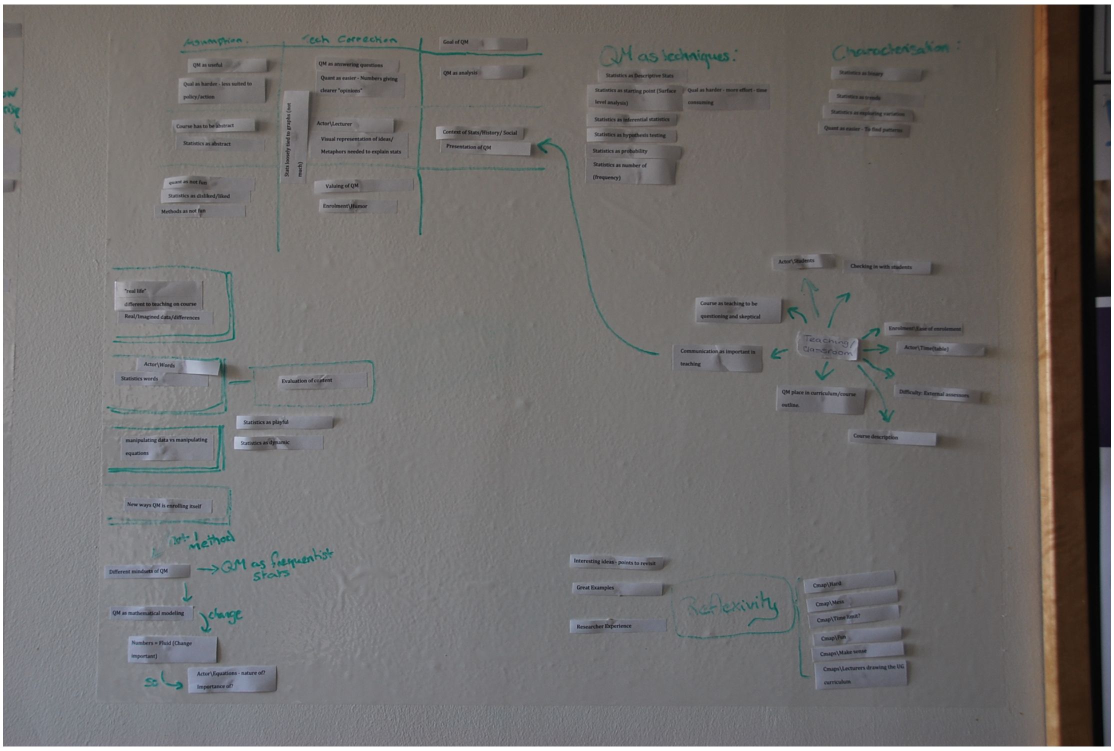


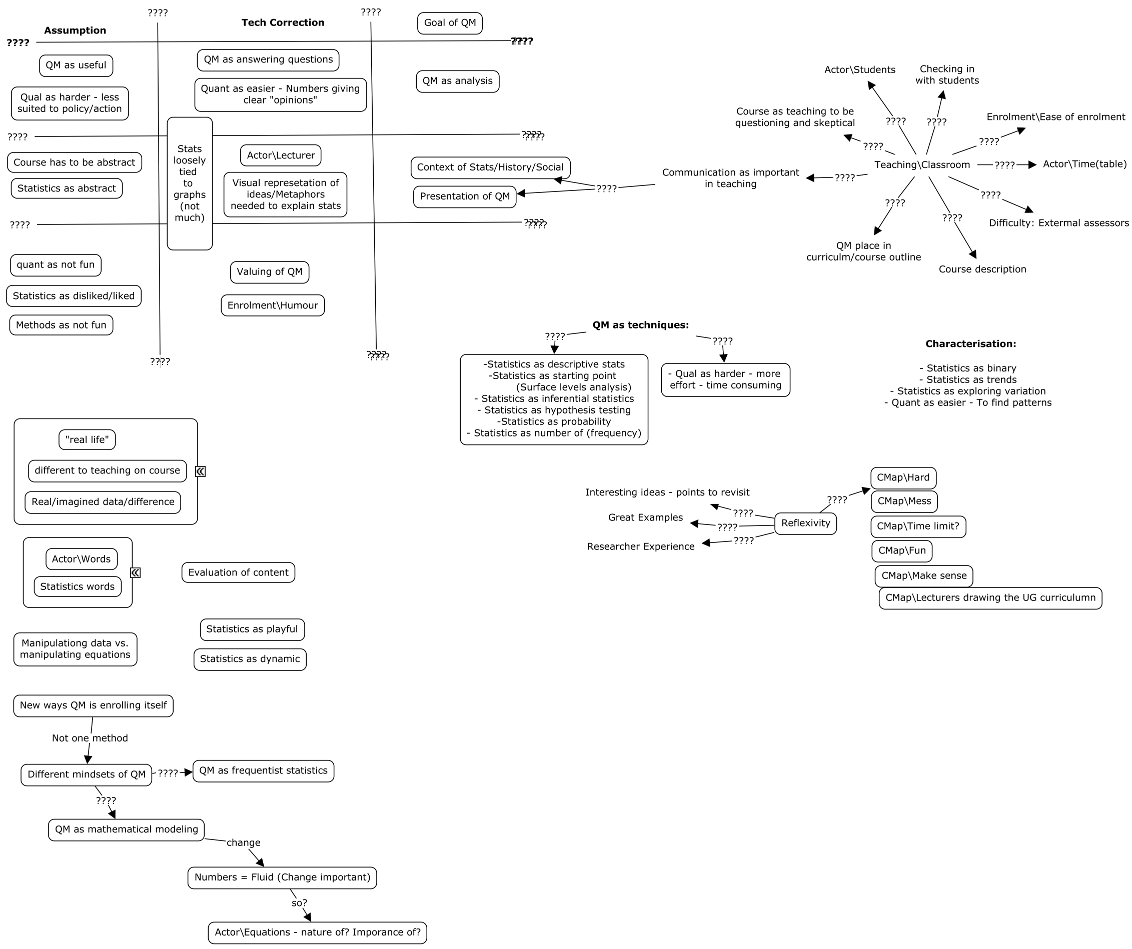
(see subsequent pages for redrawn versions)


