CHAPTER 3

THE DEVELOPMENT OF A RESEARCH PLAN

3.1 INTRODUCTION

This chapter describes the events and issues that have led to the current educational environment in which quantum mechanics is taught, and describes the research setting and the preliminary research project plan. The philosophical and methodological perspectives that influenced the design and analysis phases, and guided the researcher in exploring the links between the social environments and the conceptual physics aspects of the research questions, are then discussed.

A detailed description of the research tools employed in the study, and the fully developed research plan, complete the chapter.

3.2 EDUCATIONAL ENVIRONMENT

This study is concerned with student learning in the area of quantum mechanics. As highlighted in Chapter 2, research seeking to understand how students learn quantum mechanics has only recently been conducted, and the majority of published work has focused on teaching specific ideas and concepts. As a discipline, quantum mechanics is continually undergoing change as educational systems and student expectations are changing, and new technologies are increasingly underpinned by the concepts of quantum mechanics.

The contemporary educational environment is quite different from when quantum mechanics was first formulated in the early 1900s, necessarily affecting the learning process. The development of quantum mechanics as a distinct discipline took 30 years, and the scientists who formulated it were guided by a series of unanswered questions raised by unexplained experimental findings. Physicists, themselves highly skilled analytical mathematicians, debated and refined theories which were based on contentious philosophical and mathematical principles. These debates were regularly reported in newspaper articles worldwide, and therefore any student who studied the material during and soon after this period did so in the context of discussing a contemporary and immediately relevant issue.
As G.P. Thomson remarked during a lecture at a Symposium on the History of Modern Physics in 1961:

"It is difficult for a young physicist ... to realise the state of our science in the early 1920s ... it was not just that the old theories of light and mechanics had failed. On the contrary. You could say that they had succeeded in regions to which they could hardly have expected to apply, but they succeeded erratically. ... And over the whole subject brooded the mysterious figure of h." (French and Taylor, 1990)

During the succeeding 60 years, quantum mechanics has become an accepted and successful theory, no different to any other topic in the current undergraduate curriculum. However, the social context in which this material is being learned has significantly changed. Even though, the subject is still not completely understood, it is no longer the grand intellectual challenge it seemed to be in the 1920s. Arguments and discussions concerning quantum mechanics presented in popular science books and articles are lacking in curricula, and texts seldom dwell upon such discussions. The links between philosophy and quantum mechanics are sparse and only briefly discussed in the senior years of undergraduate studies and are generally presented as digressions during lectures.

Consequently, modern students are expected to learn quantum mechanics in a social context similar to that which prevails in our secondary schools, where students are required to encode the “approved” or “censored” information that is presented to them in compartmentalised chunks.

Brousseau (1992) suggests that a conceptual shift occurs when knowledge is “taught” in courses at educational institutions separated from the context of activity where the knowledge first evolved. He states that:

"The effort made in order to obtain knowledge independently of situations where it works (decontextualisation) has as a price the loss of meaning and performance at the time of teaching. The restoration of intelligible situations (recontextualisation) has as a price the shift in meaning (didactical transposition).” (Brousseau, 1992)

The conceptual shift described by Brousseau is of particular significance to this investigation. It is submitted that the process involving the loss of meaning during teaching could be closely linked to the inherent difficulty encountered by students studying the subject.
In traditional teaching settings, in which a transmission model of learning is frequently adopted, a student’s “success” is measured by accurately encoding and reproducing information on demand for assessment tasks. In this context “success” for teachers lies in facilitating these processes. Whereas “success” in professional or research settings, equates to an ability to appropriately apply concepts and principles, knowledge is gained through experience in troubleshooting and problem solving, and this can then be applied in the interpretation, definition and resolution of related problems.

The social context for learning physics in undergraduate courses at university is similar in many ways to that present in secondary schools. Course designers tend to compartmentalise the learning content, divorcing that part of the subject which the scientific community has agreed upon. Tertiary textbooks and lectures, particularly in the earlier years, provide “correct” information1.

For assessment purposes, students are required to demonstrate that they have encoded the information accurately, can reproduce essential facts and ideas in examinations and can apply physical models to solve problems. Such an educational context favours cognitive processes associated with encoding and reproducing information. It is not conducive to reflection and review, nor to the construction of personal meanings that are necessary to develop new concepts or a new schematic lens through which to interpret the physical world. Assessment tasks usually assume an absolutely correct answer, even though the scientific mental models that are the focus of study are constantly under review.

Successful learning is measured in terms of correctly completed assessment tasks that demonstrate a “correct” interpretation of the course “content”. These tasks traditionally involve paper and pencil activities that are completed under pressure of time2. Teachers of physics at university level, even those actively researching in the field, come to view well established topics in terms of their experience as providers of information — decision making about the best textbook to use, how best to convey key ideas to groups of students and how to check that

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1 For example, in two undergraduate texts; (Young (1992) and Hecht (2000)) only the Copenhagen interpretation of quantum mechanics is presented without any hint that alternative interpretations exist and continue to be debated.

2 At the School of Physics, University of Sydney between 50% and 90% of a student’s assessment is by formal written examination.
students “understood” the material. In such a context, “difficulty” is noticed when students are unable to perform assessment tasks. When many students are unable to complete the tasks according to teacher expectations of “correctness”, the topic or physical concepts are then considered to be difficult.

Quantum mechanics is a good example of a field where students experience this kind of difficulty. Learning about quantum mechanics involves a fundamental reconceptualisation, or shift in intellectual activity, in many different areas. In thinking about quantum mechanics students must move beyond models based on sensory experience towards models that encapsulate theoretical sets of abstract properties. It may be expected that if the context of learning does not promote the kinds of activity that foster conceptual development and personal involvement in meaning making and remaking, then students will fail to develop adequate mental models as a basis for reasoning, researching and problem solving in this field.

A final feature of the educational environment is the mismatch between the progression of the mathematics courses and the levels of mathematics required to successfully undertake more advanced quantum mechanics courses. Generally in intermediate university physics courses a substantial portion of the introductory lectures in quantum physics deal with mathematical techniques that are required to solve problems in quantum mechanics. For example, linear algebra, calculus of many variables and the concept of an operator generally form the basic tool set. Although these mathematical tools are taught in the standard second and third year options in the School of Mathematics they are considered advanced techniques and are therefore presented later in their courses.

