

## CHAPTER SIX

### DISCUSSION

#### 6.1 SUMMARY OF FINDINGS

The relevance of the results of this study can be best expressed by presenting them in a different order from the way they were reported in Chapter 5. The results can be thought of as a description of what a student goes through when introduced to a new concept in quantum mechanics. This will give a picture that exposes the extent of the difficulties students encounter.

##### 6.1.1 Assimilating new concepts (Question 2)

When a new concept is presented, the student will attempt to make sense of it. This process appears to take a path of “least resistance”, one that requires the least effort. The new concept is considered superficially and is quickly associated with other ideas in their current body of knowledge. This process does not guarantee that this attachment is appropriate. The student may fail to recognise that the new concept is contextually very different from the ideas that it has been attached to.

In this study the term “uncertainty” was examined. Our results showed that students did not recognise that the meaning was indeed different from that used in everyday language or measurement. Instead it was simply assumed that this type of quantum uncertainty was closely related to the other types. This attachment may have been challenged by what was said subsequently in the classroom but the initial relationships in the assimilation process were not broken, remapped, or integrated to more appropriate relationships.

##### 6.1.2 Integration of pre-existing concepts (Question 4)

A student may be forgiven for confusing the term “uncertainty” because it is a subtle idea and the new context may not have been clearly articulated. Ideally what should happen in subsequent learning is that the initially inappropriately assimilated concept settles into a more suitable position. However the results we found from question 4 suggest that this does not often happen. The concepts explored, “energy level” and “wavelength fitting in”, are not new and have been

known to the students since earlier in secondary school science. As has been stated earlier they would have first encountered these concepts with the introduction of atomic models in Junior Science and again in their Higher School Certificate electives of chemistry and physics. Our analysis revealed that despite having dealt with these concepts for at least two years, the students had not thought about the overall integration of the associations they held. There was no evidence that they had constructed new links to other disciplines or developed alternative ways of describing the concepts during more recent studies. Their knowledge has simply been filed by tacking it onto the first notions associated with these ideas. This point was clearly demonstrated by our contextual analysis. Students did not provide analogies to describe either of the concepts they were asked about. The evidence they did provide was limited to the content and context found in the chapters of a secondary school modern physics text. There was no evidence that they had related these concepts to their everyday experiences.

### 6.1.3 Development of mental models with time (Question 3)

The next finding may just be a corollary of the aforementioned points. When students collected all these concepts into what might be called a mental model, there is little evidence that these mental models are any more than collections of isolated facts. They do not show much structure that comes from these facts having been fitted into an internally consistent framework.

Question 3 was designed to find out if the mental models of first year students differed from those of third year students revealed in the earlier study. The comparison strongly indicated that there was very little development in content, context, structure or complexity. The majority of students still retained a secondary school view of waves. The third year responses were slightly more confined, yet the distributions between and internal to the phenomenographic categories were very similar. This is even more surprising when one considers that the first year sample comprises a mixture of students from a variety of backgrounds with varying interests. The third years on the other hand have chosen physics as their major line of study and have completed a minimum of two years in secondary school and two and half years undergraduate level physics.

#### 6.1.4 Using models to interpret data (Question 1)

Clearly the final and inevitable consequence of these observations is reflected in the analysis of question 1. When presented with a model comprising a number of different concepts, the students are unable to assimilate this new information. They do not have the capacity to make the correct associations between their understanding of a concept, their mental models and those in the presented model. For example, this study found clear evidence that the majority of students did not understand the terms frequency and intensity in relation to the “bird on a wire” analogy.

Our students are clever and it is assumed that they are quite capable of performing this process quite efficiently. It appears though that they do not see that a good model will help them solve problems in much the same way as using a formula to calculate the area of a circle. Whether this is due to the lax and inappropriate assimilation of individual concepts and ideas by the students, or simply to a lack of practice in performing these tasks, the end consequence is the same. The students are left with limited avenues to solve a new or novel problem.

In summary, the processes associated with the comprehension of simple models, the ability to use them, to identify their limitations, to adjust existing mental models and to accommodate new information are not currently held in our students’ intellectual tool-kit (at least in the context of quantum mechanics).

The outcome of this investigation has in a sense aligned itself with the findings in other areas of physics educational research on one important issue. Studies into mechanics, optics and electricity have found that the preconceptions held by students do not change easily.

## 6.2 IN SEARCH OF THE REASON

Reviewing the points identified in the previous section it is entirely possible that the teaching and assessment strategies commonly adopted by physics departments are encouraging exactly the kind of fragmented conceptual development being observed. The difficulties that students are encountering may merely be artefacts of the educational system. The majority of students view the physical sciences as hard sciences. They also perceive there is a right answer to any problem and view the world by using simplistic models usually summarised by a

single formula. They seldom realise that real world physics problems produce “fuzzy” answers which are subject to a multitude of constraints.

The current educational system does not readily reward students who explore the boundaries of their mental models. Seldom are the assessment tasks any more complicated than restating a law or selecting the appropriate formulae, and substituting in values in order to solve an idealised problem. Indeed it could be argued, on the results of this study, that the system has not adequately provided any consistent models for the students to explore.