Assumption:
-Method part of discipline
-Subject linked to QM
-QM as essential to research
-Research as quantitative
not static
Change over time of role of QM
so can have a relationship with
QM as a thing
????
Actor\QM knowledge
????
Actor\QM theory
????
Separation of subject and QM
Separation: Stats and data collection
Separation of numbers and theory/logic
in
Psychology
involved
Actor\BPS
they
Streaming of students
issues of
Tension between knowledge and application
Reliability
uses
????
Labwork
link to
PSYC: As experimental (assumption)
use of
Different testing assumptions
on belief that
QM as rigorous
as
Proves
as
Importance of significance
as
QM as testing theory
and
in
Criminology
dominance of
Statistics as demographics
focus on
CRIM: Patterns and trends of crime.
????
QM as patterns
in
Geography
had
GEOG: Quantitative Revolution
uses
QM as problem solving
discipline as
Discipline as multiple
as
Human
Physical
and
Interdisciplinary
defined by
Maps
use
Software: GIS
Labwork
Fieldwork
as
QM as measuring
QM as estimation
involved in
Actor\Instruments
ideas that
-Nature of discipline linked to type of skills
-Discipline as having tools to be learned
- Disciplines as having different ways of thinking
Qual more suited to subject nature
often
Maths/QM as unepectedly central
related to
Separtion of subject and research
captured in
Disciplinary standards/ optials/conventions
evidenced in
Pervasiveness of discipline on thinking
i.e.
Defining disciplinary boundaries
defined by
Actor\REF
Actor\Journals/Publications
Actor\Industry
????
Actor\ Researcher
????
in
Economics
Discipline aim: "understand the world and quantify it"
Ubiquitousness of QM
has
Market/Individual - Macro/Micro - Tension
use
Double Speak
so
Definitions as key
are
Relationship with QM: Reliant on it
as
Speed of theory change -> importance of techniques
QM as evaluating evidence/decision making
QM as
Separation of maths & empirical
QM as econometerics
-Maths
-Modelling
should
ECON: Make things as good as possible
as a
Econ as a language
see
QM as a language
used
evidence found in
QM mindset in speech/everyday framing



Research/Ideas
QM as part of Research Process
????
Students narrow characterisation
beliving
Ideal: Research as building a complete picture
Qualitative as richer picture
involves
Research skills as practical research not RM
Epistemology
assumes
Quant tied to positivism
????
leads to
Statistics as untrustworthy
Statistics as unreliable
????
Qual as personal
Qual as honest
different
Qual = better/>valued
Qual as variety
Link between theory and data
as
Grounding/Underpin (Methods first)
Discipline AS theory and methods
Reciprocal relationship with theory and method
Assumes: Separation of subject and QM
assumes
Idea of: QM as different
exmplified by
Actor\Notation
as
Language
makes
Maths as art/beautiful
includes
QM as maths
is a
QM in focused/specific modules
QM as having a specific place
Quant/Qual split in curriculum
Assessed on
Nature of QM: Passive - applying techniques
is
Divide between QM and creativity
is
QM as a tool
idea of
Methods as preference
Pervasiveness of QM in curriculum
QM found across modules
reinforced by
Quant as dominant
tied to
Idea that: Discipline as quantiative
links to
Others view of discipline
Qual pushed to the edges
Qual as less important (valued)
but sometimes
Two types of research quant & qual
leads to
Contrasting of quant and qual
idea that
Mixed quant and qual module
Mixed methods (Methods working together)
is
Tied to different epistemologies
Quant/Qual guiding how you look at your data
draws on idea of
Methods as a skill
Quantitative methods
is
Students: Mixed ability
????
????
Evalutation of content
Quant/qual as asking different questions
leads to
leads to
Different mindsets of QM
and
Actor\Statistic
Competition between methods
embodied in people
Techniques used as denoting identity of individual
not always accepted
Dissmassal of quant/qual divide
Problematizing quant and qual boundary
that
Objective trend - Subjective option on explaination
????
is a
Students having a narrow characterisation of research approaches
i.e.
Qual as surveys
that there are
Idea that: QM as a way of viewing the world
is
Partial view - acknowledgment of assumption
and
Acknowledging the flip sides of stats.
includes
Issue with stats: Missing/hidden data/partial
Impact of valuing stats/QM