3.3 RESEARCH SETTING

This study focuses on student learning of quantum mechanics at a tertiary or university level. The subjects who participated in this study were drawn from the University of Sydney community in Sydney, New South Wales, Australia.

At the University of Sydney, quantum mechanics is taught in the Faculty of Science within the School of Physics and the School of Chemistry. The general philosophy of teaching in these Schools is based on the desire to equip students with skills used by professional physicists and chemists. These skills include

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3 Based on discussions with students and lecturers at the University of Sydney, 2000.
problem solving, development of theories through experimentation and observation, research methods and design, communication of scientific material, reasoning and deduction about physical systems, and proficiency with computer technology.

The academic staff employ a variety of individual styles and media including lectures, experimental laboratories, computational laboratories and conceptual tutorials to achieve these skills. For example, the aims of the School of Physics teaching program are as follow:

"The teaching and learning programs of the School aim to develop an understanding of the major concepts that underlie current views of the natural world, to provide insights into the experimental and theoretical methods that lead to these concepts, and to reveal the intimate and abundant connections between these concepts and the material and cultural welfare of modern society.” (The University of Sydney, School of Physics - Strategic Plan 1998-)

The Schools of Physics and Chemistry at the University of Sydney offer a variety of undergraduate programs ranging from service courses for Dentistry students to Honours courses for physics and chemistry majors. Courses are offered at four levels: Junior (1st year), Intermediate (2nd year), Senior (3rd year) and Honours (4th year) level.

3.3.1 The School of Physics

The School of Physics currently consists of approximately 60 academic/research staff, more than 70 postgraduate students and some 20 administrative and technical staff. Physics is taught by the School to around 1600 students at all levels. Over 1200 of these are enrolled in Junior (1st) year Physics courses of various types. Approximately 230 of these students progress to Intermediate (2nd) year and a further 30 take Physics as a “major” in their Senior (3rd) year. The number of Honours (4th) year students typically varies between 15 to 20.

Description of Junior Physics Courses

Students studying physics at the Junior level are enrolled in a range of Faculties including Arts, Dentistry, Education, Engineering, Science and Veterinary Science. The School of Physics provides service courses in physics for Dentistry, Veterinary Science and Engineering students. The remaining mainstream students have the choice of taking junior physics at either advanced or normal levels.
The advanced level of junior physics is intended for students with a strong background in physics and calculus-based mathematics. The course runs over two semesters covering more material than the normal level and in greater mathematical detail. Students are invited to participate in this level if they have satisfied certain entrance requirements based on the New South Wales University Admission Index (UAI) or equivalent.

At the normal level of junior physics, there is a further division of the course into the regular and fundamental options in first semester to accommodate different student backgrounds. The regular option is suited to those students who have studied physics at secondary school level. The fundamental option is primarily for those students who have not previously studied physics. Both the regular and fundamental options of the normal level share a similar syllabus and a number of common examination questions are present in their final examinations. In second semester students choose between Technological and Environmental and Life Sciences options depending on interest and professional relevance.

The first year junior Technological Quantum and Material Physics, the Environmental and Life Sciences Atoms, Nuclei and Quanta and the Advanced Quantum, Materials Physics and Superconductivity courses comprise fifteen one-hour formal lectures. Non-compulsory tutorials designed to promote student conceptual understanding are available and student attendance is encouraged. These courses (at time of study) are based on relevant chapters in the textbook, Fundamentals of Physics (6th Edition) by Halliday, Resnick and Walker, and students are expected to own a copy. References given during the course and assignment problems for class assessment are contained in this textbook.

The junior physics courses are assessed by assignments, laboratory checkpoints, laboratory tests and formal examinations at the end of each semester. These three assessment components are weighted for each course option; however, in all cases the formal examinations are the most significant component.

Description of Intermediate Physics Courses

Intermediate physics is offered at advanced and normal levels. Students are allocated to these streams based upon their previous performance in university physics. Teaching and learning environments provided are lectures, experimental laboratories and computational laboratories. To meet the course requirements,
students must complete units whose content includes quantum physics, astronomy, electromagnetism, optics, instrumentation and thermal physics.

The intermediate quantum mechanics courses comprise a 20 lecture course which builds on the basics of quantum mechanics covered in Junior Physics, blackbody radiation, Planck's hypothesis, the photoelectric effect and Compton scattering. Students derive the Schrödinger equation, examine quantum phenomena in one-dimensional systems and investigate a number of interesting phenomena including the Uncertainty Principle and quantum tunnelling. These and other phenomena are linked to form the basis of much of 20th century physics, underpinning areas such as atomic physics, superconductivity, particle physics and chemistry. In the last part of the course, quantum physics is applied to the solid-state such as conductors, insulators and semiconductors. Symmetry of wave functions, exclusion principles and statistical physics are introduced to explain these behaviours. The physics behind some electronic solid-state devices such as diodes and transistors is then examined within the context of quantum physics. The Advanced course covers the same material as the Technological and Environmental course and is more detailed.4

Several quantum physics experiments are available in the Intermediate Physics Laboratory, including Holes and Electrons in Semiconductors; the Photoelectric Effect; Collisional Excitation of Atoms; Fine Structure of Spectral Lines; Photons and the Wave-Particle Dilemma; and Atomic Emission Spectra.

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A quantum mechanics computational physics course is coordinated and offered concurrently with the core lecture course, Quantum Physics. The course is accompanied by a set of Computational Physics Notes. The software package on which the course is based is Matlab. The course is conducted in the School of Physics' micro-computer laboratory, runs over 10 weeks and comprises 10 two hour sessions, allocated problem sets (sessions 1-7); projects (sessions 8-9); and examination (session 10).

Description of Senior Physics Courses

Senior level quantum mechanics comprises 12 lectures and covers the three-dimensional Schrödinger equation; Hydrogen-like atoms; Orbital angular momentum and spin; Radiation from excited atoms; Identical particles; Helium and other atoms; and molecules. The recommended textbook is Eisberg and Resnick, Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles.

