# Synopsis of Teaching Advanced Subjects and Survey on Studying Quantum Computing

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***Abstract*** – Quantum Computing is an emerging field of advanced technology poised to revolutionize the modern way of life. Adult education of this subject is lagging and lacking the necessary support to be effective. Educators focus on adapting currently established, but limited, coursework to serve this purpose. As such, it I evident that there is a need for comprehensive research of the adult student population in search for the right way to develop, deliver, and inspire current engineers and technological leaders into adopting Quantum Computing into their technological stack.

## 1 INTRODUCTION

For nearly seven decades, Moore's Law has dominantly guided Microprocessor manufacturing. As transistor size reaches the limits of physical possibilities (Wang, 2012), the Quantum world takes over, opening the door to new laws of physics, new technological advancements, and new areas of study. Based on this, the technological evolution of computing is spearheaded by Quantum Mechanics as Quantum Computers begin making their way to real-world applications. In the coming years, Quantum Computer will become an indispensable staple in modern technologies and everyday life. Artificial Intelligence, Big Data Analytics, Machine Learning and other hot topics will see a thrust of capabilities, previously unattainable by Classical Computing. Quantum Computers will join Classical computers as vital tools in the fields of medicine, manufacturing, architecture, engineering, and other industries.

In order to prepare current students, industry professionals and technological leaders of the world to be ready and eager in integrating Quantum Computing (QC) into their technological stacks, education of these groups on the topic becomes increasingly important. There are several in-person or on-video classes, educational textbooks and other resources available to educate oneself. However, as (Krijtenburg-Lewerissa et al, 2017) has noted, there is no cohesive, standardized and effective course material. For such a complex subject, involving "strange" particle behavior, counter-intuitive interactions and unexplained phenomena to be boiled down and restructured for the general well-educated but subject-illiterate public to comprehend requires a deep understanding of the target audience, their needs, and best methods to reach understanding and comprehension.

While some research has been conducted on the matter, most has been from the perspective of academic researchers exploring different options on a cohort of students. The subject of the individual student, however, has been generally ignored. The focus of this paper, as such, is to broadly survey a representative cohort of the well-educated technological industry professional and determine best methods, practices and materials required to provide the necessary foundation for integrating Quantum Computers into the existing technological stacks.

## 2 SURVEY METHODOLOGY

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 mate-rial 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.

## 3 SURVEY RESULTS ON 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. Furthermore, traditional lecture-style teaching methods common to most universities appear to be least effective in garnering interest, retention and under-standing of such concepts.