QM as techniques:
Characterisation:
Reflexivity


Assumption
Tech Correction
Goal of QM
????
QM as useful
Qual as harder - less suited to policy/action
QM as answering questions
Quant as easier - Numbers giving clear "opinions"
QM as analysis
Course has to be abstract
Statistics as abstract
Stats loosely tied to graphs (not much)
Actor\Lecturer
Visual represetation of ideas/Metaphors needed to explain stats
Context of Stats/History/Social
Presentation of QM
quant as not fun
Statistics as disliked/liked
Methods as not fun
Valuing of QM
Enrolment\Humour
Actor\Students
Checking in with students
Course as teaching to be questioning and skeptical
Enrolment\Ease of enrolment
Communication as important in teaching
Teaching\Classroom
Actor\Time(table)
Difficulty: Extermal assessors
QM place in curriculm/course outline
Course description
QM as techniques:
-Statistics as descriptive stats
-Statistics as starting point (Surface levels analysis)
- Statistics as inferential statistics
- Statistics as hypothesis testing
-Statistics as probability
- Statistics as number of (frequency)
- Qual as harder - more effort - time consuming
Characterisation:
- Statistics as binary
- Statistics as trends
- Statistics as exploring variation
- Quant as easier - To find patterns
"real life"
different to teaching on course
Real/imagined data/difference
Actor\Words
Statistics words
Evaluation of content
Manipulationg data vs. manipulating equations
Statistics as playful
Statistics as dynamic
Interesting ideas - points to revisit
Great Examples
Researcher Experience
Reflexivity
CMap\Hard
CMap\Mess
CMap\Time limit?
CMap\Fun
CMap\Make sense
CMap\Lecturers drawing the UG curriculumn
New ways QM is enrolling itself
Not one method
Different mindsets of QM
QM as frequentist statistics
QM as mathematical modeling
change
Numbers = Fluid (Change important)
so?
Actor\Equations - nature of? Imporance of?

12.5 Breakdown of documents gathered from each discipline

Affiliation	Documents[1] gathered (n)
Criminology	6
Economics	16
Geography	22
Psychology	20
Total:	64

[1]Included: Lecture slides, handouts, exams, coursework guidelines questionnaires, screenshots, module handbooks, programme handbooks, module evaluations.

12.6 Maximum credits allocated to compulsory QM(s) modules across undergraduate degrees

Department	Credits allocated by UG programme year[1]				Total	% of degree
	Year 1	Year 2	Year 3	Year 4		
Criminology	40	60	0	0	100	27.8
Economics	40	30	0	0	70	19.4
Geography						
BSc	40	45	0	0	85	23.6
BA	40	60	0	0	100	27.8
Psychology	40	30	0	0	70	19.4

[1]Note: This is the total credits for each compulsory module containing any QM(s) content, including modules where QM(s) content was taught alongside other skills or disciplinary knowledge. Content included in option modules is excluded.

12.7 Terms listed on participants' concept maps

(20 concept maps out of 33 listed terms on original maps)

Words	Frequency on original concept map	Frequency on redrawn concept map
Statistical Significance	0	1
Text Analysis	0	1
Balance Sheets	1	1
Census	1	1
Data handling	1	1
Data Collection	1	1
Demographics	1	1
Empirics	1	1
Frequency	1	1
Predictive	1	1
Questionnaires	1	1
Reports	1	1
Satellite Imagery	1	1
Simulations	1	1
Spatial Science	1	1
Stats tests	1	1
Time Series	1	1
Turnovers	1	1
Data analysis	2	2
Laboratory work	2	2
Models	2	2
Numbers	2	2
Crime Statistics	3	3
Descriptive Statistics	3	3
Econometrics	3	3
GIS	3	3
Maths	3	3
Surveys	3	3
Experiments	4	4
Hypothesis testing	4	4
Statistics	5	5

12.8 Example worksheets and handouts – Geography and Psychology

Workshop handout/question sheet from 1st year UG workshop, extra QM(s) module, Geography

[redacted] Errors and Uncertainty

1. Convert the following absolute errors in to relative errors:

a. 27.3 ± 7.1 **b.** $5.0\times10^{11} \pm 3.2\times10^{10}$ **c.** 0.142385 ± 0.000010 **d.** $9.17\times10^{-3} \pm 1.4\times10^{-3}$

2. Convert the following relative errors in to absolute errors:

a. 27.3 ± 11% **b.** 5.0×10^{11} ± 18% **c.** 0.142385 ± 0.3% **d.** 9.17×10^{-3} ± 54%

3. In an emergency you measure the volume of spilt diesel fuel using a graduated bucket accurate to ± 0.2 litre. You measure volumes of: 2.1, 4.3, 1.9, 3.4, 3.9 and 0.4 litre.

a. What is the total volume measured together with the absolute and relative error.

b. You bucket has a 5.0 litre capacity, how may you minimise the measurement error, and what is the minimum error in this case.