Students may choose to attend a further 12 lectures covering the interpretation of the Schrödinger Equation, the formalism of quantum mechanics, representations including matrix mechanics, Angular momentum and spin, Three dimensional Schrödinger Equation, Perturbation Theory and Approximation methods. The recommended reference for this more advanced stream is Bransden and Joachain, Introduction to Quantum Mechanics.

Additionally, a significant proportion of physics majors choose to study optional Nuclear and Particle Physics courses which cover quantum mechanical ideas and concepts for example topics covered include properties of the nucleus, particles and their families, the quark model, nuclear models, nuclear instability and decay, nuclear interactions, fission and fusion reactions, interaction of radiation and matter, and detection devices.

Assessment across all courses is dominated by a formal examination at the end of each semester.

3.3.2 The School of Chemistry

The School of Chemistry currently consists of approximately 27 academic/research staff, more than 100 postgraduate students and some 20 administrative and technical staff. Chemistry is taught by the School to around 2200 students at all levels. Over 1800 of these take Junior (1st) year Chemistry courses of
various types. About 200 of these students progress to Intermediate (2nd) year and a further 90 take Chemistry as a “major” in their Senior (3rd) year. The number of Honours (4th) year varies between around 25 to 40.

Description of Junior Chemistry Courses

Students studying chemistry at the junior level are enrolled in a range of Faculties including Arts, Medicine, Education, Engineering, Science and Veterinary Science. The School of Chemistry provides service courses in chemistry for dietetics, nutrition, molecular biology and genetics students. The remaining mainstream students have the choice of taking one of four junior chemistry courses: Fundamentals of Chemistry 1; Chemistry 1; Chemistry 1 Advanced; or Chemistry 1 (Special Studies Program). These four courses have essentially the same curriculum but are tailored to suit students of different chemistry backgrounds and abilities. The course Fundamentals of Chemistry 1 is especially designed for students who have no previous experience studying chemistry, while entry to Chemistry 1 Advanced is determined by the student’s UAI. The Special Studies Program targets students who are considered gifted and talented in chemistry and includes a mentoring program with a research chemist.

The junior chemistry courses do not specifically address quantum mechanics apart from a brief introduction to atomic structure, and descriptions of ionic and covalent bonding. The junior course focuses on organic compounds, heat of reactions, stoichiometry, reduction and oxidation. The students participate in lectures, tutorials and laboratory activities. The laboratories aim to enhance student conceptual understanding and teach skills needed by practising chemists.

Description of Intermediate and Senior Chemistry Courses

Intermediate and Senior chemistry is offered at advanced and normal levels and students are allocated to these classes based upon their academic performance in junior chemistry. In these later years the course is split into three strands covering the major research areas of the School: Organic Chemistry, Inorganic Chemistry and Physical/Theoretical Chemistry. Each strand incorporates lectures, tutorials, seminars and extensive laboratory experience.

The students’ exposure to ideas in quantum mechanics is extended as atomic and molecular models are further developed. An orbital model is used to give a more sophisticated understanding of bonding. The use of spectroscopy as a tool in
chemical identification is explored in great detail. For example, the School uses nuclear magnetic resonance (NMR), mass spectroscopy, atomic absorption spectroscopy and infrared spectroscopy techniques extensively in research and discussion of these techniques is included in the senior course.

Up to 25 senior chemistry students choose to take an optional course called Quantum Chemistry. The recommended references for this course are Quantum Chemistry of Atoms and Molecules by Mathews, Molecular Quantum Mecahnics by Atkins and Friedman and Introduction to Molecular Orbitals by Jean and Volatron. Topics covered include: Schrödinger’s Equation; quantum mechanical operators; wave functions and their interpretation; the role of symmetry and its use in molecular orbital theory; quantisation tunnelling and covalent bonding.

3.4 A PRELIMINARY RESEARCH PLAN

In order to conduct research into how students go about learning the subject in these wide and diverse contexts, it was necessary to select appropriate methodologies and research tools. To this end a preliminary research project plan was developed based on the research setting and the range of available data sources.

As researcher, I considered that a multi-methodological approach would be needed to adequately address the research questions proposed in Chapter 1; as the selection of a single research methodology, and following a prescribed path dictated by this choice, could possibly obscure other valid perspectives.

As the plan evolved it also proved a useful tool for communicating the basic framework of the study to non-educational researchers throughout the early stages of the study (refer Table 3-1).
# Preliminary Research Project Plan

## Generate Initial Research Questions

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus group discussions</td>
<td>Lecturer staff, research staff, post-graduate students</td>
<td>Development of a set of research questions covering attitude, content, learning and teaching</td>
</tr>
</tbody>
</table>

## Literature Review

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review a wide selection of related research articles in physics and chemistry educational research</td>
<td>Library databases, research articles</td>
<td>Clear understanding of the scope of related research</td>
</tr>
</tbody>
</table>

## Identify Key Themes, Ideas and Concepts

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter the field with open and responsive research outlook</td>
<td>Mentors within the Faculty of Education</td>
<td>Adaptation of an appropriate research methodology</td>
</tr>
<tr>
<td>Collect and analyse data from a wide range of sources</td>
<td>Lecturers, students, researchers, examination scripts, lectures, tutorials, laboratories</td>
<td>Adaptation of appropriate data collection and analysis tools</td>
</tr>
<tr>
<td>Identify key categories</td>
<td>Analysis software</td>
<td>Awareness of emerging concepts</td>
</tr>
</tbody>
</table>

## Develop an Interview Based Research Instrument

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progressively focus toward the initial research questions</td>
<td>Adaptation of appropriate data analysis tools</td>
<td></td>
</tr>
<tr>
<td>Isolate the key areas of interest and the key aspects of quantum mechanics</td>
<td>Development of a set of interview questions</td>
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</tbody>
</table>

## Conduct Interviews

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interview lecturers and students</td>
<td>15 lecturers 60 Students</td>
<td>Development of a responsive interview protocol</td>
</tr>
<tr>
<td>Analyse interview data to identify themes</td>
<td>Categorisation of responses</td>
<td></td>
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</tbody>
</table>

