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A Literature Review of Quantum Education in K-12 Level

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A literature review of quantum education in K-12 level

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Abstract: Quantum computing is a new computing model that has the ability to tackle computational problems that are now unsolvable using traditional computers or digital technologies. Since quantum learning is a long process, it is necessary to teach quantum concepts early in K-12 schools in order to develop a highly educated and competent quantum workforce that matches future industrial demands. Students often begin learning physics in high school since essential quantum knowledge are derived from physics. We did a literature review with a focus on quantum computing education at K-12 level and addressed the research gap since resources and curriculum design for quantum education at the K-12 level are few.
Keywords: Quantum education,Quantum computing,K-12,Quantum information science

Introduction

Quantum computing is an emerging technology paradigm of computing and has the potential to solve computational problems intractable using today's classical computers or digital technology (Franklin et al., 2020). The power of quantum computing technologies is based on the fundamentals of quantum mechanics, such as quantum superposition, quantum entanglement, or the no-cloning theorem (Gyongyosi & Imre, 2019). Quantum computing is expected to be disruptive for many industries. It is estimated to have almost 600,000 new jobs in the quantum area in 2040 (Venegas-Gomez, 2020) and numerous industries will need a lot of professionals specializing in quantum computing. To build a highly trained and skilled quantum workforce that meets future industry needs, there is a need to introduce quantum concepts early on in K-12 schools since the learning of quantum is a lengthy process (Amin et al., 2019; Venegas-Gomez, 2020). As fundamental quantum concepts derive from physics, students usually start to learn physics in secondary schools. So, we conducted a literature review with a focus on quantum computing education in secondary schools.

Methodology

A fundamental bibliographic research procedure (Tranfield et al., 2003; Webster & Watson, 2020) is followed to select and filter the extant literature. The detailed process of article screening is shown in Figure 1. Since the quantum computing articles with a focus on K-12 education are limited, we primarily relied on the Google Scholar search engine to expand our search range (Gusenbauer, 2019). We used three keywords, 'quantum', 'computing' and 'education', to filter potentially relevant articles. We implemented several criteria to screen these articles. Three individual reviewers reviewed each of the selected article's titles, abstracts, and keywords in detail to double-check whether a paper focuses on K-12/secondary education. We deleted all papers that were irrelevant and not in English. Also, by using the 'Publish or Perish' software (Harzing, 2007), any paper with less than two citations was deleted. Moreover, citation chasing was conducted by analyzing the bibliography of references for each article (backward) and through Google Scholar (forward). Only include articles with evaluation data, so the conceptual paper that only proposed teaching ideas was not included. Our final data set includes 29 articles for in-depth review and analysis.

