Proposal: What Does It Take To Effectively Teach Quantum Computing

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Abstract – The next technical revolution will not be seen in the advent of more transistors packed onto a microchip, a new programming language, or a new algorithm. Instead qubits, superposition, tunneling, and quantum teleportation are the buzzwords which will be heard around the water-coolers of tomorrow's offices. It is the intent of this study to conduct a survey of a graduate student body to determine the best methods, materials, and delivery systems required to best educate current engineers and technical leaders in order to interface with the first mainstream generation of such machines.

1 INTRODUCTION

For the past few decades, semiconductor development has roughly followed Moore's Law of doubling of the number of transistors every two years. However, with modern lithography reaching 10nm sized transistors the manufacturing technology is hitting the limits of what is physically possible (Wang, 2012). Quantum Computing is poised to take the helm as the next revolution in technological advancements. Alongside classical computers, Quantum Computers will allow unprecedented performance boosts in applications such as AI, Big Data, and Machine Learning which is applicable to a number of fields in medicine, manufacturing, architecture, engineering, and other technology based industries.

Quantum Mechanics presents its own set of challenges, residing in a world with "strange" behavior, phenomena and effects on surroundings. Although some courses on teaching Quantum Mechanics and Computing have been developed, there is no cohesive, standardized effective course material to bring the necessary knowledge to engineering students, technical leadership and professional engineers who will be tasked with interfacing with Quantum Computing machines in the coming years (Krijtenburg-Lewerissaet al, 2017).

Most research into teaching methods presents a theoretical curriculum, application, or resource and then tests it on a cohort of students. One missing element is the feedback from current students into their own educational perspectives on advanced topics. The Georgia Institute of Technology Online Masters of Computer Science cohort provides a unique student body, learning advanced technological and conceptual concepts, while also working in the area of interest most likely to be affected by the Quantum Computing revolution. It is this cohort which must be surveyed for best practices, material, and teaching methods that are most effective in presenting, teaching, and retaining advanced concepts.

2 RELATED WORK

2.1 Teaching methods

The current set of teaching methods for delivering abstract physics concepts to students is very limited. (Krijtenburg-Lewerissa, 2017) concludes that, in general, there is a severe lack of assessment tools to determine best practices, study material, and delivery method for teaching Quantum Mechanics. Additionally, there is a lack of standardization of teaching method across the discipline, leading to students who do not understand a concept, misunderstand facts or lack the necessary tools for proper information retention.

Furthermore, traditional lecture-style teaching methods common to most universities appears to be least effective in garnering interest, retention and understanding of such concepts. (Deslauriers, 2011) concluded that interactive engagement produced noticeable better retention rates in students while maintaining proper understanding of advanced material. Similarly, (Hackathorn et al, 2011) present a study of most common teaching-styles (lecture, demonstrations, discussions and in-class activities) and their effectiveness in advanced material retention and comprehension. Lectures and Demonstrations proved to be least effective in fostering student understanding. Discussions appeared to have a negative effect, as wrong ideas have an equal opportunity to confuse and lead students astray. Unequivocally, in-class activities proved to be most effective at cementing conceptual understanding, content retention, and garnering interest in the subject being taught.

2.2 Study Material

As the subject of Quantum Mechanics and Computing transitions from theoretical physics to mainstream adoption, the material presented to students and professionals of a broad range of disciplines must also adjust. Many concepts and background theories can be relegated to deeper studies whereby the basic understanding and comprehension can be presented to students in a simpler form. (Freericks, 2007) presents one such study where a MOOC class developed to teach Quantum Mechanics without advanced prerequisites successfully completes the study of over 14,000 students. Similarly, (Kohnle, 2010) study of undergraduate Quantum Mechanics curriculum emphasized the fact that the material is not dependent on mathematics beyond Linear Algebra.

Furthermore, the material itself requires a specific plan of delivery in order to maximize retention and comprehension. (Kohnle, 2010) suggests the best method of delivery to include short articles which can be digested at the student's own leisure in congruence with simulations and laboratory studies during class which demonstrate the effects of the concepts being covered. The need for original content is further emphasized as (Westfall & Leider, 2018) note that most student resources are written by, and for, physicists and mathematicians. The authors suggest that educators should redesign, and present their own concept, for a curriculum void of unnecessary complexity while retaining the necessary information for full grasp of complex concepts.