## Investigate the Variation in Understanding of Key Quantum Mechanics Concepts

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step back from the data and refocus on isolating a set of key concepts relating to the teaching and learning of quantum mechanics</td>
<td>Interview transcripts</td>
<td>Adaptation of appropriate research methodology and analysis tools</td>
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<tr>
<td></td>
<td></td>
<td>Mapping the variations in understanding</td>
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</tbody>
</table>

## Link Results

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyse the results for trends and connections</td>
<td>Analysis software tools</td>
<td>Research findings</td>
</tr>
</tbody>
</table>

Table 3-1: Preliminary Research Project Plan
3.5 METHODOLOGICAL AND PHILOSOPHICAL PERSPECTIVES

This section describes the issues explored, the assumptions made and the rationale that guided the final planning of the investigation. During this phase the preliminary research plan became a framework for ideas and thoughts. Notes from discussions, reviewed literature and other items concerning philosophies, methods, ideas, examples and links were considered and mapped to assist in the development of the final design.

This section concludes with the identification of a set of research methodologies and tools which were considered most appropriate to meet the requirements of the research plan.

3.5.1 Foundations for Selecting Appropriate Educational Research Methodologies

This section outlines the theoretical views that influenced the design of the final research plan. As researcher I considered the research plan would benefit from the utilisation of a range of appropriate methodologies and associated research tools, increasing the perspectives in which research data could be viewed.

Cohen and Manion’s analysis (1994 p6-7), which was based on the work of Burrell and Morgan, identified four sets of assumptions with which to approach an understanding of social reality and research. They commence their commentary by stating that there are two views of social science representing strikingly different ways of considering social reality. These are constructed on correspondingly different methods of interpretation. The traditional view holds social and natural sciences as essentially the same, while a more recently emerging radical view emphasises how people differ from inanimate natural phenomena and indeed each other (Cohen and Manion 1994 p5). The four sets of assumptions are set out below.

Ontology

The first set concerns the very nature of the social phenomena being investigated. Is social reality external to individuals, imposing itself on their consciousness from without, or is it the product of individual cognition? These questions spring directly from the nominalist (objects of thought are
merely words) versus the realist (objects have an independent existence debate). (Cohen and Manion 1994 p6)

**Epistemology**

The second set of assumptions concerns the very bases of knowledge: its nature and forms; how it can be acquired; and how it can be communicated. Alignment in this debate profoundly affects the appropriate method of uncovering knowledge of social behaviour. The positivist view that knowledge is hard, objective and tangible will demand of researchers an observer role, together with an allegiance to the methods of natural science; to see knowledge in an anti-positivist way is personal, subjective and unique, and imposes on researchers an involvement with their subjects and a rejection of the approach of the natural scientist. (Cohen and Manion 1994)

**Human nature**

The third set of assumptions concerns human nature and, in particular the relationship between human beings and their environment. Since the human being is both the subject and the object of the study, the consequences for research of assumptions of this type are extensive (Cohen and Manion 1994). Burrell and Morgan in 1979 describe two images of the human being that can emerge from such assumptions:

*Thus we can identify perspectives in social science which entail a view of human beings responding in a mechanistic or even deterministic fashion to the situations encountered in their external world. This view tends to be one in which human beings and their experiences are regarded as products of the environment; one in which humans are conditioned by their external circumstances. This extreme perspective can be contrasted with one which attributes to human beings a much more creative role: with a perspective where “free will” occupies the centre of the stage; where man is regarded as the creator of his environment, the controller as opposed to the controlled, the master rather than the marionette. In these two extreme views of the relationship between human beings and their environment, we are identifying a great philosophical debate between the advocates of determinism on the one hand and voluntarism on the other. Whilst there are social theories which adhere to each of these extremes, the assumptions of many social scientists are pitched somewhere in the range between.* (Burrell et al 1979)

**Methodology**

The fourth set of assumptions concerns itself with philosophy. The two initial ways of looking at social reality are the traditional, which holds social and natural sciences as essentially the same; and a more recently emerging
radical view which emphasises how people differ from inanimate natural phenomena and indeed each other. (Cohen and Manion 1994 pp38-40)

A researcher selects the methodology which encapsulates the philosophy, principles and assumptions they hold about the nature of their research. It consists of the ideas underlying data collection and analysis (Holloway 1997 p105).

If a researcher intends to employ multiple methodological perspectives, the underlying assumptions are very important. As the researcher in this project, I considered that the inherent danger of adopting multiple methodologies is that I may also ‘muddle’ different research methods, tools and procedures (Baker et al 1992). As each methodology and its associated research tools imports a unique set of underlying principles and assumptions, it was decided that each research component should be kept separate during the data collection and analysis phases, as this would minimise confusion between the differing research purposes and procedures employed.

For example, grounded theory as an approach to data collection has as its aim the generation of theory from data collected by a researcher, whereas phenomenology is not a method as such but a philosophy, and it has an aim that through the data meanings are found which demonstrates the characteristics of a phenomenon. Both “methodologies” have origins linked to the symbolic interaction movement but each has a distinct research purpose.

An additional advantage of maintaining this segregation is that a researcher, informed by the methodology’s assumptions, can make informed judgements when tailoring specific data collection and analysis tools to a particular task.

As a researcher I consider that research methodologies are tools and each can be used to search for meaning and understanding. In reality, the various research approaches are by no means mutually exclusive and many educational studies today use, for example, both controlled experimentation and qualitative exploration.

5 Symbolic interactionism is a term coined by Herbert Blumer (1900-1987) in 1937, it is an approach in sociology which focuses on the interaction of human beings and the roles which they have. The model of the person in symbolic interaction is active and creative rather than passive.
As a researcher I agree with Gill (1996) that the significance of any research methodology is the relationship between the findings and the theorising, rather than what research methods were used. It is important to bear in mind that if the assumptions underlying the data collection and analysis are poorly articulated or ‘muddled’ then this relationship may not be well developed, leaving research findings open to criticism.

