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The Interaction Between Learning About **Nature of Science and Quantum Physics** in Secondary Education

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Introduction

In many countries, quantum physics (QP) is taught in secondary schools (Stadermann, van den Berg & Goedhart, 2019). Literature reports that QP in secondary education is challenging because QP phenomena do not align with students' classical and mainly positivist ideas about physics knowledge (Greca & Freire 2014).
In other fields of physics, it is shown that explicitly addressing Nature of Science (NOS) in lessons can improve students' concept knowledge (Michel & Neumann, 2016). The connection between QP and NOS is even more obvious (Hadzidaki 2008). We shown some of the connections between QP and NOS in examples below.
However, little empirical research has been done on the connection between students NOS-views and their conceptual knowledge of QP in secondary education.

Research Questions

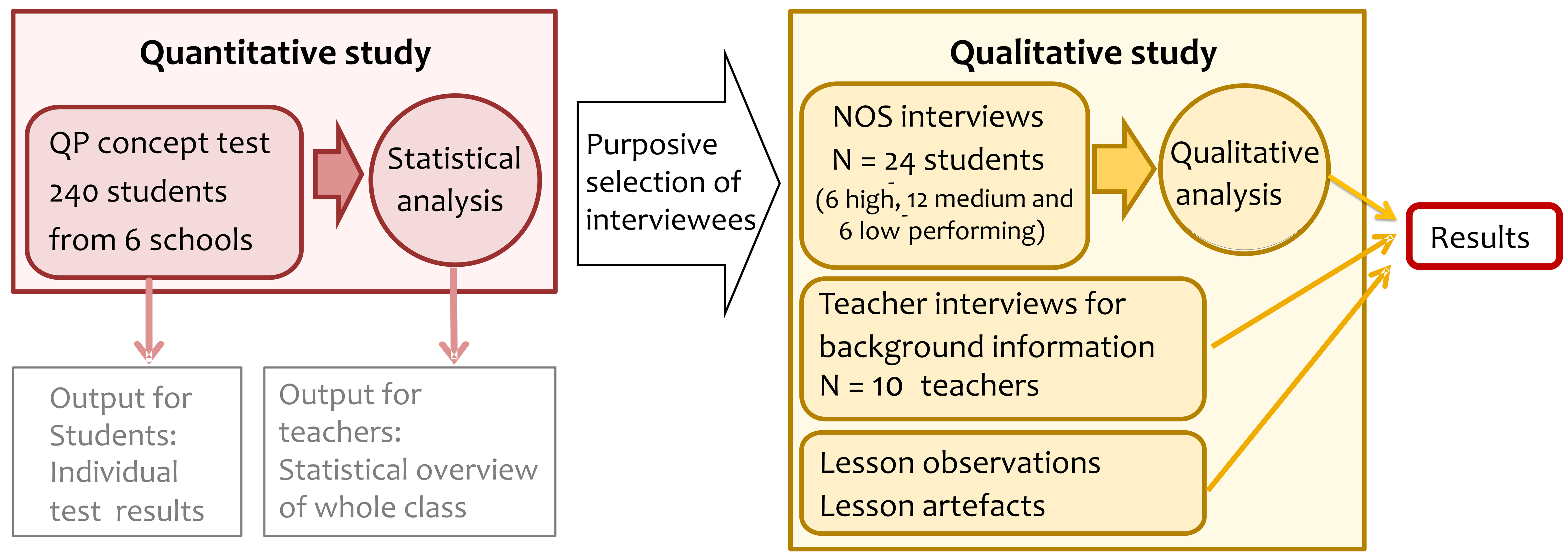
What are upper secondary students' NOS views after following regular lessons about QP?

What, if any, is the connection between students' QP content knowledge and their views of NOS?

Method

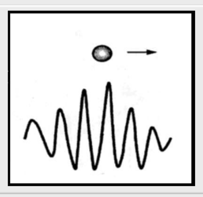
Participants and data collection: 240 Dutch pre-university students (grade 12) from six different schools and their teachers participated. The students had followed regular physics lessons from teachers who were not specially trained for this study. Nine of the ten teachers did not focus on teaching NOS.
To uncover possible connections between students' NOS views in QP and their content knowledge, we interviewed students with different levels of conceptual knowledge, based on a QP concept test. The semi-structured NOS interviews in the context of QP used questions from research on QP interpretations (Baily & Finkelstein, 2015) and the Views of Nature of Science Questionnaire (Lederman & O'Malley, 1990).

Overall setup:



Examples of NOS in QP

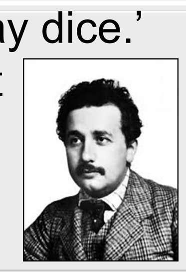
Wave model and particle model for electrons or light.



In Newton's physics, it is impossible to understand phenomena like the double-slit experiment; new theories had to be developed.

To find out if the wave function is more than a conceptual tool, scientists develop creative experiments to test their interpretations.

Einstein said 'God does not play dice.' because he was convinced that QP is not complete; he could not accept the randomness of QP as fundamental.



The Einstein and Bohr discussions show how different philosophical positions result in contrasting interpretations. The open atmosphere without strict ideologies made new developments in QP possible.

Results

On average the students scores 7,6 of possibly 20 points on the QP test. Nevertheless, nearly all (23/24) students were, able to describe the setup and result of the double-slit experiment correctly, independent from their QP test score.
Additionally, **all students** showed informed NOS views on all investigated aspects. Some students said that interpretations of QP should not belong to physics lessons because there are no right or wrong answers.

NOS aspect	Uninformed view	Informed view
Scientific models	Scientific models represent reality as much as possible.	Scientific models show aspects of phenomena in a simplified way.
Tentativeness of scientific knowledge	Scientific knowledge is unchangeable and certain.	Scientific knowledge is always open to change and improvement.
Creativity in science	Scientists always follow strict rules.	Scientists use their creativity and imagination.
Subjectivity in science	Science is universal, and scientists are objective;	Science is influenced by personal, historical, cultural and social aspects.
Controversies in science	New scientific know-ledge is directly accepted. Only one interpretation can be correct.	Discussions and disagreements are essential in science. Different interpretations may exist.

Conclusion and discussion

The results were unexpected because other research showed that only an explicit and reflective NOS teaching yields informed students' views (Khishfe & Abd-El-Khalick 2002).
We see some possible explanations for these results:

1. Our NOS questions are highly contextualised, unlike most other NOS tests.
2. Students experience the problem of explaining the double-slit experiment them-selves. In other historical examples, the solution is found long ago. Alternative ideas for those problems seem unscientific to students now. (Abd-El-Khalick & Lederman, 2000).

Further research should indicate if insights in the nature of QP also make students aware of NOS in other contexts.

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