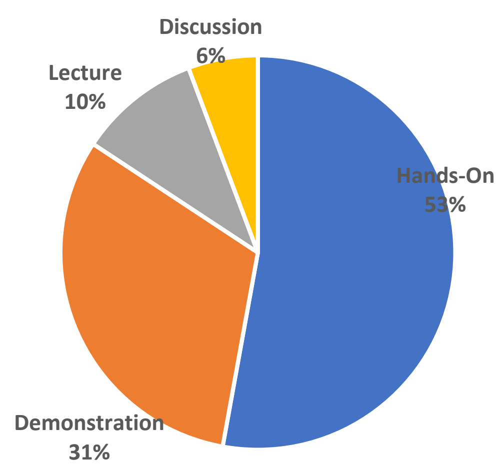


*Figure 1: Survey on Teaching Style*

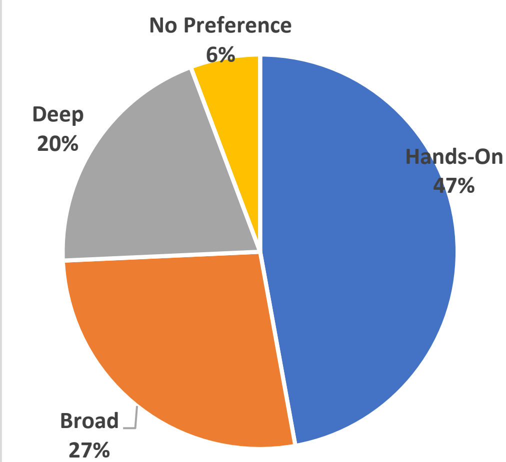


*Figure 2: Survey on Knowledge Depth*

As expected, the survey results in *Figure 1* validate the background research, showing that most students (53%) prefer hands-on style learning instead of Lectures, discussions, or demonstrations. It is interesting to notice that demonstrations are a close second option for students. This is due to the fact that demonstrations provide a practical usability display for a student, even if they cannot interact directly with or explore further the methods being displayed. Lecture and Discussion further removes the student from direct interaction with a phenomenon, thus being generally regarded as least effective in effective knowledge transfer. In correlation, *Figure 2* demonstrates students prefer knowledge gained to be that of hands-on, rather than theoretically deep or surface-level broad. Students tend to desire class material to reflect the need for direct applicability in their current working conditions. Similarly, the target cohort, being working professionals, have no need for deep knowledge into particulars of a phenomenon or surface level knowledge which bars the student from feel armed with the right knowledge to use the material in their work.

(Deslauriers, 2011) concluded that interactive engagement produced noticeably 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.

Furthermore, the target cohort determined that peer interaction is an important part of studying, but it must also be paired with individual research, software-based assignment, and other materials used to solidify knowledge.

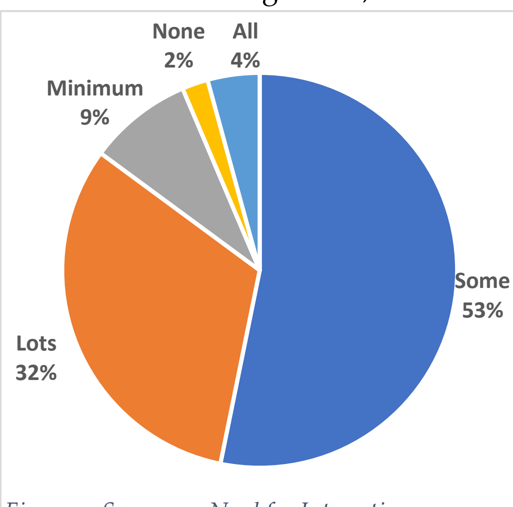

*Figure 4: Survey on Need for Interaction*

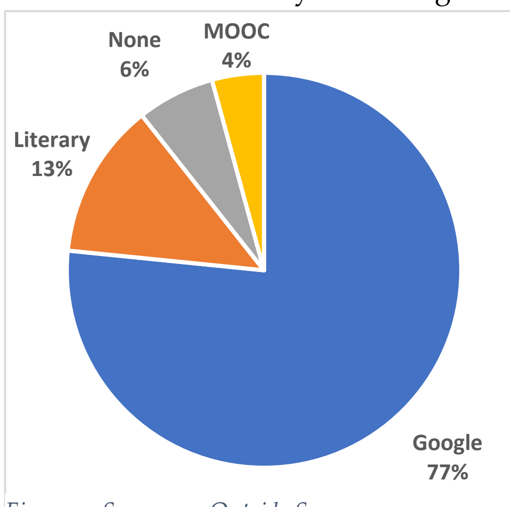

*Figure 3: Survey on Outside Sources*

*Figure 3* clearly demonstrates a majority preference for only some interaction with Professors/Teaching Assistants/or Peers whereas *Figure 4* provides context into the fact that an overwhelming majority of students rely on Google (or similar) search in order to fill in the gaps in knowledge, rather than relying on literary scholar search or supplemental course studies.