3.6 SELECTING RESEARCH TOOLS

The preliminary research project plan can be divided into two distinct stages. The first is the development of the set of interview questions and the second involves conducting and analysing the resulting interviews. Development of the interview questions required an open approach to generate a list of options, and which allowed exploration of various possibilities before settling on the final set. The interview process required an approach which was flexible and responsive, and would allow the researcher to become immersed in the analysis process throughout the data collection.

To meet these research project objectives two approaches were selected and adapted for this study. For the development of the interview questions a Grounded Theory approach was chosen and for the interviews a Phenomenological approach was adopted. The utilisation of interviews formed a major common component across both activities, and therefore a robust interview protocol was necessary to ensure that interview data was recorded and presented appropriately. The research was conducted in a social context and it was recognised that the complexity of human behaviour requires the triangulation of both data and methods to increase validity and reliability. A description of these methods and their adaptation to this study are described in the following sections.

3.6.1 Grounded Theory Approach – Stage 1

Grounded theory is a qualitative approach to data collection and data analysis. The approach was developed by Barney Glaser and Anselm Strauss in the 1960s and has its origins in sociology. By the late 1980s Glaser and Strauss had moved in differing theoretical directions (Melia 1996, Stern 1994). For this study the perspective described by Strauss and Corbin (Strauss and Corbin 1998) was adopted.
The aim of grounded theory is the generation of theory from the gathered data, although for the purpose of this research project the grounded theory approach was utilised to identify a list of key elements and generate a set of interview questions. These interview questions formed the starting platform which launched the phenomenological stage of the study.

Selection Criteria
Grounded theory was selected for the first stage of the study for the following reasons: results generated are based directly on the data; the research approach starts with an area of interest, then data is collected and relevant ideas are allowed to develop; the approach encourages the researcher to collect data from multiple sources and guides the researcher to examine the data from all sides rather than staying fixated on the obvious; the researcher compares each section of the data with every other part throughout the study looking for differences, similarities and connections; and the approach is considered especially useful in situations where little is known about the subject under investigation.

Developing Theoretical Sensitivity
The researcher’s theoretical sensitivity provides a platform for multifaceted examination of the collected data rather than becoming fixated on the obvious. In this study the researcher informed and developed his theoretical sensitivity throughout the research project by reviewing related literature, seeking discussions with a wide range of practitioners in both teaching and research settings and through the processes associated with data management and analysis.

Data Collection
In grounded theory the processes of data collection and analysis are intertwined; as the data is collected from various sources it is analysed and compared with all other data to identify trends, differences, similarities and connections.

Grounded theory does not begin with a hypothesis. Instead, after the initial data collection and analysis, relationships are identified and provisional hypotheses

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6 Theoretical sensitivity in this context of grounded theory means that the researcher is sensitive to the important issues in the data. Glaser believed that sensitivity assists the researcher in developing theories and in relation to this investigation we are stopping short and only developing themes. Theoretical sensitivity is derived from professional and personal experience. Additionally a thorough
can be formulated, which are then checked against further data and modified. Researchers are encouraged to utilise the widest selection of data sources possible which, for this study, included observations, interviews, examination scripts, diaries, literature and curriculum related documentation.

For this study this recursive process allowed the researcher to formulate, test, modify, review, discard and develop many provisional hypotheses within the context of the collected data. These processes increased my theoretical sensitivity and assisted in the final formulation of the interview questions.

Theoretical Sampling
The sampling process employed in grounded theory is driven by theoretical, rather than purely statistical, considerations. This provides the researcher with a responsive research tool and allows for additional leads to be adequately investigated. In this study, theoretical sampling allowed me to target specific types of students, which in turn verified several aspects under investigation by allowing categories to reach an obvious point of saturation. These may have been inconclusive or overlooked if a predetermined sampling regime had been employed.

Data Analysis
As previously discussed data analysis in grounded theory is an iterative, continual and integrated process performed throughout a research project. The initial analysis consists of coding and categorising, and usually involves a line by line analysis of transcript style documentation. The key feature of the codes and categories generated by this analysis is that they are based directly on the data.

Coding in grounded theory comprises three steps, elaborated below. The first two steps form a cyclic system and the researcher alternates between the two processes of Open and Axial Coding processing for the incoming data. The third step of Selective Coding attempts to identify a core category which links all other categories together.

Open Coding
The aim of open coding is to break down, conceptualise and code the data. Each separate idea in the data is labelled and similar ideas are grouped and labelled. Knowledge of the relevant literature, interaction and immersion in the data can also contribute to this
The codes generated are often words or phases from the data which describe the phenomena, and these are referred to as ‘in vivo codes’. Early in this coding step a large number of codes are generated, and examined, grouping schemes are considered and the concepts with similar ‘traits’ are collapsed into categories. These categories tend to be more abstract than the initial codes and the main properties and dimensions of these categories are identified.

**Axial Coding**

The aim of axial coding is to reassemble the data broken down by the open coding process. This involves grouping categories together to build major categories.

This cyclic process of coding and categorisation should continue until the category has been adequately described with all its properties, variations and processes, the links between categories are firmly established and no new information on a category can be found after attempting to collect more data from a variety of sources.

**Selective Coding**

The aim of selective coding is to reveal the core category that links all the other categories together. The category should provide the story line for the data. The process of linking around a core is called selective coding.

Incoming data should be checked for its inclusion in existing categories, comparison between new and existing categories which assists in finding their properties and dimensions or their consolidation. The overall process of coding and categorisation should, throughout the research involve constant comparison between all aspects.

Although grounded theory possesses a theory generation component, this component is not useful within the constraints of this investigation. The selective coding step has instead been adapted to assist me in identifying the key elements and the set of interview questions which feed into the second stage of the research project. A set of core categories would provide the foundations of the final interview questions.
3.6.2 Phenomenological Approach – Stage 2

Phenomenology is a philosophical approach to the study of phenomena and human experiences; it has been adopted as the primary philosophical standpoint for this study. The ‘father’ of phenomenology is Franz Brentano, who developed the concept of *intentionality* which is an idea central to the philosophy. Intentionality is “the internal experience of being conscious of something” (Moustakas 1994). When studying people and their understanding of phenomena their consciousness is always directed at an ‘object’. People are aware of, perceive, understand or describe ‘something’.

