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Developing learning resources and investigating students' learning in general relativity and quantum physics

Ellen Karoline Henriksen

Heraeus-seminar, Bad Honnef
February 2019

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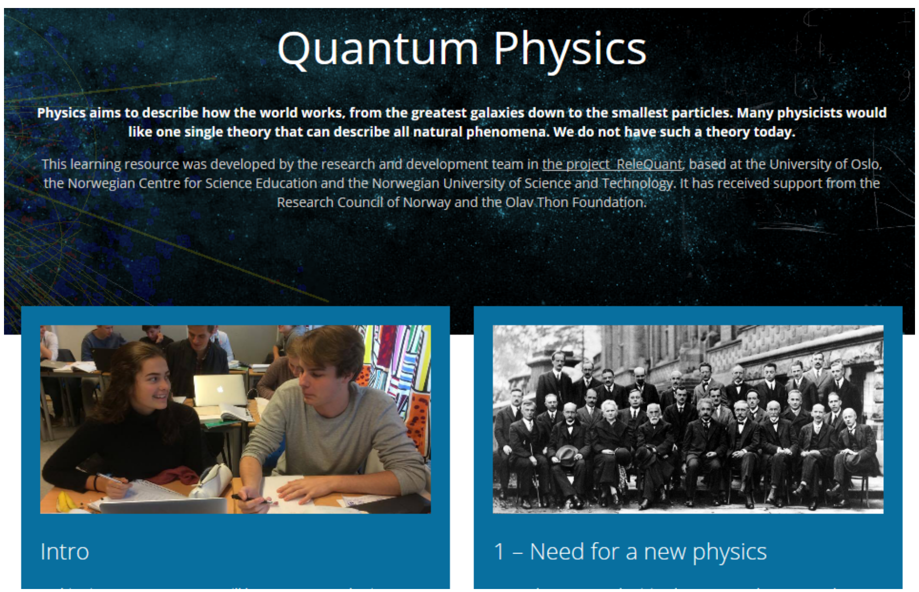
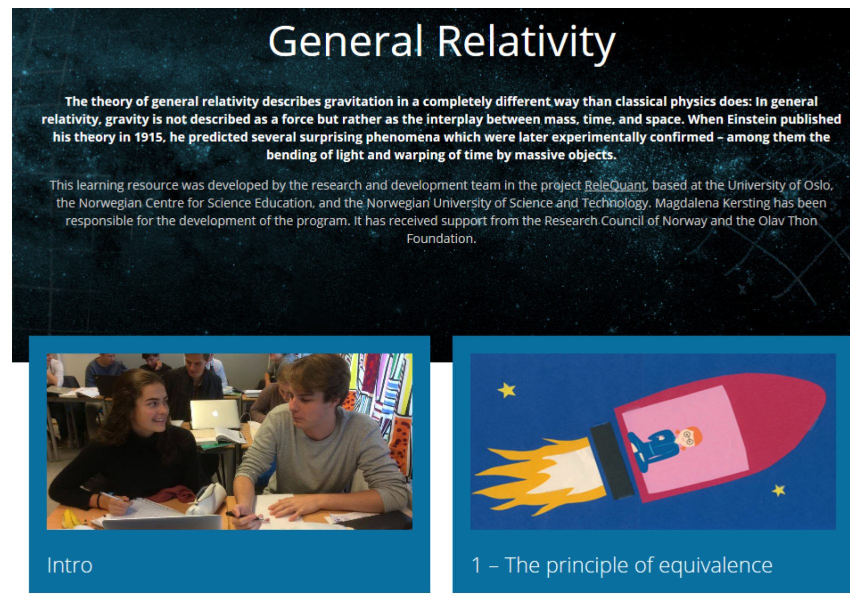
A ReleQuant experiment?

In this talk, I will:

- describe the ReleQuant project
- present examples from the learning resources developed in the project
- present examples of research results from the project





The ReleQuant project

ReleQuant develops digital, research-based learning resources in general relativity and quantum physics for upper secondary school. Practicing physics teachers and physics teacher students are included in the project through ReleQuant Competence.