### 6.2.1 Morals Drawn from Our Results

#### *Be aware of difficulties students have with concepts*

New concepts must be connected with pre-existing knowledge. Once these connections are made they remain steadfast and are not easily remapped with more appropriate connections over time. This reluctance to change can be seen in the way mental models are constructed. Our results suggest that the old models are simply added to with new ideas and the whole structure remains basically the same over time. The students do not appear to challenge their conceptualisations and rework the structures to ensure their validity or usefulness. As a consequence, students have great difficulty interpreting data utilising their own mental models or by using a presented model that requires the concepts to be interpreted.

#### *Be aware of background they bring*

Obviously the preceding moral carries with it the message that the knowledge brought into the teaching environment will be used as a foundation for the students to assimilate new materials. This study, for example, revealed that waves were only superficially understood and that students cling to their secondary school ideas. Might it then be argued that waves be taught properly before introducing quantum mechanics? There would be grounds to direct effort to make the students reorganise their mental models into consistent and useable tools, instead of the apparently unstructured collections of tacked-together concepts.

#### *Be aware of the teaching philosophy in physics*

It was pointed out earlier that there is a strong tradition in physics departments for ‘transmissionist’ education strategies – teach them how to do the subject first, and let them worry about what it means when they get to research level. Perhaps it is time to query that tradition, especially if, as suggested at the

start of the study, there is an increasing need for quantum mechanics to be understood by professionals who will never be researchers.

It should also be noted that the same teaching philosophy is present in the majority of texts. The teaching methods employed and the textbooks chosen strongly favour an operational approach rather than deep conceptual understanding.

### 6.3 TEACHING STRATEGIES

The morals drawn from the investigation point toward some possible teaching strategies. Each strategy has merit but also comes with its own set of difficulties.

#### 6.3.1 Possible strategies

##### *Reject an historical approach*

This approach is particularly advocated by the German school of physics educational research<sup>1</sup>. Make a break from the conceptions of the mechanical models portrayed in classical physics. The use of such models sets up additional obstacles for the appropriate understanding of quantum physics (Fischler and Lichtfeldt, 1992). Introduce quantum mechanics as a fresh new subject and do not present or relate the concepts to any previous work. The rejection of an historical approach would stimulate and increase the level of cognitive conflict by making the students think more about the new concepts and how they might relate to preconceptions, concepts and ideas they possess.

The aim of this strategy is to minimise the stumbling blocks by removing the avenues that would potentially develop inappropriate foundations that the student would want to build upon. The major drawback of this approach is that the majority of educational material uses a historical approach as a launching point for the topics, therefore new teaching materials would be required to implement this strategy.

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<sup>1</sup> Refer to bibliography regarding the German school of physics educational research. Fischler, H. and Lichtfeldt, M., specifically the papers entitled "Learning Quantum Mechanics" and "Modern physics and students' conceptions".

### *Technological approach*

Ignore the historical and conceptual approaches and teach the students how to solve technical problems related to specific industrial applications. This approach may be appropriate in advanced trade and technician courses. Computer simulations could be utilised to great effect in the description and testing of various scenarios. For example, increasing the temperature at a semi-conductor junction could easily be simulated. Other areas such as imaging techniques in nuclear medicine, the operation of photomultipliers used in industry and processes in chemistry would lend themselves to this mode of teaching.

The main advantage would be that a broader range of students would be familiar with the application of quantum theory. The disadvantage would be again that there are no (or very few) teaching materials which show how such an approach could be implemented in practice. It also seems to fly in the face of most accepted pedagogical theory that concepts like the ones we have been investigating should be introduced to students without some attempt to explain what they “mean”. And once you try to do that, how else but by a traditional approach?

### *Concentrate on misconceptions*

In other areas of tertiary physics teaching where somewhat similar difficulties have been recognised, there is apparently widespread agreement on a solution. The work of Edward Redish, Ronald Thornton and Lillian McDermott and others<sup>2</sup> concentrates on the idea of focussing on individual “misconceptions” and “correcting” these. This is often done by isolating the misconceptions associated with the subject material and developing questions and materials that expose or challenge the students’ preconceptions, with the idea that a scientifically correct conception will supersede the misconception.

The major disadvantage of this strategy is that it does not necessarily guide the students towards more complete holistic mental models. For example, students in classical mechanics can remove many of their misconceptions relating to Newton’s Laws using this strategy. But if they are then confronted by a novel circular motion problem a new set of difficulties is revealed, thus suggesting that the mental models are still incomplete.

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<sup>2</sup> For a comprehensive literature reading list refer to the University of Maryland, Research in Physics Education (RIPE) WEB site (URL <http://www.umd.edu/ripe>).

### *Model orientated approach*

Again reject the notion of the historical approach. Introduce quantum mechanics as a simple model that is capable of describing the micro-world. Explain and make clear that it does not describe the processes, only the outcomes of experiments. Reinforce the fact that the quantum mechanical model is based on postulates and is supported by complex mathematical tools.