Edmund Hurssel was Brentano’s student and enlarged the field of phenomenology during this period commonly referred to as the German phase of phenomenology. Two important concepts developed by Hurssel were *intuition* and *phenomenological reduction*. Hurssel believed in the phenomenologist’s intuitive understanding of human experience. To reach an intuitive understanding, researchers must become immersed in the phenomena and become aware of their own and other people’s perceptions of the phenomena. Phenomenological reduction is when objects or phenomena are viewed without prior judgement or assumptions. They are seen and described as they appear through observation and experience. This suspension of preconceptions is also called *bracketing*. Complete reduction is never possible because researchers are themselves human too, but in attempting to understand phenomena using this concept it is necessary for people to clearly identify their preconceptions.

Existential phenomenologists such as Gabriel Marcel, Jean Paul Sartre and Maurice Merleau-Ponty (referred to as the French phase of phenomenology) do not believe in reduction or bracketing, so that human beings cannot be separated from their perceptions. Schutz was an influential existentialist who was interested in understanding the meaning and structure of everyday life. He introduced the concept of *reflexivity* in which people interpret meaning from a stream of consciousness by reflecting on what has been occurring. In everyday life, people interpret the behaviour of others and the world around them by classifying and organising concepts and encounters into ‘ideal types’ from their previous experiences and social interactions.
Phenomenology is not a research methodology as such, so there are no hard and fast rules for conducting analysis under this approach. However, several practitioners (Giorgi et al 1971, Colaizzi 1978 and van Manen 1984) have developed analytic strategies that allow phenomenology to be applied at a practical level.
For this study Colaizzi’s (1978) seven steps of phenomenological analysis were adopted to reduce the data. The seven steps are as follows:

1. Researchers review the collected data and become familiar with it. Through this process they gain a feeling for the subject’s inherent meanings.

2. Researchers return to the data and focus on those aspects that are seen as most important to the phenomena being studied. From the data they extract significant statements.

3. The researcher takes each significant statement and formulates meaning in the context of the subject’s own terms.

4. The meanings from a number of interviews are grouped or organised in a cluster of themes. This step reveals common patterns or trends in the data.

5. A detailed, analytic description is compiled of the subject’s feelings and ideas on each theme. This is called an exhaustive description.

6. The researcher identifies the fundamental structure for each exhaustive description.

7. The findings are taken back to the subjects who check to see if the researcher has omitted anything. This is called a member check.

3.6.3 Phenomenographic Influence – Capturing Variation

Phenomenography is a research approach that focuses on phenomena and peoples’ understanding of phenomena. The principle areas of interest are identifying peoples’ conceptions of social and natural phenomena and documenting the ‘distinctly different ways’ in which people interpret the phenomena. It was developed in the 1970s by Ference Marton (1981) and has been used extensively in science education research (Prosser 1993 and Walsh et al 1993).

In this study, a phenomenographic approach to peoples’ understanding of scientific phenomena (quantum mechanics) has influenced part of the analysis phase within the Colaizzi (1978) framework. A phenomenographic approach is used to pinpoint and map variations in students’ understanding of quantum
phenomena during the analysis phases. (Refer to Appendix 10 for a literature review on Phenomenography)

3.6.4 Interview Protocol

To understand student learning in quantum mechanics it is necessary to question practitioners, researchers, teachers and learners of quantum mechanics. Interviews were selected as a principal data collection tool for both stages of this study. Interviews would provide opportunity for asking questions on a wide range of subjects, the possibility of probing issues more completely and exploring unknown issues as they arose.

Initially, estimates suggested that up to 100 subjects would be interviewed for this study. A task of this magnitude required a consistent interview protocol for the following purposes:

- To plan interviews to match the approach specified for each stage.
- To increase the validity and reliability of the interview process and the data collected.
- Provide an appropriate format for interviews.
- Provide a reliable system of data recording.
- Provide a framework for data analysis.

An in-depth interviewing technique was selected for this study, as it was best suited to the grounded theory and phenomenological approaches used in the two stages. Taylor and Bogdan (1984) give the following description of an in-depth interview:

“repeated face-to-face encounters between the researcher and informants directed toward understanding informants’ perspectives on their lives, experiences or situations expressed in their own words.”

The grounded theory stage of the study required in-depth data covering a range of ideas and examples in quantum mechanics, some of which were initially unknown. Subjects were to be engaged in a conversation and encouraged to articulate their understanding and models of quantum mechanics in their own words. Flexibility was needed to be able to diverge from an interview plan and
explore specific issues when they arose. Issues that emerged in early interviews could be addressed in later interviews, allowing the flow of conversation to direct the research process. To fulfil these requirements the preliminary interviews were unstructured, or recursive, in nature; and progressively focussed toward a semi-structured format in preparation for the phenomenological stage.

The phenomenological stage of the study required in-depth data that was more focussed in its scope. The data from the preliminary interviews and other sources was analysed and used to produce an interview guide for the second stage. These interviews had many common elements, and dealt with specific issues brought to light by the grounded theory stage. The interviewer still required flexibility in the ordering and the depth of probing of individual questions but essentially the questions asked of each subject were the same. Interviews in the phenomenological stage were focussed, or semi-structured, in nature.

The interview questions were predominantly open-ended in format, and the subjects were also asked to draw or sketch as a part of their responses. The style of questioning was dominated by descriptive, structure, opinion and probing questions which are briefly described below (Table 3-2).

