BOUNDED RESEARCH FOR QUENTUM MECHANICS

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ABSTRACT

This thesis presents a comprehensive review of research into students' depictions of quantum mechanics. Taxonomy to describe and compare quantum mechanics education research is presented, and this taxonomy is used to highlight the foci of prior research. A brief history of quantum mechanics education research is also presented. Research implications of the review are discussed, and several areas for future research are proposed. In particular, this thesis highlights the need for investigations into what interpretations of quantum mechanics are employed in teaching, and that classical physics – in particular the classical particle model – appears to be a common theme in students' inappropriate depictions of quantum mechanics. Two future research projects are presented in detail: one concerns inter-pretentions of quantum mechanics, the other concerning students' depictions of the quantum mechanical wave function

INTRODUCTION.

Introduction to quantum mechanics

This section briefly introduces one way of looking at quantum mechanics. The description follows the so-called modal interpretation of quantum mechanics, although this will not be particularly important at this introductory level. It is, however, important to note that this is *one* way of looking at quantum mechanics. I have chosen this view because I believe it to be relevant for a non-physicist reader. It introduces quantum mechanical concepts in a way that (hopefully) can be understood without prior knowledge of quantum mechanics or sophisticated mathematics. Some limitations of this particular view are discussed in the end of this section.

Introduction to the problem

Possibly the greatest joy of conducting education research in quantum me-chanics is the feeling of making a substantial contribution to a research field that is very important. Although I am aware that each researcher probably considers her or his own research field as particularly important, I cannot help feeling that I am particularly favored in my choice of research field, since the necessity of quantum mechanics education research is dramatically obvious Why is this? In short, it is because quantum mechanics is an extremely important and influential physics theory, and because teaching and learning quantum mechanics is a challenging task for both lecturers and students. In this section I will elaborate on this, in order to make the importance of quantum mechanics education research clear.

Influence of quantum mechanics outside physics

However, I am not completely satisfied with the conclusion that quantum mechanics is important in physics. Yes, quantum mechanics *is* an extremely important theory in physics, but the importance of quantum mechanics goes well beyond physics theories. To make this clear, we will also ask a few other imaginary representatives from other professions. An engineer familiar with quantum mechanics would tell us that if it was not for quantum mechanics, we would not be able to make semiconductors in the way we do today. This means, for

example, that we would not have cell phones, LCD displays, computers, light emitting diodes, and basically all other electronic equipment. A medical doctor would add that we, among other things, would not have magnetic resonance imaging; a powerful tool used for imaging the inside of our body. Also, the medical doctor would agree with the molecular biologist that quantum mechanics has made it pos-sible to simulate how medical substances interact with the proteins of our body – an efficient and safe first step in testing new medical substances. If we would go on to ask a science fiction writer about quantum mechanics, she or he would probably get excited. The writer would talk about quan-tum computers that are immensely more powerful than our ordinary computers; about quantum teleportation, creating an exact replica of whatever is teleported and at the same time destroying the original; or about quantum cryptography, a way of transmitting information without even a theoretical possibility of eavesdropping. This may seem a bit far-fetched, and indeed, quantum computers and quantum teleportation still have a long way to go before they can leave the laboratory environment.

Phase A: starting point

The purpose of doing this literature review was to get to know the field in which I intend to conduct my own research. When starting the literature review, I already had some ideas regarding the focus of my research. Thus, articles that focused on these planned research topics were read with greater interest and detail.

The research topics of particular interest were the following:

- students using classical depictions to describe quantum systems;
- surveys for investigating students' depictions of quantum mechan-ics;
- inappropriate depictions linked to pictures and diagrams in quan-tum mechanics teaching and textbooks.

Phase B: pre-study

The first part of the literature study concerned research in students' depic-tions of orbitals and toms. This topic was covered in quite some detail, and during this phase the method of working was anged and refined. The results of the research were summarized in a separate review, which intended to distribute to quantum mechanics lecturers. This was not done to the extent that winitially planned, but the goal of presenting the results still guided the work of gathering quantum mechanics education research and summarizing it in an accessible and accurate way. The result is presented in

Phase C: main literature study

In the main part of the literature study, considerable effort was put into gath-ering articles and references concerning quantum mechanics education. When any article was read particular attention was put on the reference lists, and all articles that seemed of any relevance were located and gathered as far as possible. Even articles that could not be accessed were entered in the ref-erence manager, along with any useful notes.

- The main method of locating articles was using internet and library searches. The main article retrieval method was electronic library resources, complemented by physical library resources and e-mailing authors. All available literature was gathered; not only published articles, but also con-ference presentations, proceedings, theses, and unpublished monographs. The gathered material was stored and catalogued electronically, with very few exceptions.
- The reading of articles was somewhat themed, either focusing on a par-ticular author or on a particular sub-topic. However, the order in which arti-cles were read was not particularly strict, and generally focused on articles that seemed the most interesting.

CONCLUSION

- In summarizing research into quantum mechanics education, it also becomes possible to draw conclusions on a larger scale. Paper 1 presents a number of important future research topics.
- These questions involve not only extending research to include large-scale studies and more advanced quantum mechanics topics, but also inves-tigating what interpretations are employed in quantum mechanics teaching. It is also suggested that investigations into the relation between classical mechanics and quantum mechanics in students' depictions is an important key for understanding the learning of quantum mechanics.

Research questions

Again, proposed research questions are divided into one overall and several detailed research questions. The overall research question is:

- How do quantum mechanics students depict the quantum wave function?

In particular, this will be investigated through the following questions:

- How do students who have successfully passed quantum mechanics courses depict the quantum wave function?
- How do students who struggle with introductory quantum courses depict the quantum wave function?
- How do students depict the relation between the quantum wave function and its associated particle?
- Do students use a consistent depiction of the quantum wave func-tion when presented with different physical situations?

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