ReleQuant combines:

- development of digital learning resources
- research on pupils' learning and motivation in physics
- research on how the participating physics teachers and physics teacher students develop their professional competence

www.mn.uio.no/fysikk/english/research/projects/relequant/

The starting point:
Norwegian national physics curriuculum for year 13

Students should:

- give an account of Einstein's explanation of photoelectric effect, and give a qualitative account of how results from experiments with photoelectric effect, Compton scattering and the wave nature of particles represents a break with classical physics
- give an account of Heisenberg's uncertainty relations, describe the phenomenon ”entangled photons” and give an account of their cognitive [epistemological] consequences
- (…) give a qualitative description of the general theory of relativity

The curriculum goals within modern physics present a challenge to physics students and teachers:

- With their qualitative and epistemological/philosophical focus, they are very unlike most other parts of the curriculum
- There is no strong tradition and few learning resources nationally and internationally targeting these learning goals
- Teachers' preparation is often weaker within modern physics

ReleQuant was designed to tackle these challenges

ReleQuant builds on findings from physics education research saying that:

- students may master mathematical procedures, but lack qualitative understanding of quantum physics
- students are not aware of how quantum physics breaks with classical physics, and they often mix classical with quantum reasoning…
- …sometimes leading to misunderstandings such as interpreting wave-particle duality as particles moving in wave-shaped trajectories, or mixing up quantum uncertainty with classical measurement uncertainty
- in general relativity, students particularly struggle with four-dimensional spacetime and with interpreting and applying the equivalence principle

The ReleQuant learning resources:

- draw on sociocultural theories of learning where language and discussion are seen as central in the learning process
- address documented conceptual challenges for students
- let students explore phenomena through animations and simulations
- illustrate how scientific knowledge is negotiated and developed as a human product
- use examples from the history of physics in supporting conceptual development
- inspire philosophical and epistemological reflections
- clarify how quantum physics breaks with classical physics
- present examples and applications that are relevant to students' life-world

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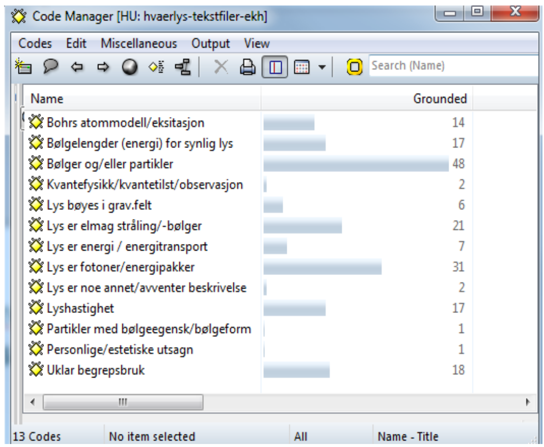
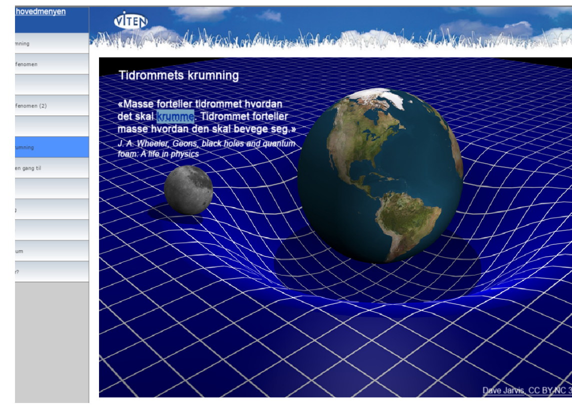
ReleQuant uses design-based research (DBR) to jointly develop learning resources and conduct research on student understanding through several cycles



Analyse results, modify resources



Develop learning resources

Try out resources in classrooms; collect data

ReleQuant research publications

ReleKvant

Sci & Educ
https://doi.org/10.1007/s11191-018-9963-1

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ARTICLE

What Is Light?

Students' Reflections on the Wave-Particle Duality of Light and the Nature of Physics

Ellen Karoline Henriksen[1] · Carl Angell[1] · Arnt Inge Vistnes[1] · Berit Bungum[2]

Phys. Educ. 51 (2016) 055009 (8pp)

PAPERS
iopscience.org/pe

'From the cat's point of view': upper secondary physics students' reflections on Schrödinger's thought experiment

...erit Bungum[2]

BERIT BUNGUM
Programme for Teacher Education,
Norwegian University of Science and Technology, Norway
berit.bungum@ntnu.no

ELLEN K. HENRIKSEN
Department of Physics, University of Oslo, Norway
e.k.henriksen@fys.uio.no

CARL ANGELL
Department of Physics, Universi...
carl.angell@fys.uio.no

CATHRINE W. TELLE...
Department of Physics, University...
c.w.tellefsen@fys.uio.no

MARIA VETLESETER ...
Norwegian Centre for Science Educ...
m.v.boe@naturfagsenteret.no

ReleQuant – Improving teaching and learning in qua... physics through educational design resea...