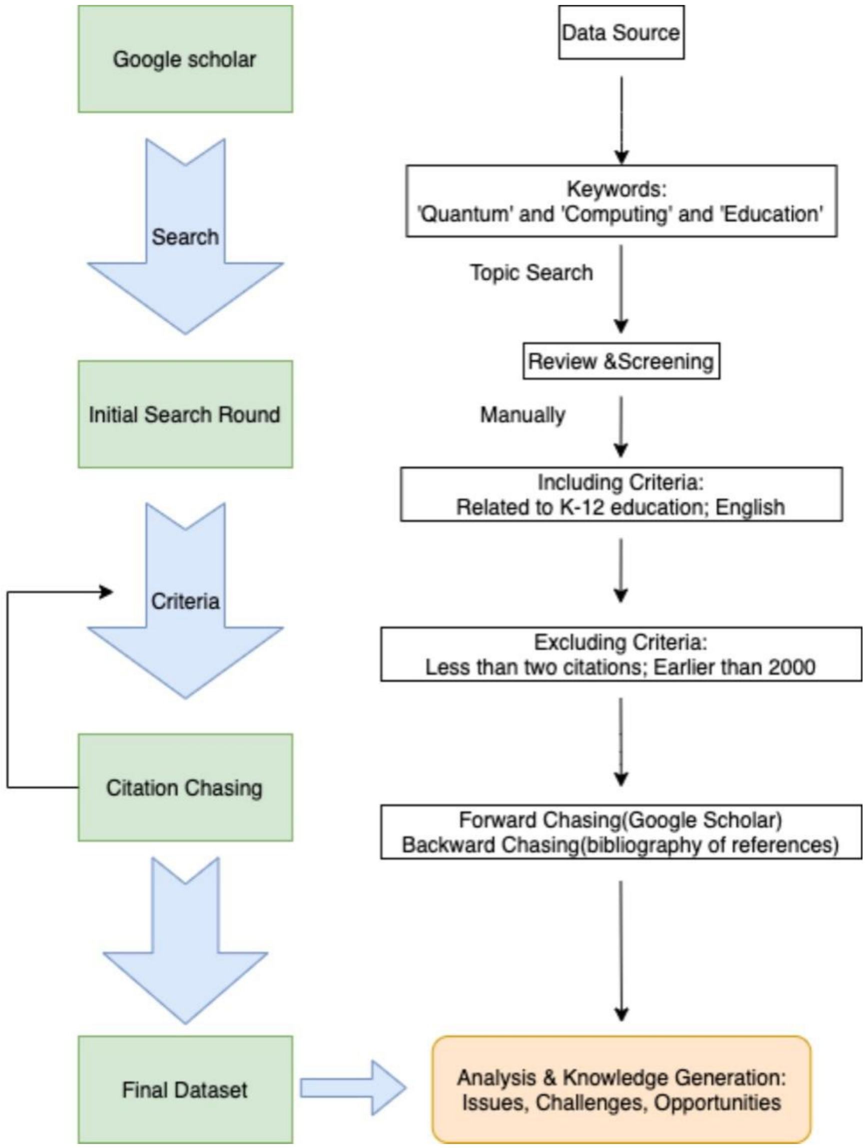

Figure 1. Literature selecting and identifying procedures

Findings

Through the relevant papers, we recognized a series of challenges which need to encounter in quantum computing education at the secondary school level. The corresponding insights are listed below.

Insight #1: Making quantum concepts relevant to everyday events.

Franklin et al. (2020a & 2020b) created initial learning trajectories to help young students better understand basic quantum computing concepts such as reversibility, superposition, entanglement, and measurement by relating them to everyday concepts. Farris et al. (2021) designed learning activities for middle school students to explore quantum methods in the context of drug discovery. Moraga-Calderón et al. (2020) examined a group of high-school students' perceptions before and after an intervention teaching Quantum rule. Students reported that quantum science was important but was not relevant to them. The authors posited that this perception could be due to the fact students did not see how quantum learning could result in societal and community changes. Thus, it is necessary for educators to find creative ways such as metaphors, real-world applications, and simulation to make quantum computing more relevant to students.

Insight #2: Using active learning strategies

Using strategies such as project-based, inquiry-based, hands-on experiment, and game-based learning, to engage students (Vilarta Rodriguez et al., 2020; Rodriguez et al., 2020; Testa et al., 2020). Akdemir et al. (2021) uses active, collaborative, inquiry-based learning techniques to engage students in hands-on learning, evaluating, and discussing the fundamental steps of quantum key distribution, and understanding the technical details behind quantum technology. Krijtenburg-Lewerissa et al. (2017) reviewed studies of quantum education in secondary schools. They identified 74 articles published between 1997 and 2017, among them very few examined the secondary school setting. Fourteen topics related to wave-particle duality, wave function, atoms, and complex quantum behavior were found to be taught in high school or lower college levels. The authors also found that active learning strategies, such as project-based and collaborative learning, benefit students' conceptual understanding. Pashaei et al. (2020) shared a number of educational resources (e.g., games, interactive tools, guided coding) that promote talent in quantum computing.

Insight #3: focusing more on conceptual understanding with less mathematical formulations.

Traditional approaches of teaching quantum inherited from years of practices in teaching physics and rely heavily on mathematical formalism, which are perceived to be difficult, disengaging and inaccessible to secondary school students. Krijtenburg-Lewerissa et al. (2017) recommend teaching counterintuitive quantum concepts based on conceptual ideas rather than complex math-ematical formulations. Educators proposed creative ideas to teach secondary students quantum science. For example, (Galante et al., 2019) proposed to use the sound wave analogy and the Close Encounter theme to introduce students to the uncertainty principle. Other authors also suggested based on their findings that quantum education should focus on not only the correct understanding of a single concept but also the connection between concepts and experiments (Malgieri, 2016; Malgieri et al., 2017).

Insight #4: Aligning quantum learning with existing standards.

Farris et al. (2021) point out the need to develop quantum learning opportunities that correspond with Next Generation Science Standards (NGSS) and Common Core Mathematics and Literacy Standards for K-12 students since K-12 science and engineering teachers have the responsibility to align their instructions with the required national, state or professional standards. Choudhary et al. (2018) compared Grades 7-10 students' learning of gravitational waves. Based on their findings, the authors suggested that the core concepts of Einstein's physics could be introduced as early as Grade 7. However, Grade 10 students had a better understanding of some subtle concepts, such as the uncertainty principle, than younger students. Although this study was conducted in Australia, the results confirmed the appropriateness of the NGSS standard of teaching K-12 students quantum concepts.

Insight #5: teaching quantum through informal learning opportunities.

Besides formal classroom teaching, it is worthwhile to engage K-12 students and teachers through quantum computing workshops, exhibits, local events, summer camps, after-school clubs, competitions, hackathons, and media outreach (Pashaei et al., 2020). It is essential to broaden participation by attracting and engaging young people from diverse backgrounds to learn quantum computing and related technologies.

Conclusion

In summary, to develop a quantum computing workforce, we need to start educating K-12 students about quantum computing. As K-12 science and engineering teachers are not familiar with quantum, professional development is urgently needed to help K-12 science and engineering teachers develop both pedagogical and content knowledge in terms of teaching quantum computing in classrooms. The above insights will be instrumental for quantum computing education at the secondary level. We hope some of these insights can inspire educators to find ways to lower the barriers for entries in quantum computing.

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