<table>
<thead>
<tr>
<th>Question Types</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>Used primarily at the start of each interview or when moving to a new topic. This question type allows subjects to discuss their experiences in their own words and from their perspective.</td>
</tr>
<tr>
<td>Structural</td>
<td>Used to elicit how subjects organise their knowledge. This question type is very important in this study as it encourages the subject to reflect and think metacognitively.</td>
</tr>
<tr>
<td>Opinion or value</td>
<td>Used to determine what the subject thinks about a particular issue or person. This question type was used to elicit the subject’s opinions and feelings, not just the ‘correct’ answer.</td>
</tr>
<tr>
<td>Probing or nudging</td>
<td>Used to elicit information more fully, on a particular topic. This question type was used extensively.</td>
</tr>
</tbody>
</table>

Table 3-2: Description of Interview Question Types

To maximise internal validity the interviewer must constantly check perception and understanding (the interviewer’s and the subject’s) against possible
sources of confusion. Probing, cross checking and recursive interviewing are techniques used to minimise this problem. For example, a common validity error can be as simple as asking the wrong question. Approaching the interview issue using multiple contexts, representations or examples can help as well as using other non-interview methods to get similar information (e.g. examination scripts, concept maps, drawings).

Reliability is increased by repetition. However in-depth, semi-structured interviews do not lend themselves (by their nature) to large sample sizes or exact duplication of interview conditions. Every effort should be made to improve reliability by careful planning of the interview, meticulous documentation of the interview conditions and process, accurate recording of interview data (e.g. note taking, tape recording etc) and wherever possible duplicating the interview conditions for each subject. This will also improve external validity.

A format was developed for conducting the interviews to ensure a consistent and pleasant experience for both subject and interviewer. A safe, non-threatening location for the interviews was selected and then fitted with suitable furniture, lighting and audio recording equipment. Subjects were invited to participate in an interview at a time convenient to them. Information about the interview was provided to subjects in advance. Before each interview the subject gave informed consent. The interviewer commenced each interview with questions to relax the subject and form a rapport. The interview was brought to a close with a series of reflective questions. The subject was thanked for their participation and provided with follow-up information on their interview.

All interviews were recorded on audio magnetic tape and later transcribed. Audio tape recording was chosen over field notes as a method for recording interview data for the following reasons:

- It provides a comprehensive and accurate record of the interview.
- It reduced bias introduced by the observer. Observers often differ in approaches and hence field notes can differ in perspective and emphasis.
- It allows the interview to have a more natural and conversational style, not punctuated by breaks to make notes.
- The interviewer can listen fully and attentively to the subject during the interview.
It must be acknowledged that an audio tape record of the interviews also had disadvantages:

- There was no record of the subject’s mood, facial expression or body language.
- The possibility of changes in subject behaviour due to the presence of the recording equipment cannot be discounted.
- In the first three interviews the sound recording was poor due to background noise, a problem overcome in later interviews by using sound studio equipment that produced a high quality recording.

Directly following an interview the audio tape record and the interviewer’s memories and impressions had to be processed into a form that would allow complete and detailed data analysis at a later date. This form is called the *transcript document* and follows a suggested outline given by Ridge (1995).

The audio tape was transcribed and stored as a word processed file. A cover page was prepared containing details of the interview such as date, time, duration, location, interviewer, subject (coded to conceal identity) and key features that emerged from the interview. The cover page provided brief information that helps the interviewer recapture the events and feeling of the interview.

Following the cover page is the complete typed interview transcript, clearly indicating statements made by the interviewer and subject. It is situated in the middle of the page with a column on either side. On the left hand side is a personal log and on the right hand side an analytical log (refer to Figure 3-1).
### Sample Page from Interview Transcript

#### PERSONAL LOG

0080 This is a reflective probe attempting to elicit further ideas. It should have been stated more clearly in respect to each of the sub-questions.

<table>
<thead>
<tr>
<th>TRANSCRIPT</th>
<th>ANALYTICAL LOG CATEGORIZATION</th>
<th>ANALYTICAL LOG MAJOR POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0080</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### TRANSCRIPT

(P011-)

PF

If you are worried about teaching uncertainty at high school are there any other things that can be taken back and taught? Or should they.

0092

(P012-)

TED

I think Quantisation of... of thing that... I think getting the idea that umm, the idea like, like that waves of light can be treated as a particle can probably be, you can probably teach reasonably early but, you can like the this taught can be a way it is a different concept that you hang on but it umm, you can see it as a wave or it can you treat it as a particle with photons with a particular energy I think that that could be taught at quite an early stage.

Although umm... and possibly even some of the ideas that umm... with with possibly some of the ideas of matter being treated as waves waves and and streams could also work but... I'm... not sure how must you can get out of that.

#### TRANSCRIPT

0094

0095

0096

0097

0098

0099

0100

0101

0102

0103

0104

0105

0106

0107

0108

0109

0110

0115 The reflective probe worked quite well despite the weakness of the questions structure.

005 -- 0110 The informant provides a number of important ideas and is changing his focus to a broader perspective.

C – Quantisation P012/0095

C – Key Conc P012/0095

PC – Teach HS P012/0095

C – Duality P012/0097

PC – Teach HS P012/0097

C – Matter Waves P012/0106

PC – Teach Early P012/0106

PC – Teach Qual P012/0109

P012 Informant feels that Quantisation is a key idea.

Informant feels that Duality is a key idea.

October 6/10/1999/01-TED

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Figure 3-1: Example page from preliminary interview transcript showing layout

The personal log is an annotated chronological record of the interviewer’s reflections on the issues that arose during the interview/study. It is an instrument for recording reflective notes on the questions and responses, and it highlights areas for improvement and development in the interview process.

The analytical log includes reflective notes on the questions and responses, records emerging ideas and is a platform for discovering and organising ideas. Topics that are discussed or emerge are identified and connections made to the broader research questions. Trends or points of convergence usually emerge as the interviews proceed.

A detailed and accurate transcript document is produced for each interview and this allows analysis using different coding schemes to be overlaid as necessary. More details on the transcript document and its analysis appear in later chapters.
3.6.5 Triangulation

Triangulation is the use of two or more methods of data collection in the study of human behaviour (Cohen and Manion 1994 p233). Triangulation in social research has the same aim as in navigation or surveying - to improve validity and overcome bias, but the type of triangulation used is dependent on the nature of the research project. Denzin (1970) defines six types of triangulation that can be used in research as time triangulation, space triangulation, combined levels triangulation, theoretical triangulation, investigator triangulation and methodological triangulation. Three of these types were used in this study and they are described below.