...and relativity are demanding for teachers and students, but have the...
...ience physics as fascinating and meaningful. Project ReleQuant engag...
...arch to improve teaching and learning in these topics in Norwegian...
...r focuses on the first cycle of development of a teachin...
...principles were developed. We construct th...
...e and conducting three pilot...
...quantum phy...

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH 14, 010130 (2018)

General relativity in upper secondary school: Design and evaluation of an online learning environment using the model of educational reconstruction

Magdalena Kersting,* Ellen Karoline Henriksen, Maria Vetleseter Bøe, and Carl Angell
Department of Physics, University of Oslo, P.O. Box 1048 Blindern, 0316 ...

(Received 27 September 2017; revised manu...

Because of its abs...

Science & Education (2018) 27:593–623
https://doi.org/10.1007/s11191-018-9997-4

ARTICLE

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Understanding Curved Spacetime

The Role of the Rubber Sheet Analogy in Learning General Relativity

Magdalena Kersting[1] · Rolf Steier[2]

Published online: 17 September 2018

WILEY

RESEARCH ARTICLE

Actual versus implied physics students: How students from traditional physics classrooms related to an innovative approach to quantum physics

Maria Vetleseter Bøe | Ellen Karoline Henriksen | Carl Angell

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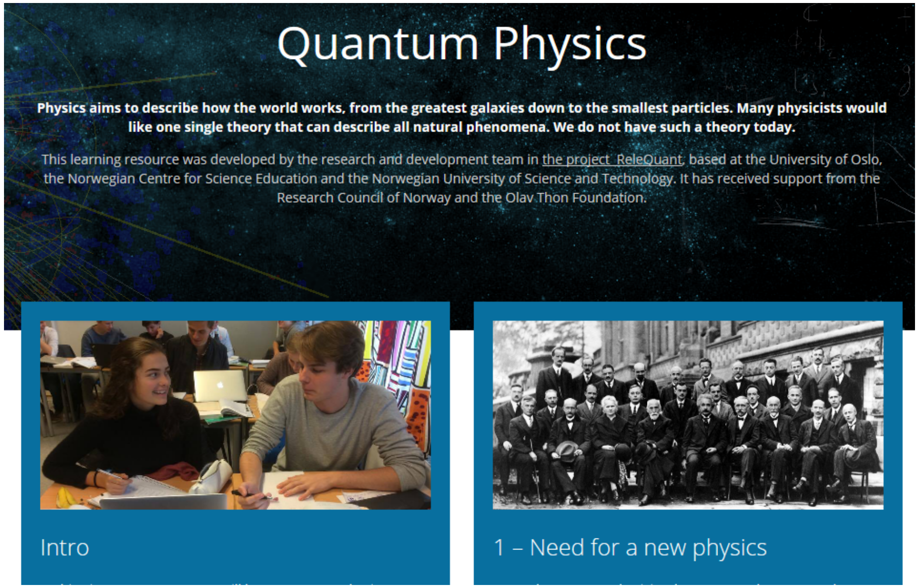
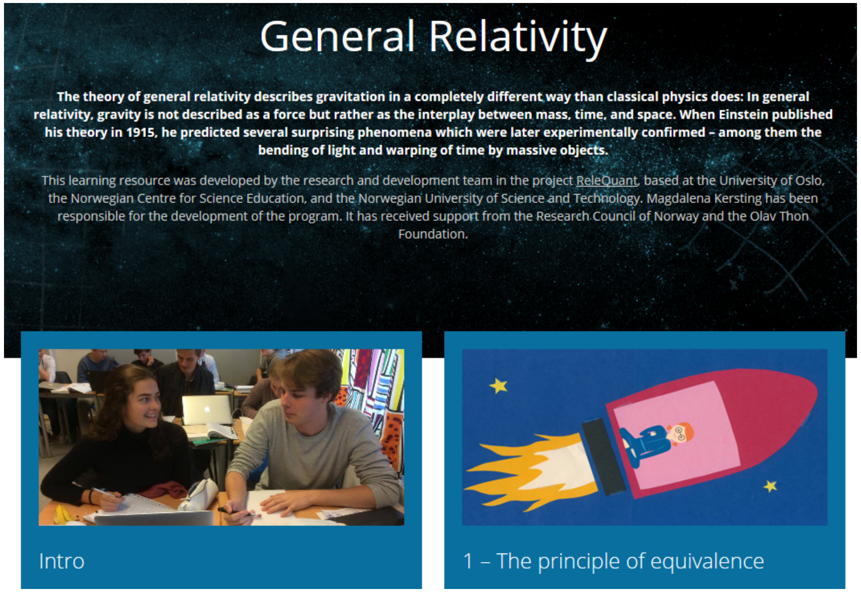
The ReleQuant learning resources