4. The velocity (*V*) of a cricket ball is measured at 161 ± 5 km/h, a world record! The mass (*M*) of a cricket ball must be 159.45 ± 3.55 g. Calculate the kinetic energy (*K*, in Joules) of the fastest cricket ball (about the same muzzle energy as a .22LR bullet.), estimating uncertainty, remembering SI units.

$$K = \frac{MV^2}{2}$$

5. During a sustained volcanic eruption the magma volumetric flow-rate, Q (m^3/s), for a collapsing volcanic fountain is estimated from:

$$Q = \frac{g^{*2} H_f^4}{11.71 u^3}$$

where g^* is effective gravity (m/s^2), H_f is measured fountain height (m) and u is the exit velocity(m/s) of the volcanic jet from the vent.

a. Is this equation dimensionally correct?

One specific set of measurements gives:
H_f = 800 m, g^* = 8 m/s^2, u = 150 m/s.

The associated uncertainties on these measurements are estimated as:
δH_f = 70 m, δg^* = 2 m/s^2, δu = 20 m/s.

b. Evaluate Q and δQ.

c. Comment on the difficulties of making measurements of natural environmental processes and the consequences of these difficulties on measurement uncertainty.

Workshop handout/worksheet from 2nd year UG practical, QM(s) module, Psychology (two pages)

[redacted] **Seminar: Week 1**

Becoming Familiar with the Binomial and Goodness of Fit Chi-square Tests

Aims

This week's class is designed to [1] familiarise you with categorical data analyses; [2] enable you to think about how they work; and [3] get you familiar with applying the tests without the aid of computers. Performing statistical analyses by hand is a neat way of overcoming a fear of numbers and in achieving the second aim above. In the exam I will expect you to be able to remember a few key procedures and be able to apply them – as we shall see next week there are different types of chi-square tests and each has an appropriate use.

Exercise 1:

Matt Armitage has conducted an experiment in which he has tested university students' abilities to choose which of two hands he has hidden a coin. Matt finds that students divide into two groups – those that can select the correct hand and those that do not. In a sample of 50 Matt finds that 31 succeed while the rest fail. Your task is to perform the following tests:

[1] Calculate the binomial probability of finding 31 successes out of 50, assuming that Matt expected to find an equal proportion of students who succeed and those that fail. Do it in two different ways:

- With the standard calculation

$$Z = \frac{X - Np}{\sqrt{Npq}} = \frac{\_\_\_\_ - \_\_\_\_}{\sqrt{\text{-----} \times \text{-----} \times \ldots}} = \text{------------------} = \_\_\_\_\_\_\_\_$$

[for those of you without a suitable calculator, the square root of 12.5 is 3.54, but how did I get there?]

- With the calculation involving the following correction [do you remember why the correction was made?]

$$Z = \frac{(X\text{-}.5) - Np}{\sqrt{Npq}} = \frac{\text{------} - \text{------}}{\sqrt{\text{-----} \times \text{-----} \times \ldots}} = \text{------------------} = \_\_\_\_\_\_\_\_$$

Look up the tables for the significance of Z. Try to work how to read these and call a tutor over either to explain what you think the data suggest or to ask how you read the table. There's a catch to the table – so beware.......

[2] Construct a table in which you show the observed and expected frequencies of successes and failures. Calculate a goodness of fit chi-square: Obs_1______ Obs_2_________

$$X^2 = \frac{(O_1 - E_1)^2}{E_1} + \frac{(O_2 - E_2)^2}{E_2} = \frac{(\_\_ - \_\_)^2}{\_\_\_\_} + \frac{(\_\_ - \_\_)^2}{\_\_\_\_} =$$

How Many degrees of freedom are there? ______ What's the formula to calculate df? ______

Compare the results of the binomial test and chi-square. What do you conclude?

Exercise 2:

A variant of this example is taken from Siegel & Castellan's book Nonparametric Statistics (pages 47-48) if you need to check your answer or to reconsider the way in which the inferential argument is constructed using chi-square. He raises the example of a circular horse track in which there are 8 lanes. The aim is to test whether running on an inside or outside lane has an advantage. The following table presents the results of a series of observations of 144 races. Here are the winners' starting lanes. Your first task is to fill in the expected frequencies:

	Starting 'posts' [gates?] of the horses								
	1	2	3	4	5	6	7	8	TOTAL
Number of wins (Obs)	**29**	**19**	**18**	**25**	**17**	**10**	**15**	**11**	**144**
Expected Frequencies									