## 4 SURVEY RESULTS ON CONTENT 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.

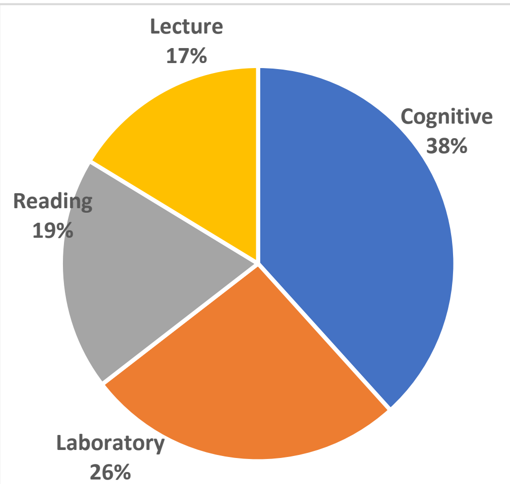

*Figure 5: Survey of Effective Study Material*

*Figure 5* shows an interesting trend in survey answers by the target cohort. The conclusion of the Section on Teaching Methods was that students generally have a strong preference for hands-on learning allowing for better comprehension and material retention. The survey results for individual student study material, however, suggests that Lecture and Reading material is valued in supporting and solidifying new knowledge. However, considering the true meaning of Laboratory Experimentation and Cognitive problem-solving tasks, one may consider the two to be part of the same action – active problem solving. Similarly, Reading and Lecture Material can also be grouped into passive knowledge absorption. Thus, with this redefinition, the survey results can be interpreted as 64% students preferring hands-on problem-solving study material, while 36% would prefer to read or review lecture notes. This perspective reinforces similar findings for Teaching Methods which shows student preferring hands-on problem-solving as the Teaching Method for best information retention.

(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.

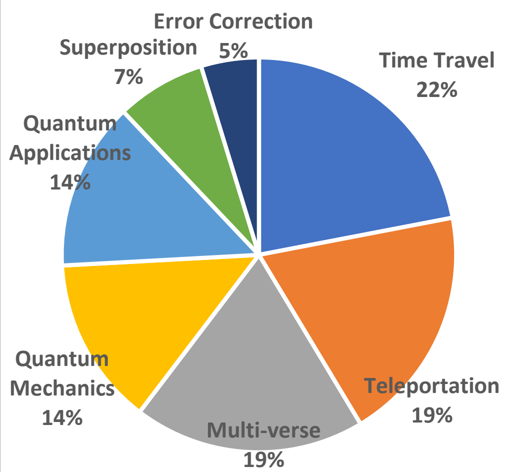

*Figure 6: Student Interest in Quantum Topics*

A survey on topics of Quantum Mechanics and Computing, commonly found in teaching material yielded interesting results. "Buzz-words" such as Time Travel, Teleportation and Multi-verse garnered the most attention while not being fundamental phenomena that a broad survey course in Quantum Computing would cover. However, Superposition and Error Correction which are vital topics as well as Quantum Applications account for only 26% of interest by the responders. These results show that in order to shift the general comprehension of Quantum Computing, study materials which express interested parties, must reflect and draw in interest to the necessary topics and concepts required.

## 5 SURVEY RESULTS ON LEARNING ENVIRONMENT

One of the most difficult, and least explored, areas of education technology in regard to Quantum Computing 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.

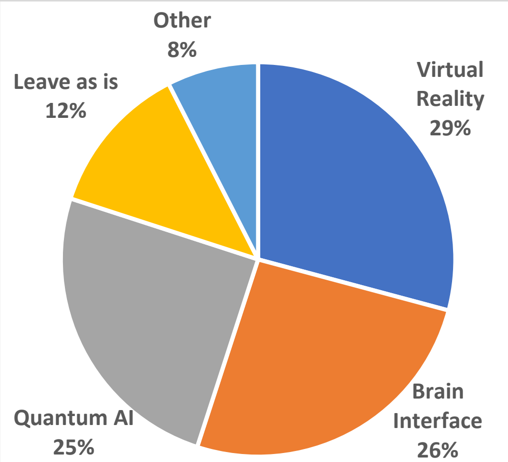

*Figure 7: Survey on New Teaching Technologies*

A survey on new-age technologies which are poised to revolutionize Educational Technology field supported the premise that Virtual Reality classrooms are a viable choice for the future of education. *Figure 7* demonstrates that almost 1/3$^{rd}$ of the respondents felt Virtual Reality was a good teaching environment for complex subject studies. Considering the alternative technologies presented to the students are much further from mature technological realization, Virtual Reality is the most promising technology for the near future.

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.

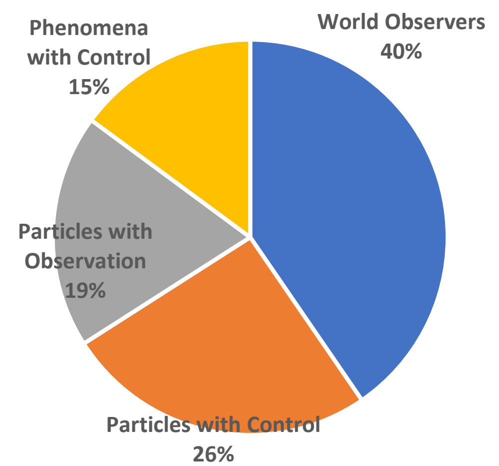

*Figure 8: Survey on VR Control*

A survey of the student cohort in other preferences for manual control of a virtual world yielded surprising results. *Figure 8* results show a majority of 59% of responders who would prefer to be observers of a Quantum World with 41% which would actually prefer to have control over their world. The irregularity of tis survey may stem form many variables. Prior researchers had students actually use Virtual Reality simulations, before surveying the students. Consequently, this survey did not expose the target cohort to any technology so as not to bias their answer in any way. As such, this response may require further refinement and investigation.