NATURFAGSENTERET
NASJONALT SENTER FOR NATURFAG I OPPLÆRINGEN

www.viten.no/eng/

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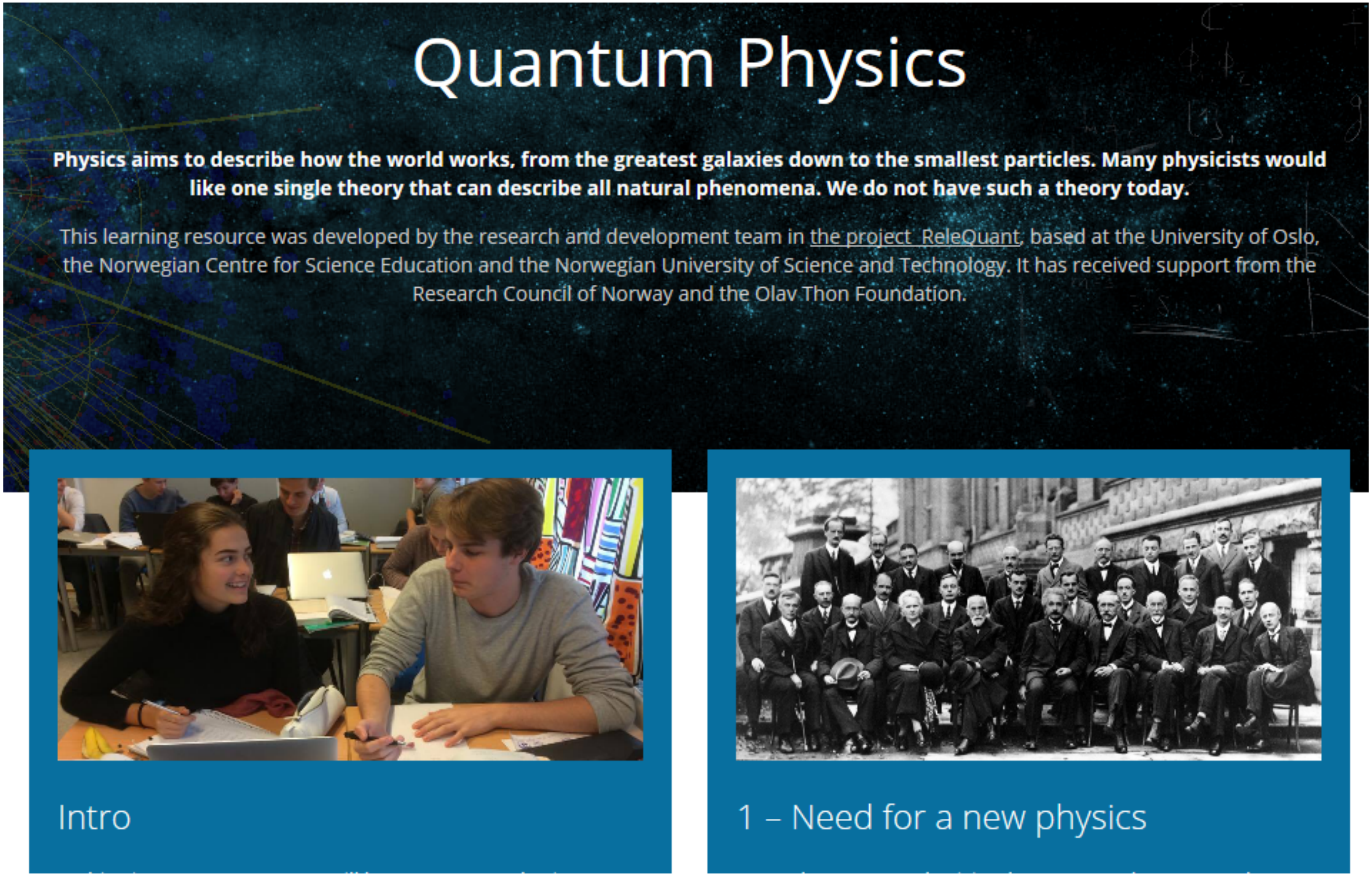

www.viten.no/eng/

- Show the five modules
- Go into “What is light”
- Illustrate:
    - writing task
    - Animated film
    - “Ask a scientist”
    - Discussion task