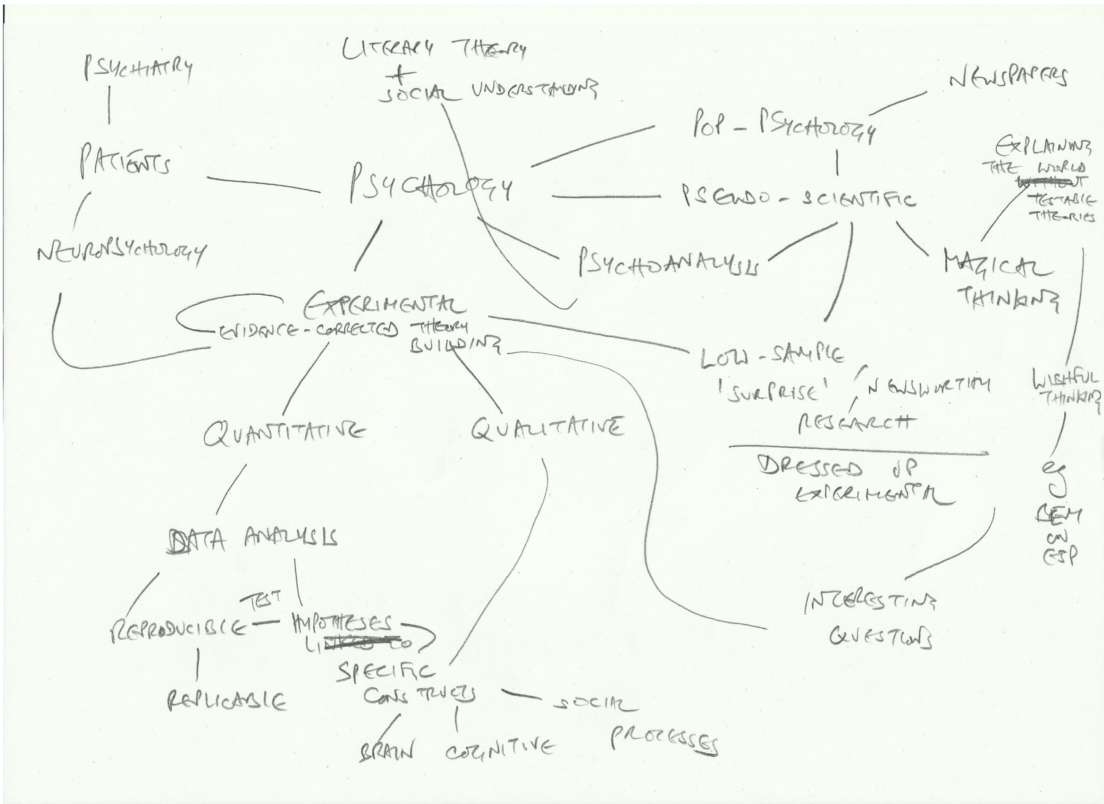
Calculate a chi-square value for each cell and add them:

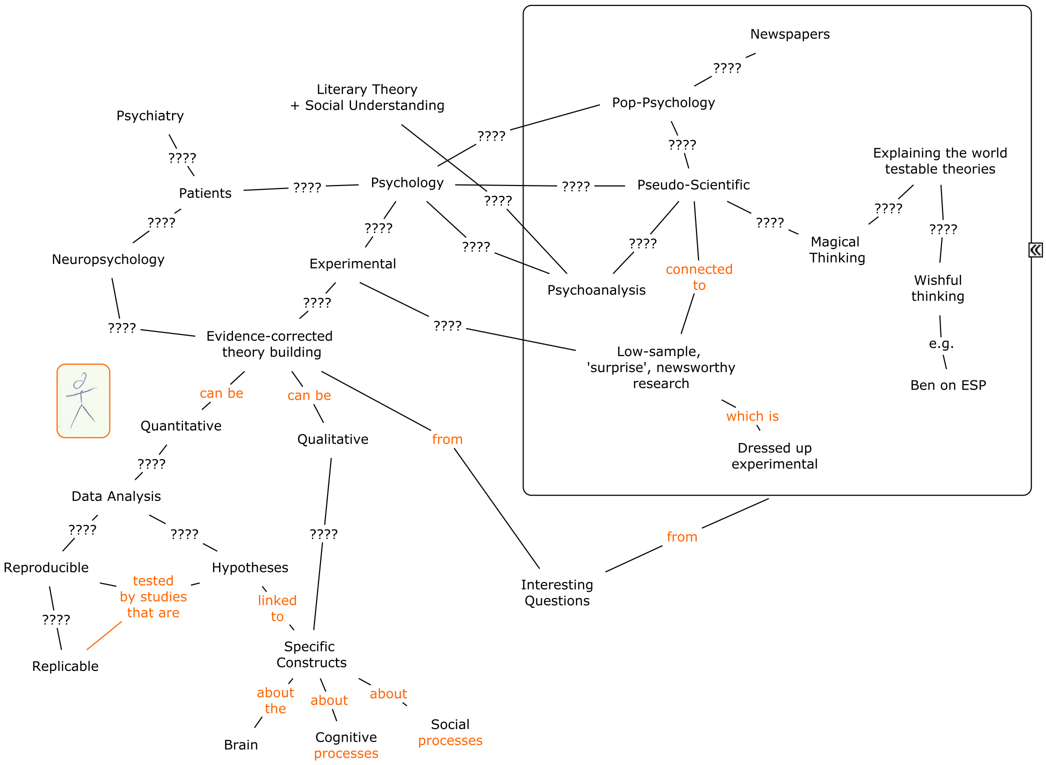
Total chi-square value =

What are the degrees of freedom?

Look back at the table. What can you conclude from this calculation of chi-square? Summon a tutor and discuss your result….

