Visualising the Invisible: Reviewing the Literature on Demonstration Material for Quantum Entanglement

Bart FOLKERS, Kirsten STADERMANN, Alexander BRINKMAN

University of Twente, Enschede, the Netherlands

Abstract. We present an overview of publications on demonstration material for quantum entanglement. Our study analysed over 80 publications, covering experiments and demonstration materials (DM) for quantum entanglement from 2000 to the present. We provide insights into studies regarding design choices and considerations of different types of DM, differences in the use of mathematics, the role of technologies or possible applications within DM, and conclusions about the impact of DM on students. Understanding choices and considerations made in previous studies can contribute to the development of demonstration materials for quantum entanglement.

Introduction

The abstract nature of Quantum Physics (QP) makes teaching QP challenging. Using Demonstration Materials (DM) such as experiments or simulations could enhance the teaching of QP concepts [1]. DM allows learners to observe and engage with QP effects. These empirical interactions can provide a foundation for students to formulate their ideas or explanations. Such an approach has been successfully employed in hands-on education strategies such as Inquiry-Based Learning and Predict-Observe-Explain [2]. Furthermore, DM can increase student motivation and offer chances to explore real-world contexts and technological applications [3].

However, visualizing QP concepts, in particular quantum entanglement, is difficult. It involves other abstract QP concepts such as superposition, quantum states, probability, and measurement. Visualizing entanglement using macroscopic objects that exhibit classical correlations is challenging. Therefore, we reviewed publications on quantum entanglement DM as a support for future research.

Goal and Methodology

We provide an overview of entanglement DM reported in science education research from 2000 to the present. The study focuses on teaching materials that interactively visualise quantum entanglement. These teaching materials include experiments, games, simulations, analogies, demonstrations, and haptic visualisations. The analysed publications target education for the general public, upper secondary, and lower-level undergraduate students.
Academic journal and conference publications were collected through a systematic search within title, abstract and keywords via ERIC, Web of Science, and SCOPUS. Search queries were built up by terms related to three categories: “Quantum AND [demonstration term] AND [education term]”. From over 80 publications on DM for entanglement, we 1) analysed publication trends over time, 2) compared research questions/goals within studies, and 3) identified used research methodologies and conclusions on using DM for quantum entanglement.

Preliminary results and perspectives

Our initial findings reveal a variety of DM types, each employed for different teaching objectives. Figure 1 depicts different types of DM for entanglement.

We identified various decisions made by authors when designing or implementing entanglement DM. In the presentation, we will focus on the following aspects: 1) design choices and considerations for different types of DM, 2) differences in the use of mathematics in relation to DM, 3) the role of technology or applications within DM, and 4) conclusions about the impact of DM on students.

Fig. 1: Different types of entanglement DM: Experiments [4], Games [5], Analogies [6], Simulations [7].

Some developers of DM strive to incorporate real entangled states to underscore the necessity of the quantum model. This approach may be challenging for students due to complex experimental setups. Other DMs employ analogies or digital simulations, which tend to be easier to handle. Nonetheless, transferring these analogies to quantum concepts is also challenging.

Most authors mention mathematics as a challenging factor in teaching QP. They suggest that DM can provide support. We observe two implicit, but distinct strategies on how DM is supposed to do this. The first strategy aims to avoid mathematics altogether. It involves developing DM that requires no math to describe or understand the effect. The second strategy uses DM to provide a context for the mathematics. Here, students are expected to apply and learn mathematics through the use of DM.

When authors refer to the need for QP education, the majority mention the importance to understand quantum technologies, including the general public. Yet, despite the recognized need, over 80% of the publications use DM without an explicit connection to technologies, and even fewer to technologies accessible to the general public. This emphasises the importance of teaching material development around the DM, such as teacher manuals and student instructions.

While most publications focus on the design or use of the DM, less than 20% mention the impact of the DM on students. Some studies analyse qualitative descriptions of student reactions or student responses. Other studies use a pre/post-test design, focussing on short-term retention. To aid the development of entanglement DM, it is key to strengthen the structural investigation of impact and effectiveness on students as well as considerations for practical implementation.
Our presentation further discusses these aspects and provide recommendations for future research.

References

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