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General Relativity

The theory of general relativity describes gravitation in a completely different way than classical physics does: In general relativity, gravity is not described as a force but rather as the interplay between mass, time, and space. When Einstein published his theory in 1915, he predicted several surprising phenomena which were later experimentally confirmed – among them the bending of light and warping of time by massive objects.

This learning resource was developed by the research and development team in the project ReleQuant, based at the University of Oslo, the Norwegian Centre for Science Education, and the Norwegian University of Science and Technology. Magdalena Kersting has been responsible for the development of the program. It has received support from the Research Council of Norway and the Olav Thon Foundation.

Intro

1 – The principle of equivalence

www.viten.no/eng/

- Show the three modules

- Go into “Equivalence principle”
  - Show falling bottle film

- Go into “Relativistic phenomena”
  - Show gravitational frequency shift animation
  - Scroll down and show GPS writing task

Sample of ReleQuant research on student understanding and learning

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…from our point of view the cat is both dead and alive, but from the cat's point of view it is either dead or alive.

(from student discussion)

PAPERS

Phys. Educ. 51 (2016) 055009 (8pp) iopscience.org/ped

'From the cat's point of view': upper secondary physics students' reflections on Schrödinger's thought experiment

Henning Vinjusveen Myhrehagen[1] and Berit Bungum[2]

[1] Asker Upper Secondary School, Asker, Norway
[2] Programme for Teacher Education, The Norwegian University of Science and Technology, Trondheim, Norway

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LEARNING

Quantum talk: How small-group discussions may enhance students' understanding in quantum physics

Berit Bungum[1] | Maria Vetleseter Bøe[2] | Ellen Karoline Henriksen[2]

[1]Department of Teacher Education, The Norwegian University of Science and Technology, Trondheim, Norway
[2]Department of Physics, University of Oslo, Oslo, Norway

Abstract
Quantum physics challenges our views of the physical world and describes phenomena that cannot be directly observed. The use of language is hence essential in the teaching of quantum physics.

2016:
Physics Education 51(5)

2018:
Science Education 102 (4), 856-877

What characterizes students' small-group discussions about fundamental issues in quantum physics?

Data material

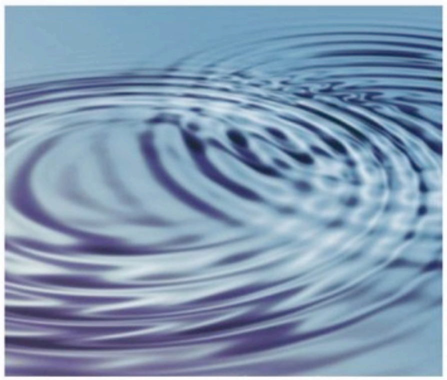
- 96 recorded student discussions (a total of ca 130 students from 7 physics classes participated)
- Two discussion tasks

Discussion task 1

Is it possible to think of light as being both wave and particle?

Both wave and particle?

In the film you saw that [Physicist 1] and [Physicist 2] disagreed about whether a particle can have a wavelength.



A wave is a movement that propagates. A wave is always extended; it cannot be positioned in a single point.

A particle is limited to a small area in space.

Discussion 1

Discuss with a fellow student: Is it possible to think of light as being both wave and particle?

Name the sound file «wave-part-[your-name] and send it to the teacher before you leave the class.

Ask a physicist: What is light? (1)

Physics uses two different models of light. How do physicists respond if we ask them what light is?

Addressing students' 'uncritical duality' responses:

Light is energy in the form of small particles, photons. The light has different colour depending on which wavelength it has.