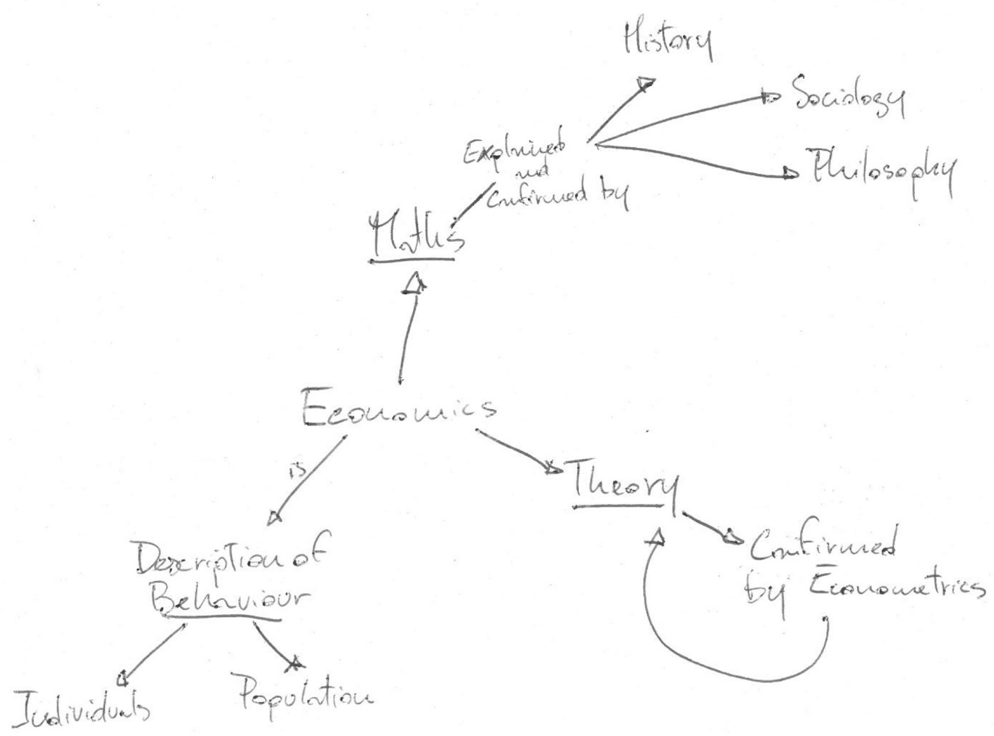
12.9 Original and redrawn concept map drawn by Mark

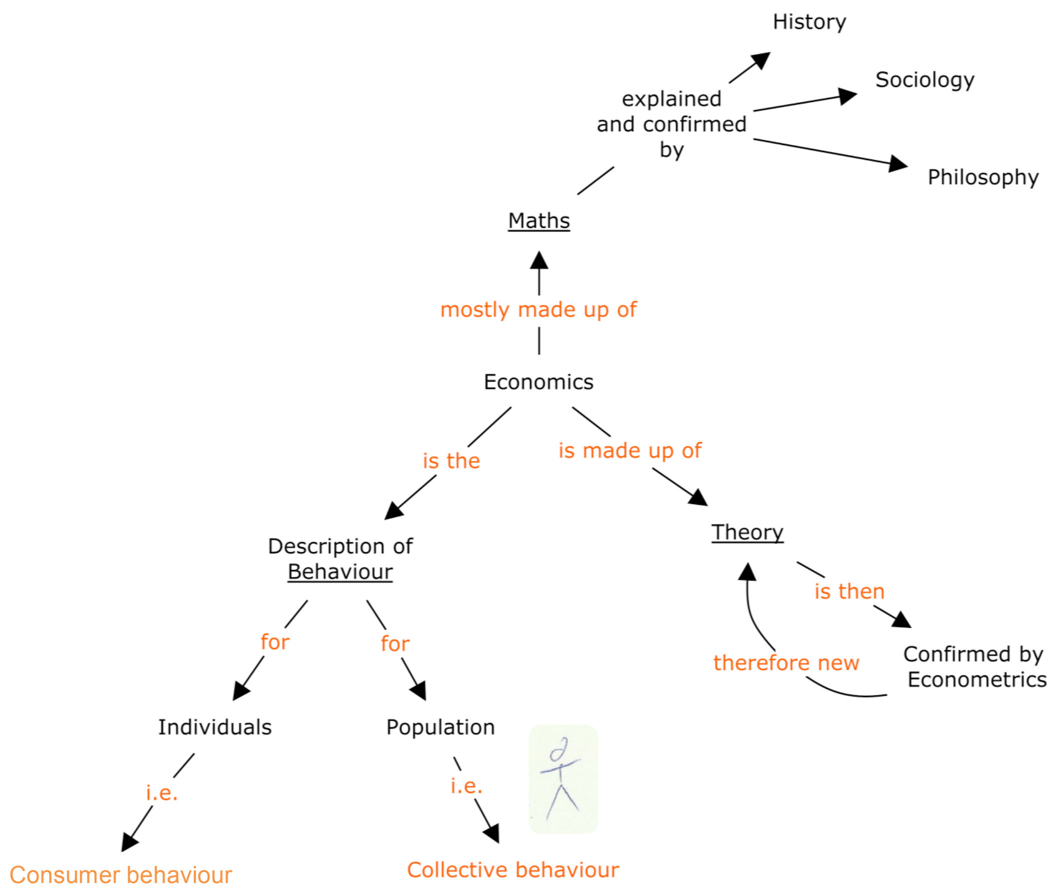




(Original and redrawn concept maps drawn by staff member, Psychology – Mark)

