Teaching Quantum Computing at a Middle School

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Abstract. The field of quantum computing has been progressing rapidly recently and universities started to offer courses about quantum computing [1]. On the other hand, whether teaching quantum computing at a middle school can be helpful or not has not been explored yet [2]. We believe that it will be certainly helpful because early exposure to quantum computing will help students be quantum literate [3]. In this poster, we report a preliminary result that supports our hypothesis which asserts that teaching quantum computing at a middle school will help.

Keywords: quantum computing · quantum literacy · physical system.

1 Introduction

In this poster, we are concerned with whether it is appropriate to introduce quantum computing to middle school students. It is true that many people are aware of the importance of quantum computing [3] and well known companies such as IBM, Google, Intel etc put efforts to make quantum computers with many qubits, in which a qubit is the unit of information on a quantum computer [4]. However, it may be too difficult for middle school students to understand principles of quantum computation because it requires the knowledge about matrices and other mathematical concepts that students do not learn in schools.

To investigate whether it can help if we introduce middle school students to quantum computing, we organized an introduction course about quantum computing that consisted of two sessions of 45 minutes each in May 2023. The number of students participated in the course was 32 and based on the answers to questionnaires from the participating students at the end of the course, we came to believe that there certainly will be gains for students.

2 Current and Ongoing Work

In this section, we describe the sequence of subjects that were taught in the course. The first session focused on basic ideas about quantum computing and the subjects explained were as follows.

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1. The session started with the general ideas about quantum technologies by mentioning differences between classical physics and quantum physics. Although students do not learn quantum physics in school, most students already heard of it because they knew the movie "Ant-man and the Wasp: Quantumania" [5]. It was mentioned that there is a world that we cannot experience. This naturally leaded to a discussion of differences of the two worlds which are the world that is describable by classical physics and the sub-atomic world that can be describable by quantum physics, respectively.

   Then, Moore's law [6] was mentioned in order to point out one of the reasons why we need a new kind of a computer. It took about 20 minutes or so for this part of the session and generally students did not have difficulty understanding the subjects explained.
2. For the remaining 25 minutes of the first session, a comparison between a classical computer and a quantum computer was made by pointing out a similarity and a difference. They are similar in that both are physical systems [7] whose operations are governed by physical laws. One of their differences is the unit of information used in both types of computers. While students are familiar with the notion of a bit, none of them heard of a qubit previously and they had hard time understanding it.

   It was mentioned that the implementation of quantum computers requires a lot of qubits in general because as the number of qubits increases the number of different possibilities maintained by a quantum computer increases exponentially, which is not possible on a classical computer.

   At this stage, the concept of superposition as well as entanglement were explained and there were questions from some students about why these phenomena occur and how they could be exploited for quantum computation.

The second session focused on hands-on experiences with simple quantum programs and the subjects addressed were as follows.

1. This session began with introducing different quantum operations that can be used for quantum computation. These included Hadamard operation, CNOT operation, and NOT operation.

   Then, we used Azure quantum computing service [8] to run simple quantum programs. Students had to register for the service using Azure for students [9]. After registration, it was possible to run a sample program, "HelloWorld" written in Q# programming language [10].

   While students did not have any experiences about quantum programming, the code was relatively straightforward and they could see the result of executing their first quantum program on their computers. It took about 20 minutes for this part of the session.
2. For the next 15 minutes, a second quantum program written in Q#, "BellState" was explained. Unlike the first program, the code was relatively complex and the teacher explained the code on a whiteboard. In addition, the

result was shown on the teacher's computer. This was a hardest part of the entire sessions and we thought that it would be better to use a different example to explain the idea of quantum entanglement.

3. For the remaining part of the session, we asked questions about whether they got interested in quantum computing as well as whether they had intentions to take a more comprehensive class about quantum computing. Most students responded positively to the first question while a few students mentioned that they would like to learn more by taking a comprehensive class if it is offered.

3 Conclusion and Future Directions

In this poster, we reported our experience about teaching quantum computing at a middle school. Before we gave an introduction course, we thought that not many students would be interested in knowing principles of quantum computing. On the contrary, what we found was that most students were interested in the subjects that were explained during the course. It is expected that computer science educators will play important roles to make quantum computing technologies accessible to all levels of audiences [11]. In addition, a quantum computing course can be a good example of STEM education [1]. Currently, we are investigating ways by which the same subjects can be introduced with more intuitive and simpler examples than what we used. For example, we may adapt the CHSH game [12] to explain the concept of entanglement as a game. In addition, we plan to explore how quantum computing fits into STEM education.

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