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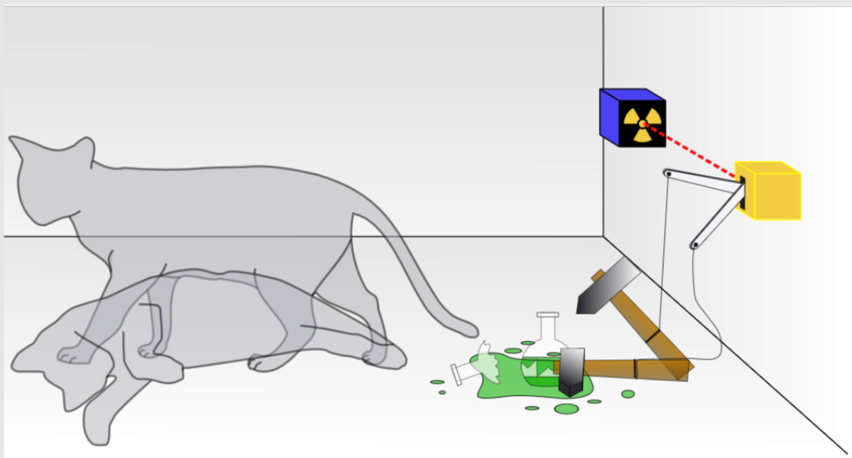
Discussion task 2

Can Schrödinger's cat be both dead and alive?

Schrödinger's cat

Erwin Schrödinger presented his thought experiment in 1935, to show that the idea of superposition of states may have absurd consequences.

In the thought experiment, a cat is enclosed in a box containing a radioactive source and a flask of poison. If the radioactive source decays (emits an energetic particle or a photon), it will release the poison and the cat will die. But a radioactive nucleus is a quantum system that can only be described by a probability for the nucleus to emit radiation during a certain period of time. We cannot, therefore, know exactly when the radiation will be emitted.



Superposition

In quantum physics, we say that the atomic nucleus is in a superposition of both states simultaneously (for example "emitted radiation" and "not emitted radiation"). An observation of the system will cause the system to collapse onto one specific state (for example "not emitted radiation"). Since the cat's destiny depends on whether the nucleus decays or not, can we then say that the cat is in a superposition of states, and hence both dead and alive?

Interpretations of quantum physics

Schrödinger's thought experiment illustrates some important philosophical aspects of quantum physics:

- When we say that a quantum system is in a superposition of states, is this a description of the world as it really is?
- Or does it mean that physicists still don't know what determines the state of a quantum system?
- If the cat in the box cannot be both dead and alive, can a quantum system then be both decayed and not decayed?

The mathematics in quantum physics gives us quite accurate results for the probability for something to take place. However, physicists still disagree on what the results really means for what we can know about the world, 80 years after Schrödinger presented his thought experiment.

Erwin Schrödinger (1887-1961)

DISCUSSION

Discuss with another student: What do you think about Schrödinger's cat? Is the cat both dead and alive before we open the box?

Student discussions: Analytical framework

1. Independent statements
2. Confirmatory talk
3. Cumulative talk
4. Exploratory talk

Non-productive discussions

Productive discussions

Building on categories from Mercer (2004): disputational, cumulative and explorative talk.

Mercer, N. (2004). Sociocultural discourse analysis: Analysing classroom talk as a social mode of thinking. *Journal of Applied Linguistics*, 1(2), 137-168.

Cumulative discussion (Schrödinger’s cat)

But like, the only thing that is for sure, is the cat really dead or alive before we open the box? No! We don’t know whether the cat is dead or alive, that is the point, it is not both dead and alive.

I agree. No, I don't understand. Is the cat both dead and alive before we open the box? It is not. It is either dead or it is alive.

$(\cdots)$

It is like, you don't know if you have got a good or bad grade, but it does not mean that you have got both.

No, and if you go home and I don't know whether you are at home or not, that does not mean that you are both home and on the way home.

We have disproved it.

Yes. With this, we have falsified Schrödinger's…

... thought experiment.

Explorative discussion (What is light)

Yes, uhm, the way I see it's like, the wave is just a representation of where it is most likely that the particle is, and that, there is a, the higher the wave crests and the lower the frequency, it means that there is more energy, which means there's a better chance of a photon coming…being created.

Yes, sure, but, we're told that light moves like a wave.

Go on.

Right? But I think of light as always a particle because it has mass, that is…

Light does not have mass.

Yes, we've written that light has mass.

No, it's an energy.

Yes, it's an energy, but there is a quantity in, under mass.

No, that's electrons.

Should we do a search, we'll do a search on it. Light…

Results: Main characteristics of student discussions

	What is light (N=55)	Schrödinger's cat (N=41)	Total (N=96)
Non-productive, total	**20**	**9**	**29**
Independent statem.	10	4	14
Confirmatory	10	5	15
Productive, total	**35**	**32**	**67**
Cumulative	28	20	48
Explorative	7	12	19
% productive discussions	**64%**	**78%**	**70%**

What is ”produced” in productive student discussions?