The whole emphasis of the subject's delivery would be based upon examining a selection of parts of the quantum mechanics model. The development path of mental models would allow the students to first answer novel questions in a non-mathematical manner and then later apply the mathematical tools to solve problems. The student would therefore not be expected to derive complex mathematical formulae but they would be expected to show how they relate to the postulates and how each variable in a formula fits into the scheme of things. The rigorous derivations would be left until honours and research years.

The major advantage of this approach is that the educational resource materials already available would be useable. In the medium term the development of some less mathematically rigorous reference books would be required. The current problem of having to spend a substantial portion of second and third year teaching students the required mathematical skills would be minimised.

Major drawbacks would include the fact that students would be introduced to new concepts each session. They would need to study and examine these in depth to ensure the subtleties and implications are recognised. A student who did not think about the ideas could miss important relationships and would be in danger of becoming very confused. Additional lecture and tutorial materials would need to be developed to minimise this problem.

## 6.4 REVISITING THE INITIAL QUESTIONS

### 6.4.1 What is quantum mechanics?

This question cannot be answered by any simple statement without first acknowledging that the answer will be entirely dependent upon the view taken. Leading physicists perceive the subject as a model with enormous complexity, containing subtle nuances and based upon a set of postulates. Physicists have built

a scaffold of complex mathematical frameworks that not many people could claim to understand.

On the other hand an electrical technologist dealing with semi-conductor components may only utilise a specific set of formulae drawn from the theory to control or design manufacturing processes. A simple description of quantum mechanics is therefore quite different depending upon its final purpose or application.

Accepting this line of argument, the challenge posed is to ensure that our students understand that the subject stretches from developing quantum theory through to industrial applications. The current postulatory approach which is shrouded in mathematical complexity may need to be made more accessible to a wider range of students.

#### 6.4.2 Importance of teaching quantum mechanics

The central argument described in chapter 1 still stands. Quantum mechanics is the theoretical foundation of all modern theories dealing with the structure and properties of matter. It is therefore important that all students of science and engineering have ready access to the information appropriate to their fields and an appreciation of the scope of its importance to other disciplines. The great challenge is to find a way to do this which avoids the difficulties we uncovered in the project.

#### 6.4.3 Research questions

*Is it possible to identify the most important concepts?*

Obviously the question has no simple answer. As previously mentioned the students who are studying quantum mechanics will require different types of conceptual understanding to be “successful” within their chosen fields. Therefore the question becomes broader and the focus shifts from individual concepts to how best our students can be prepared to apply quantum mechanics within their discipline. If we change our assessment practices so that “success” is equated with developing the kind of mental models characterised by relational richness, then our students will fairly soon work out how to attain that kind of success.

*What makes quantum mechanics difficult?*

The current students have constructed mental models to represent the abstract concepts of quantum mechanics which have very little support from anything else in their experience. Pines and West have offered a metaphor for the social constructivist theory of learning, as climbing plants growing on a trellis, the shoots growing upwards representing what students construct for themselves from their own experiences (Pines and West, 1983). In this metaphor, the quantum mechanical mental models of the present students are slender tendrils indeed, completely unsupported by neighbours.

It seems that this interpretation of the observations might yield the answer to the question. When asked directly why quantum mechanics is difficult most senior students answer something to the effect: "It's all mathematics". Our conclusions suggest this means that the mental models they are working with are tenuous constructs, extended far beyond the point where they are buttressed by perceived relationships with other, better understood concepts.

We believe that this is not really the answer. It is well documented in educational literature that students sometime have difficulties in reorganising the critical features of new concepts with their previous experience, or in developing mental models by adding new understandings, or in efficiently using mental models to interpret situations.

In learning quantum mechanics students face all these difficulties. As we have shown there are many new and unusual ideas to be taken on board, these often are quite counter-intuitive and do not seem to relate to anything else in the student's experience; often very little subsequent teaching is devoted to reinforcing what they already know; and assessment practices rarely reward student's attempts to explore the functionality or beauty of models.

Perhaps this is what makes quantum mechanics so difficult.

## 6.5 POSSIBLE FUTURE DIRECTION

This study has identified a number of interesting points. It is recognised that there are a number of shortcomings mainly concerning the reliance on written responses taken in a short time, what is needed now is to undertake an extensive

program of student interviews to confirm that our interpretations of what they are thinking is correct.

Additionally the development of a more streamlined survey instrument that could be used earlier in a course as a diagnostic instrument and formative feedback would prove invaluable. This study has provided the basic foundations to embark upon a longer research project to further explore the questions surrounding this topic<sup>3</sup>.

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<sup>3</sup> This is, of course, a simple but prominent artefact of Psysethian Logic. The Great Super-University-MAN himself (known in parental circles as Suman Seth), with whom I often frequented the Box Office Cafe and consumed copious quantities of cinnamon toast and soy-eco shakes, whilst discussing important matters concerning the philosophy of physics. He will no doubt be recognised as a world figure; and this my friends is the first reference, to this yet to be known fact. His logic, that of the Psysethian, will soon be the pointer for all to follow.

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