Personalised ChatGPT Feedback in an AR-Enhanced Quantum Cryptography Laboratory Course

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Quantum physics laboratory courses play a crucial role in helping students connect abstract quantum concepts with experimental practice while developing procedural competencies. However, concepts central to quantum cryptography, such as light polarization and measurement bases, can be difficult for students to visualize and apply correctly during experimental work. In this contribution, an AR-enhanced quantum cryptography laboratory course is presented in which virtual visualizations are overlaid onto a real experimental setup to support students' conceptual understanding while performing the experiment.

In addition to AR support, ChatGPT was integrated as an AI-based feedback system to provide individualized feedback. Students answered open-ended conceptual and procedural questions related to the experiment and received personalised feedback in one of two conditions: metacognitive feedback, aimed at prompting reflection and strategic thinking, or corrective feedback, aimed at explicitly addressing missing or incorrect elements in students' responses. Students were then given the opportunity to revise their answers based on the feedback received.

The study compares the effects of these two feedback types on students' performance in answering open-ended questions. Results indicate that both feedback types led to similar improvements on conceptual questions. For procedural questions, however, corrective feedback resulted in significantly higher learning gains, whereas metacognitive feedback appeared to support conceptual understanding more strongly than procedural performance. These findings highlight the differentiated roles of feedback types in AR-enhanced laboratory environments.

By systematically comparing metacognitive and corrective AI-generated feedback, this study contributes to the development of evidence-based design principles for integrating ChatGPT into AR-enhanced physics laboratory courses. The findings are particularly relevant for the development of instructional support strategies in emerging, technology-enhanced quantum physics laboratories.