In what ways may the productive small-group discussions support learning in quantum physics?

Students

(i) articulate conceptual challenges

(ii) formulate new questions

(iii) deepen their understanding through exchange of views

(i) Articulating conceptual difficulties

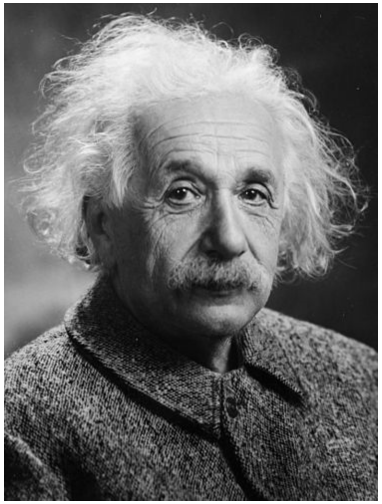
Student about Schrödinger's cat:

- Yes, it is just that we don't know. The fact that we don't know doesn't mean that it is like this and this. That it is like this then. The fact that we don't understand … no.

I can't put it into words.

But **the fact that we don't know whether the cat is alive or dead does not mean that it is both.**

(«Hidden variables»)



(ii) Formulate new questions

Discussions produced questions such as

- How does the Schrödinger's cat thought experiment depend on the **observer**? Can the **cat** be observer?
- Does the wave/particle duality mean that light is wave and particle **simultaneously**? Or does it change behaviour?
- If light can be seen as particles when the wavelength is short enough, can we also have **sound particles** when the sound has a short wavelength?
- When we hear sound, the **eardrum** vibrates. What is the corresponding mechanism when we see light? What vibrates?

Many questions were developed as a *product* of the small-group discussion

(iii) Deepening understanding by exchange of views

I share Einstein's view that the cat is not both dead and alive at the same time before we open the box, he is, or the cat is one or the other, it is just that we don't know which state it is in.

But isn't that what makes, the fact that we don't know, what makes it in a way both dead and alive?

(···)

When we are standing outside the box, then it is dead and, but I don't know, alive, that doesn't fit for me.

It has to do with the fact that that radioactive nucleus was both in state, two different states; emitted radiation and not emitted radiation, that thing that would…that poison thing. And that once you measured, it was then that it sort of fell down to one of those states. That was the point.

Conclusions

Small-group discussions may support students' understanding and reflection in quantum physics by

i. making students articulate difficulties,

ii. formulate new questions, and

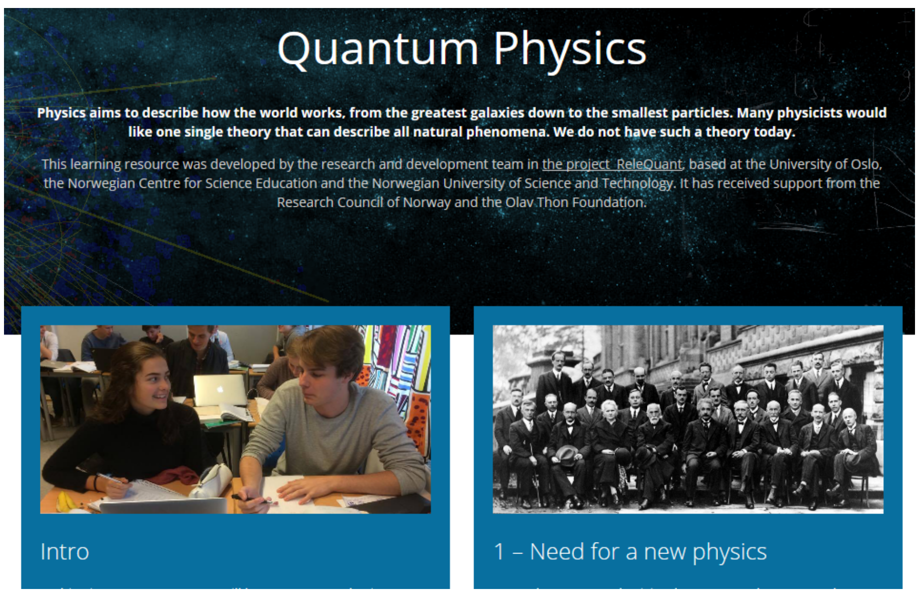
iii. deepen their understanding by exchange of views