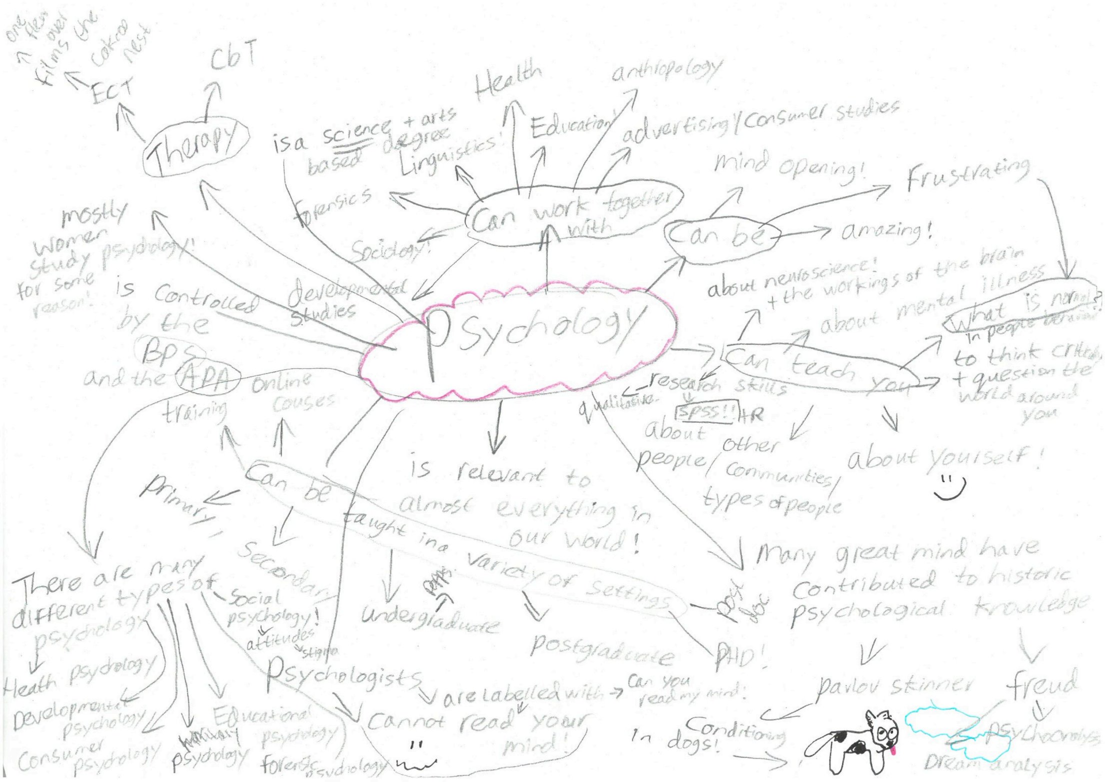
12.10 Example of a concept map with few nodes