*Time Triangulation*

A social system changes with time and time triangulation collects data to reflect this. A study with a *cross sectional design* collects data concerned with time related processes from different groups at one point in time. This study attempted to follow the development of students' ideas in quantum mechanics throughout their university studies. Data was collected from groups of students from four different levels of university study.

*Combined Levels Triangulation*

A social system can be divided into three broad levels, being individual, group and collective. Combined levels triangulation collects data from more than one level to show that human behaviour encompasses these three levels of a social system. This study collected data from individual participants and small groups.

*Methodological Triangulation*

There are two subdivisions of methodological triangulation: *within methods* and *between methods* (Holloway 1997 p157). *Within methods* aims to increase reliability by repetition of single method whilst *between methods* focuses on validity by using multiple methods and looking for convergence in the data collected. This study employed a range of data collection techniques (e.g. interviews, examination scripts, concept maps) in its initial stage that resulted in several data sets converging and revealing a set of common themes. This led to the development of an interview protocol and set of guide questions that was implemented with 60 subjects.
3.7 MAPPING APPROPRIATE METHODOLOGIES, PERSPECTIVES AND RESEARCH TOOLS TO THE FINAL RESEARCH PLAN

Finally, the preliminary research plan was reviewed and separated into two distinct stages and another column was appended containing pertinent notes associated with methodological aspects of the study.

- **Stage 1** - Grounded Theory approach which would develop a set of interview questions (refer Table 3-3)

- **Stage 2** - Phenomenological Approach which would seek to reveal underlying themes (refer Table 3-4)

This plan performed two important roles within the study, as a guide for the research and as a point of reference for discussing the research project with colleagues and students.
## Research Plan - Stage 1 - Grounded Theory Approach - Development of a Set of Interview Questions

<table>
<thead>
<tr>
<th><strong>Proposed Strategy</strong></th>
<th><strong>Resources</strong></th>
<th><strong>Outcome</strong></th>
<th><strong>Methodology Guide Notes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identify Initial Research Questions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus group discussions and unstructured interviews</td>
<td>Lecturers, research staff, post-graduate students</td>
<td>Identification of key concepts. Identification of a set of preliminary codings</td>
<td>Refine interview protocol. Use memoing and audiotape to record discussions. Transcribe audiotapes and include notes. Commence analysis of the data immediately using open and axial coding techniques</td>
</tr>
<tr>
<td><strong>Literature Review</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review a wide selection of related research articles in physics and chemistry educational research</td>
<td>Library databases, research articles</td>
<td>Clear understanding of the scope of related research</td>
<td>Primarily use this material to develop theoretical sensitivity</td>
</tr>
<tr>
<td><strong>Identify Key Themes, Ideas and Concepts</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enter the field with open and responsive research outlook</td>
<td>Mentors within the Faculty of Education</td>
<td>Fine tune grounded theory research methodology to meet requirements</td>
<td>Continually seek advice concerning the management and handling of the coding and categorisation</td>
</tr>
<tr>
<td>Collect and analyse data from a wide range of sources</td>
<td>Lecturers, students, researchers, examination scripts, lectures, tutorials and laboratories</td>
<td>Adaptation of appropriate data collection and analysis tools</td>
<td>Quantitative analysis techniques should compliment the qualitative coding if deemed appropriate Ensure constant comparison across all datasets</td>
</tr>
<tr>
<td>Identify key categories</td>
<td>Analysis software</td>
<td>Awareness of emerging concepts. Identification of a set of key categories</td>
<td>Upon review of available data analysis software the decision to develop an MSAccess and MSExcel based data storage and analysis system was taken.</td>
</tr>
<tr>
<td>Preliminary Interviews (Carries into next section)</td>
<td>10 Students</td>
<td>Honing of interviewing skills and trialling questions.</td>
<td>Fine tuning of the interview protocol in preparation for next stage</td>
</tr>
<tr>
<td><strong>Develop and Refine an Interview Based Research Instrument</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolate the key areas of interest and the key aspects of quantum mechanics</td>
<td>All datasets, coding and categorisation</td>
<td>Development of a set of interview questions</td>
<td>Adapt the selective coding process to isolate core categories and themes</td>
</tr>
<tr>
<td>Continue Preliminary Interviews</td>
<td>Remainder of 10 students</td>
<td>Final set of Guide Interview questions</td>
<td>Develop questions, trail and review in preparation for Stage 2</td>
</tr>
</tbody>
</table>
Table 3-3: Research Project Plan - Stage 1

<table>
<thead>
<tr>
<th>Proposed Strategy</th>
<th>Resources</th>
<th>Outcome</th>
<th>Methodology Guide Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conduct Interviews</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interview students 60 Students 2nd Year - Postgraduate</td>
<td>Interview transcripts</td>
<td></td>
<td>Continue to fine tune interview procedures and progressively focus research</td>
</tr>
<tr>
<td>Analyse interview</td>
<td>Interview transcripts</td>
<td>Adaptation of appropriate research methodology and analysis tools</td>
<td>Transcribe and analyse interview within 5 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Identification of categories and emerging themes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step back from the data and refocus on isolating a set of key concepts relating to the teaching and learning of quantum mechanics</td>
<td>Interview transcripts Clustered themes</td>
<td>Identification of a set of underlying themes to be used as the basis of a focused reanalysis of the transcripts</td>
<td>Extract significant statements Cluster themes Perform member checks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revisit all transcripts and develop a detailed analytical description for each theme</td>
<td>Identified Themes Interview Transcripts</td>
<td>Develop an exhaustive description of each theme in relation to both the individual student and across the entire data sample.</td>
<td>Revisit the dataset with a focused view on the data and use the identified themes as a point of reference Extract significant statements Cluster themes Perform member checks Investigate and map the variations in student understanding</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Report Findings against Themes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report findings</td>
<td>Themes and descriptions</td>
<td>Report the findings and significance of each theme</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recommendations concerning teaching and learning quantum mechanics</td>
<td></td>
</tr>
</tbody>
</table>

60
Table 3-4: Research Project Plan - Stage 2
CHAPTER 3 - REFERENCES


Holloway, I., (1997) *Basic Concepts for Qualitative Research* (Blackwell Science Pty Ltd, Carlton)


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