## 6 SURVEY SUMMARY AND LIMITATIONS

Quantum Computing, the technological revolution building up in hype, hearsay, and misconceptions yet poised to usher in a new era of computing capabilities. Incomprehensible by most, the fact that our lives will depend on it is quickly becoming a reality. As such, the survey conducted has validated prior research, brought to light some irregularities, and illuminated insights into the perspective of a student cohort, themselves industry professionals which may soon be faced with the challenge of interfacing with Quantum Computers as part of their job.

The goal of this survey was to determine, form the student perspective, best methods, materials, and tools needed to teach advanced subjects, such as Quantum Computing, in a way as to drive interest, comprehension, and material retention. Considering the responses and statistical significance of the answers provided, the survey was successful in determining the student perspective in the matter.

Students generally agree that hands-on learning and laboratory experimentation is better approach to learning rather than dry reading and lectures. Most students rely on some peer or educator feedback but also regularly rely on

Google search to fill in gaps in understanding. Quantum Computing itself, being a broad topic with many details, must be presented to such abroad student body in the right manner, as to teach the necessary material without loosing focus of what is most important to comprehend. Finally, Virtual Reality is a modern technology best suited to present the students with a Virtual Quantum World to observe, interact and learn from as supported by both the current body of research and the survey conducted here.

Some responses were surprising and did not necessarily follow the data suggested by other research. Some limitations of this survey include the absence of any material which is being discussed. Students did not have access to any Quantum Computer, Virtual Reality Headset, example software application or any of the study material. The survey truly demanded a form of thought-exercise from the responders to imagine a possible teaching course on Quantum Computing. This severely limits the capability of the students to respond to certain questions, but alternatively frees the student from any possible bias form using any one particular technology when answering the questions.

## 7 FUTURE WORK

Further research will include example Syllabi, applications, tutorials, and sample Virtual Worlds, built in such a way as to give the respondents a chance to experience some of the technology being discussed. Similarly, as Quantum Computers become more accessible, hands-on exercises may be provided to spark interest I the subject. By providing a taste of the material to the participants, the responses from the students to follow up questions will better reflect the missing pieces for the teaching curriculum which must exist in order to create a well-structured, effective, and revolutionary class on Quantum Computing.

Consequently, some of the information gathered throughout the survey was surprising considering the background knowledge conducted prior to distribution. For example, *Figure 3* shows a medium to high need for interaction form the student respondents with their peer, TAs and/or professors. Future research can focus just on this subject, determining what is the best medium, protocol, or modality in which students should communicate to optimize knowledge gain or retention. Alternatively, an entire field of research can be devoted only to human interaction in Virtual Reality, and what that may loo like if the users are represented as particles in a Quantum World.

Furthermore, Virtual Reality itself must be further researched as a viable medium through which to deliver Quantum Phenomena demonstrations, interactions and control functionality. Since the foundational understanding of Quantum forces may be hinged on proper interpretation of a Virtual World, VR must be carefully constructed in such a way as to be most accurate in it's virtualization.

## 8 CONCLUSION

In conclusion, the field of Quantum Computing is fascinating, mysterious, and vitally important to be studied by a wide variety of educators, students, engineers, and technology leaders. The goa of this survey was to expose the needs of the student in taking such a course and successfully gaining interest in the subject matter. This goal was fulfilled and brought to light even more questions that must be answered.

The survey acted as a baseline with students, to attain a "pulse" on current practices, methods, and efforts which work for the majority of students. In order to create an efficient, effective and optimal class for teaching Quantum Computing, all these things must come into consideration. However, in the course of this survey, new questions have come to light. Student interaction, Virtual Reality content delivery, Study Material and information retention all appearing as topics which deserve dedicated resources for research and further investigation.

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