2.3 Content Delivery

One of the most difficult, and least explored, areas of education technology in regards to Quantum Mechanics is that of Content Delivery. The Quantum world is unlike that of the one we live in. "Spooky" behavior such as Quantum teleportation, superposition, parallel universes, tunneling, uncertainty and other phenomena which do not exist at the macro scale require equally specialized content delivery mechanism to comprehend. As such, the Virtual Reality technological advancements may allow students to explore impossible worlds, and control their environment from perspectives of molecules, particles, or even waves. (Dede et al., 1997) present one such study where Virtual Reality technology was used to allow students to explore physics principles as particles. Most importantly, the students were given tools to manipulate their world, allowing exploration of underlying principles usually represented as variables or coefficients which could now be interpreted as interactions.

In a similar study by (McGrath et al., 2012), the authors noted an increase in collaborative discussions among students as well as a better fundamental understanding and conceptual grasp of advanced subjects. A common trend across multiple studies is the call for more, extended and refined controls of the world that the students are interacting with in their Virtual Reality. Finally, (McClellan, 1994) provides a comprehensive review and a compelling argument at how Virtual Reality can indulge and involve all five intelligences (spatial, bodily-kinetic, logical-mathematical, musical, linguistic, interpersonal and intrapersonal) in the absorption of study material and information. Senses such as smell, taste, navigation, and the ethical implications of mimicking them in Virtual Reality are all discussed in the broader sense of delivering information to the human mind in previously unimaginable channels.

3 PROPOSED WORK

The proposal centers on designing a survey-based research study. The survey will focus on three core areas of teaching advanced subjects: Teaching Methods, Study Material, and Content Delivery. Teaching methods will explore, amongst other things, student's affinity to lecture, discussion, demonstration or hands-on teaching styles. Study Material will explore the depth and breadth of material that students prefer to cover in classes. Content Delivery will explore various modes of information absorption by the students; in-person, MOOC, Virtual Reality, or other. Finally, the cohort will consist of student in graduate level Computer Sciences or Engineering disciplines. They may be working professionals in the field or technical leaders and managers and may range in age from 18 to 99.

It is evident, from past research, that there are many unknowns and a general lack of standardization in teaching such advanced subjects as Quantum computing. Many researchers have made attempts to categorize the material that is easiest to grasp, create software to bridge lack of knowledge, or design curriculum which can cater to the individual student. None, so far, have gone to the lengths of surveying the actual student body, most of which will have to use the technology in the coming decade, as to their preferences, abilities, and struggles in absorbing complex material and how they would want to structure such a class to achieve the best learning outcome.

While the previous studies provide observations or solutions looking for the problem, this study intends to provide the needs, challenges, and possible guidelines by which to design a class to fulfill the learning necessities of the incoming student population.

4 DELIVERABLES

4.1 Intermediate Milestone 1 (Due 28th June 2020)

For this milestone, the delivered material will include the concept, sections, and the entire content of the proposed Survey.

4.2 Intermediate Milestone 2 (Due 12th July 2020)

For this milestone, the delivered material will include the survey results, summary, and takeaway after two weeks of survey respondents.

4.3 Final Project (26 July 2020)

For the Final Project, the delivered material will include the final version of the survey, the statistics of the responses as well as the analysis of the responses with a summary of the results.

4.4 Final Presentation (26 July 2020)

For the Final Presentation, the delivered material will be a PowerPoint presentation, recorded as a video. The presentation will consist of the material in the Final Paper and Project, presented in a visual manner.

4.5 Final Paper (26 July 2020)

For the Final Paper, the delivered material will be a 12 page paper on the background, survey design, and summary of the conducted research study.

5 TASK LIST

Week		Task Description	Time
6	06/15-	Gather topics to cover in Survey	5 hrs.

	06/21	Formulate and format survey questions	10 hrs.
		Status Check #1	
7	06/22-06/28	Gather feedback on questions	10 hrs.
		Revise and rewrite the survey	5 hrs.
		Status Check #2 – Deliver Milestone 1	
8	06/29-07/05	Post survey on Piazza, GT Survey, Reddit, and other.	5 hrs.
		Gather and analyze responses	10 hrs.
		Status Check #3	
9	07/06-07/12	Analyze survey responses	10 hrs.
		Summarize results	5 hrs.
		Status Check #4 – Deliver Milestone 2	
10	07/13-07/19	Draft Project (Survey with Analysis)	5 hrs.
		Draft Presentation	10 hrs.
		Draft Paper	5 hrs.
		Status Check #5	
11	07/20-07/26	**Finish and Deliver Final Project**	5 hrs.
		Finish and Deliver Final Presentation	5 hrs.
		Finish and Deliver Final Paper	10 hrs.
		Total	100 hrs.

6 REFERENCES

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