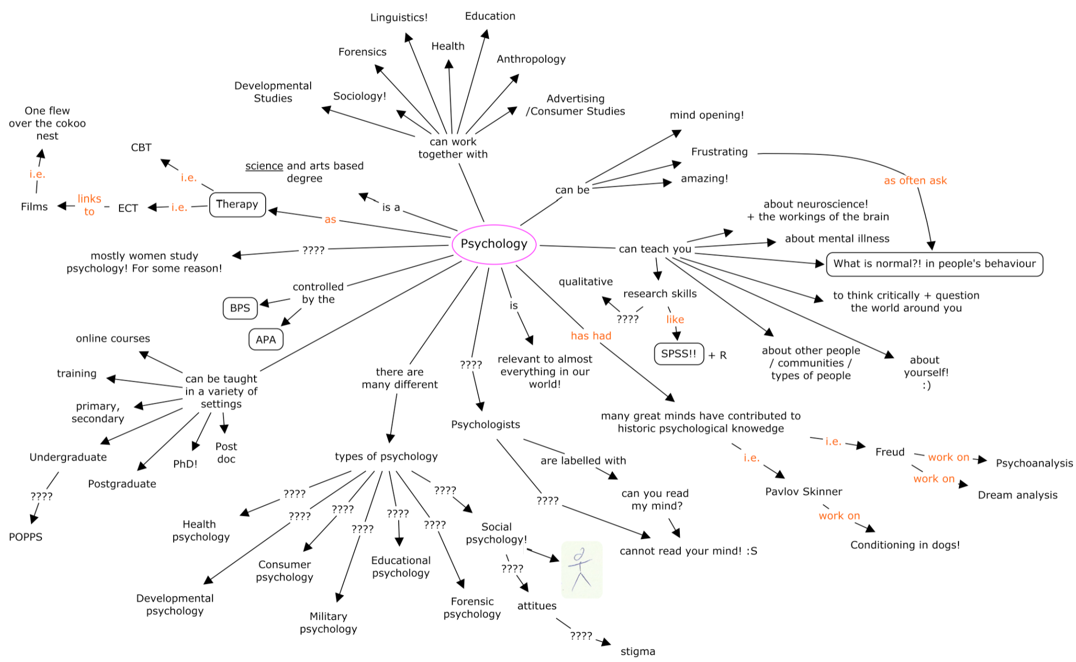




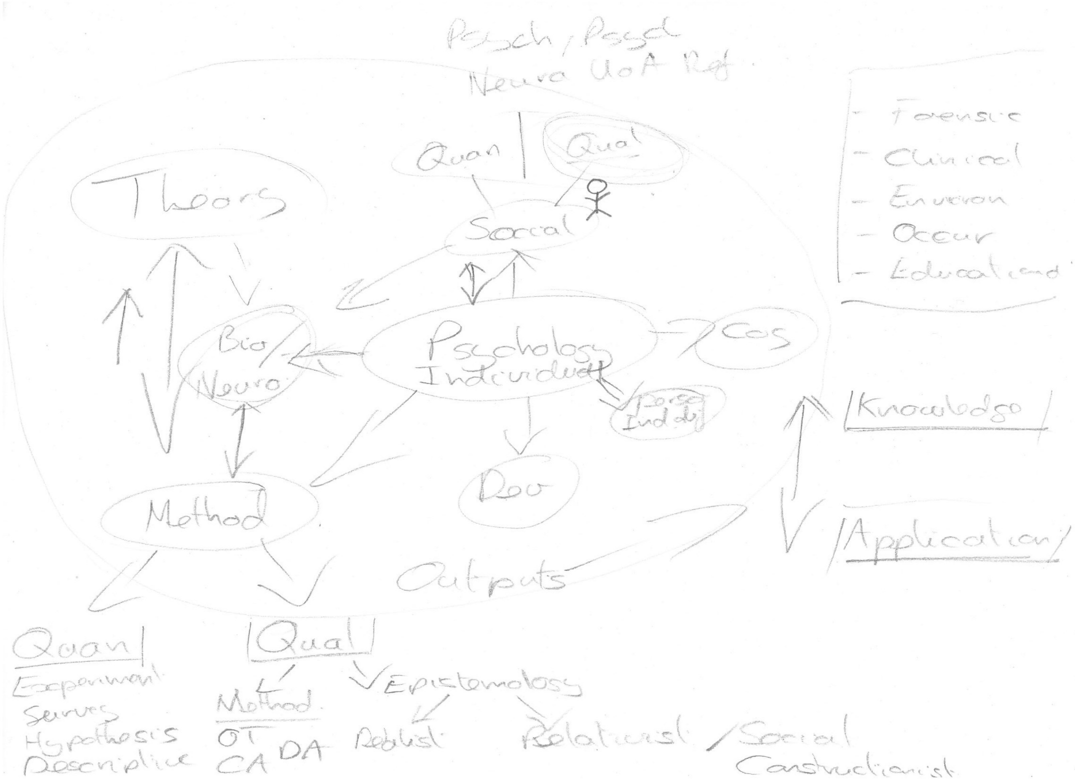
(Original and redrawn concept maps drawn by 2nd year UG student, Economics – Antonio)

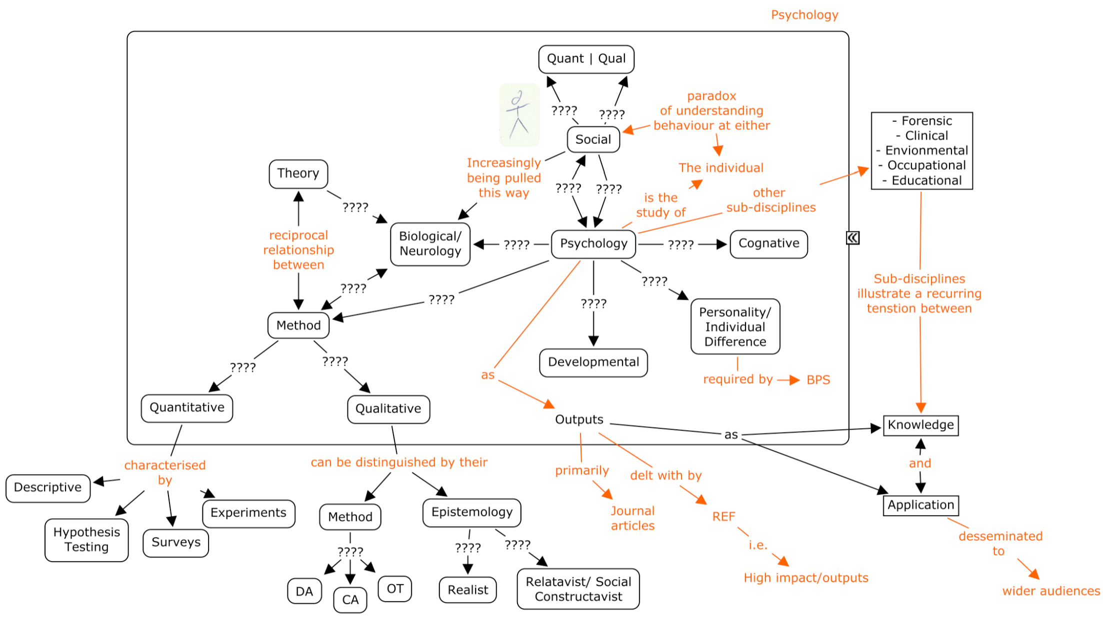
12.11 Example of two concept maps with denser structure





(Original and redrawn concept maps drawn by a Master's student, Psychology – Flora)





(Original and redrawn concept map drawn by staff member, Psychology – Tristan)