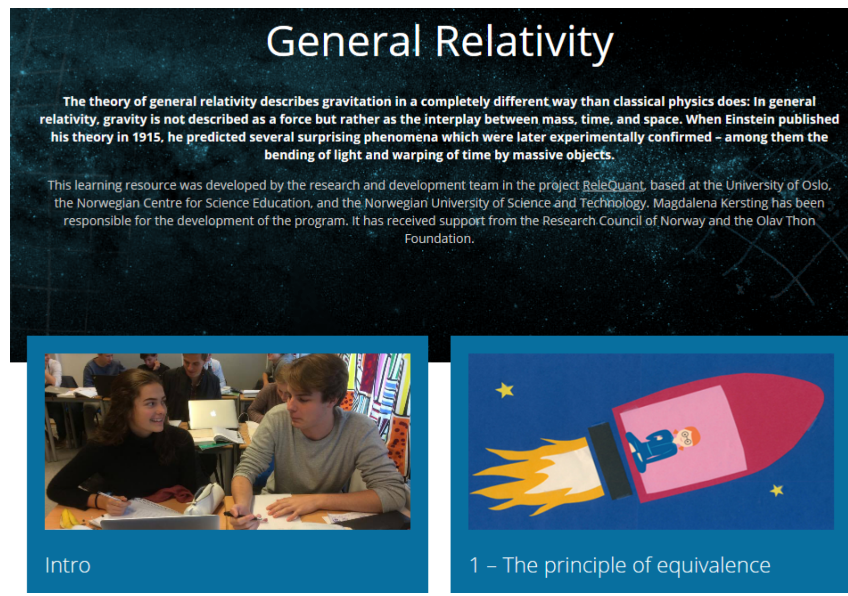
BUT:
The teacher is important for relating issues from the discussions to ideas in physics and how they have developed

- and for involving **all** students (30% discussi-ons were non-productive)

I hope I have shown that:

- It is possible to develop teaching and learning resources in modern physics based on knowledge of physics, educational research, and practical classroom experience
- By collecting and analysing data from students' work, we can obtain insight into student understanding and learning that may inform teaching and learning in similar settings





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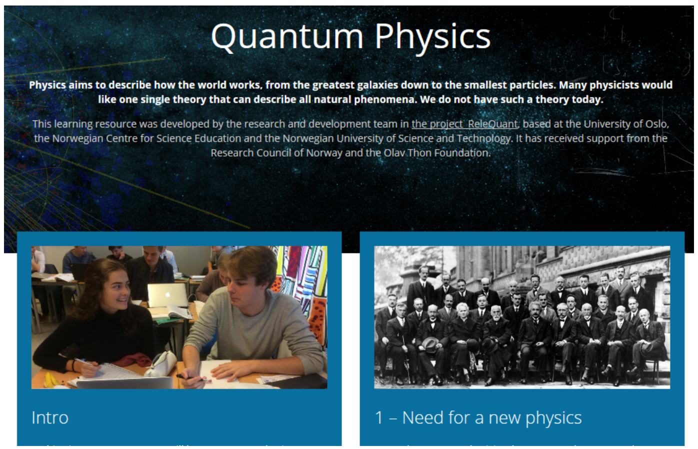
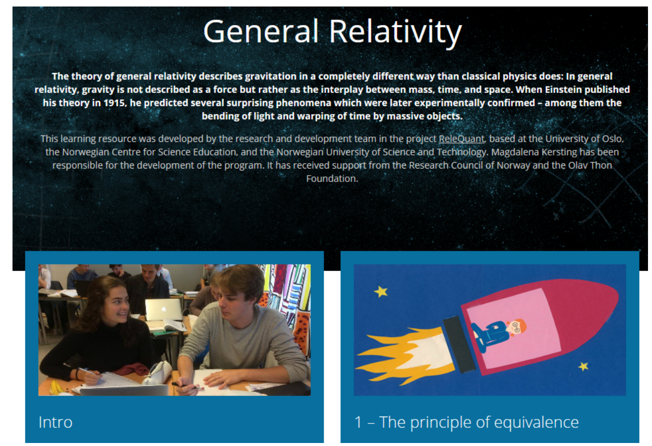
THANK YOU FOR LISTENING.

Feel free to explore our resources and send us comments!





Thanks to my colleagues and co-authors for contributions to this presentation.

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The Research Council of Norway

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