# Teaching an Elective Course about Quantum Computing

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**Abstract.** In this poster, we report our experience about teaching a one-semester elective course titled "Quantum computer and Computation" at a university in 2022. The course was intended to introduce 85 students from different disciplines ranging from liberal arts to engineering to the basic ideas about quantum computation and the power of quantum computing by exhibiting the existence of computational problems solvable efficiently by quantum algorithms, but not by classical algorithms. Especially, the emphasis was placed on intuitive explanations about the subjects in the course as much as possible because most students in the course had little or no knowledge of quantum physics. This course is offered annually and the objective of the course is to help students become quantum literate.

**Keywords:** quantum computing · quantum litearcy · P vs NP.

## 1 Introduction

This poster is concerned with our experience about teaching an elective course about quantum computing at a university. The objective of the course was to provide students without background in quantum physics with basic ideas about quantum computers as well as simple quantum algorithms that exploit quantum mechanical properties. To motivate the power of quantum computers and the limits of classical computation, we also explained the idea about computational complexity, P versus NP question, and some of well-known classical algorithms.

As was argued in [1], we thought that knowledge of quantum physics would not be necessary to understand basic ideas about quantum computers especially since our goal was not to make experts, but to help students become quantum literate so that they understand basic quantum algorithms and claims made about applications of quantum technologies [2–4].


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## 2 Ongoing and Current Work

The semester consisted of 16 weeks of lectures and the sequence of subjects addressed were as follows.

1. The class started with a motivation to quantum computing by mentioning the Moore's law, quantum supremacy, and quantum parallelism [5–7]. Then, core concepts such as a qubit, unitary transformations, superposition, entanglement, reversible computing etc. were explained. Out of these subjects, students had difficulty understanding entanglement and it was mentioned that Einstein did not believe in entanglement, either even though physicists believe that it is actually what is happening [8]. In addition, a concrete example that illustrates how entanglement can help cut down the number of steps for computation was explained [9]. This part of the course took about four weeks.
2. Then, a typical structure of a quantum algorithm was explained. It was mentioned that the description of a quantum algorithm is done by stational changes over time. While this is similar in classical algorithms, from the perspective of programmers or algorithm designers, it is different in that the description of a quantum algorithm is not done by a sequence of instructions, but by a sequence of unitary operations [10]. In addition to this, it was mentioned that the result of a quantum algorithm is obtained by measuring the state at the end. It took about a week for this part of the course.
3. For the following seven weeks or so, we explained both well-known quantum algorithms as well as classical algorithms.
   (a) More specifically, we started with Deutsch's algorithm to point out that for some specific problem, quantum computation is clearly better than classical computation. Then, we explained Deutsch Jozsa algorithm that addresses a more general situation than the one addressed by Deutsch's algorithm. In addition to these, Grover's algorithm was explained in order to emphasize that the algorithm outperforms classical algorithms for the problem of unstructured database searching. Then, both Simon's algorithm and Shor's algorithm were explained by mentioning their similarity.
   (b) In this part of the course, we also introduced computational problems that are believed to be difficult. These included the integer factorization problem, the graph isomorphism problem, etc. and it was mentioned that Shor's algorithm solves the integer factorization problem efficiently although as of yet we do not know whether classical algorithms could solve the problem efficiently or not.

   This naturally leaded to the discussion of the P versus NP question and the NP completeness of many well-known computational problems. The graph isomorphism problem was mentioned because although many problems believed to be hard are known to be NP complete, it is one of few problems that are believed to be hard, but it is not known yet whether it is NP complete or not. In addition, the status of the integer factorization problem is similar in that although it is believed to be hard, we do not know yet whether it is NP complete or not. At this stage, some classical algorithms that are relevant such as Miller's algorithm, Fast Fourier Transform algorithm, Euclid's algorithm, etc were explained.

4. For the remaining part of the semester, we addressed two views on analyzing algorithms. That is both of the worst case complexity and the average case complexity were explained and differences of these were mentioned. The reason that these were addressed lied in the following two facts. One is that many quantum algorithms are probabilistic by nature [11]. The other is that there are problems known to be hard in the sense that they are NP complete, but these problems exhibit phase transitions [12]. While the latter is not directly related to quantum computation, we thought that would be relevant because the problem that exhibited a phase transition phenomenon (in this case, it is the boolean satisfiability problem) has strange properties in that while it is believed to be hard, for a lot of instances of the problem they can be quickly answered correctly by classical algorithms. Yet, we do not know yet whether it could be solvable efficiently by any quantum algorithm.

## 3 Conclusion and Future Directions

In this poster, we reported a sequence of subjects that we taught in a course about quantum computing at a university. Students who enrolled in this course had little or no knowledge of quantum physics, but most students wrote positive feedbacks about the course in general, although a few students mentioned that the contents were too difficult to follow. It appeared that some students thought that the course was entirely for quantum computation, but there were actually subjects that were not directly related to quantum computation. We believe that it is important to point out that there are certain computational problems that can be solvable by quantum algorithms efficiently, but not by classical algorithms yet. And this inevitably brings up certain aspects of classical computation such as P vs NP question as well as the average case complexity. Currently, we are working on a way to organize the set of concepts and subjects used in the course in a more streamlined fashion in the course to be offered in the fall semester of this year. In addition, we are editing the course materials used in order to give lectures about quantum computing in a high school as a part of lecture series in a high school credit system.

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## References

1. Recent progress in quantum algorithms, Dave Bacon, Wim van Dam, Communications of the ACM, February 2010, Vol. 53, No. 2

2. Hands-on Lab Skills Key for Quantum Jobs, Katherine Wright, 2020, https://physics.aps.org/articles/pdf/10.1103/Physics.13.163. Last accessed 11, June 2023
3. Quantum Physics Literacy Aimed at K12 and the General Public, Caterina Foti, Daria Anttila, Sabrina Maniscalco, Maria Luisa Chiofalo, Universe, 2021, 7(4)
4. The challenge and opportunities of quantum literacy for future education and transdisciplinary problem-solving, Research in science & technological education, 2023, Vol. 41, No. 2
5. Technologies and Computing Paradigms: Beyond Moore's law?, Daniel Etiemble, https://arxiv.org/pdf/2206.03201.pdf. Last accessed 15, August 2023.
6. Quantum computing and the entanglement frontier, John Preskill, https://arxiv.org/pdf/1203.5813.pdf. Last accessed 15, August 2023.
7. An introduction to quantum computing for non-physicists, Eleanor Rieffel, Wolfgang Polak, ACM Computing Surveys, Vol. 32, No. 3, September 2000
8. Explorers of Quantum Entanglement Win 2022 Nobel Prize in Physics, Billings, October 4, 2022, https://www.scientificamerican.com/article/explorers-of-quantum-entanglement-win-2022-nobel-prize-in-physics1/. Last accessed 15, August 2023.
9. Demonstration of essentiality of entanglement in a Deutsch-like quantum algorithm, He-Liang Huang, Ashutosh K. Goswami, Wan-su Bao, Prasanta K. Panigrahi, Science China, Physics, Mechanics & Astronomy, June 2018, Vol. 61, No. 6
10. Quantum computing classical physics, David A. Meyer, Philosophical Transactions: Mathematical, Physical and Engineering Sciences, Vol. 360, No. 1792, 2002
11. Average case quantum lower bounds for computing the Boolean mean, A. Papageorgiou, Journal of Complexity, Vol. 20, No. 5, 2004
12. Computing Science: Can't Get No Satisfaction, Brian Hayes, American Scientist, Vol. 85, No. 2, 1997