Institution: University of Bristol		
Unit of Assessment: 30) Philosophy		
Title of case study: Transforming science education through philosophy of science		
Period when the underpinning research was undertaken: 2010-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): James Ladyman	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 09/1997-present
Period when the claimed impact occurred: 2016-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Professor Ladyman's research in philosophy of science has transformed school science education in the UK. From 2016-2018, Ladyman applied his research in philosophy of science to the Key Stage 3 Science curriculum to develop the *Thinking Science* resources, which involve conceptual and philosophical questions about key topics. These resources, and accompanying training, were disseminated to thousands of educators nationally and internationally and endorsed by respected science education organisations. As a result of this project: 1) the science curriculum in a multi-academy chain and other schools is now framed by philosophical questions; 2) teacher practice has been improved with teachers using questioning more effectively; 3) students are more engaged; and 4) PGCE science programmes nationally now include philosophy of science.

2. Underpinning research

Professor Ladyman is a leading philosopher whose ideas and publications are central to debates in philosophy of science and metaphysics throughout the world. He is well known outside philosophy for his collaboration with scientists, and outside academia for his more popular work. Since his classic early work on structural realism in philosophy of physics, and his prize-winning book on general philosophy of science **[3.6]**, he has worked across the sciences, including on the history and philosophy of chemistry. His hugely influential 2007 book, 'Every Thing Must Go: Metaphysics Naturalized', develops a metaphysics for science as a whole. Both the breadth and the depth of his work on science were essential to the project.

In 2014, Ladyman instigated the Centre for Science and Philosophy, which serves as both a platform for cutting-edge research in philosophy of science, and as a forum for public engagement and impact. At the same time, he launched the Philosophy for Children and Communities (P4C) programme, and in 2016, began research into secondary-school science education. This revealed that while biology, chemistry and physics are integrated in scientific practice, it is hard for students to appreciate this when being taught individual topics. These findings complement the Nuffield Report on Science Education in Europe (Osborne & Dillon 2008), which found that students commonly lack knowledge of how science delivers reliable knowledge and how science as a whole hangs together, even though it is essential, both for students who may continue with science beyond school, as well as for the majority who won't, in order that they can "engage critically with science in their future lives." Ladyman's collaboration with many different scientists in both teaching and research, and his prior outreach work, placed in him a unique position to address these issues.

From 2016 to 2018, Ladyman used the connections between his research and the UK science National Curriculum (Key Stage 3) to create the *Thinking Science* resources (http://www.bristol.ac.uk/philosophy/thinking-science/resources/) – conceptual and factual

questions pertaining to the biology, chemistry and physics curriculum, as well to the topic `Working Scientifically' on the scientific method and broader questions about science. Ladyman's extensive work in the philosophy of physics and metaphysics **[3.1,3.2]** addresses scientific realism and how chemistry and other sciences relate to physics, asking, for example, 'How is the periodic table important for all of science not just chemistry?' This, together with his work on theory change in the history of chemistry **[3.3]**, which directly relates to the question 'How do we know that air is not a single substance?', fed directly into and shaped the *Thinking Science* resources on physics and chemistry.

Ladyman's body of research on the nature of science, the scientific method and theory change in the history of science **[3.3, 3.5, 3.6]**, and on the scientific realism debate **[3.1, 3.4]**, directly informed the 'Working Scientifically' topic, which includes sections dedicated to 'Scientific Progress and Applications', 'Hypotheses', featuring questions such as 'If results show that a hypothesis isn't exactly right, does that mean it's false?', and 'Do we only make scientific progress when the results support the hypothesis?'. The 'Working Scientifically' topic also addresses the challenge identified by the Nuffield report. For example, there is a section on 'Reliability and Risk' which asks questions including 'Do we need to be 100% sure that a fertiliser is safe and effective before it can be used?' and 'Of the two ways a test for a disease could be incorrect, which is it more important to avoid?'.

3. References to the research

3.1 **Ladyman J** (2019). What is the Quantum Face of Realism, in Lombardi O, Fortin S, López C, & Holik F (Eds.) *Quantum Worlds: Perspectives on the Ontology of Quantum Mechanics*, Cambridge: Cambridge University Press, pp.121-132 [Available on request]

3.2 Brown R and **Ladyman J** (2019), *Materialism: A Philosophical Inquiry*, Routledge [Available on request]

3.3 Blumenthal G and **Ladyman J** (2018). Theory comparison and choice in chemistry, 1766-1791, *Foundations of Chemistry,* **20:3**, pp.169-189, https://doi.org/10.1007/s10698-017-9301-8

3.4 **Ladyman J** (2018). Scientific Realism Again, *Spontaneous Generations: A Journal for the History and Philosophy of Science,* **9:1**, pp.99-107, https://doi.org/10.4245/sponge.v9i1.29356

3.5 **Ladyman J** (2013). Toward a Demarcation of Science from Pseudoscience, in Pigliucci M and Boudry M (eds), *Philosophy of Pseudoscience*, University of Chicago Press, pp.45-60 [Available on request]

3.6 **Ladyman J** (2001), *Understanding Philosophy of Science* (first edition), Routledge https://doi.org/10.4324/9780203463680

4. Details of the impact

The *Thinking Science* resources were co-produced with teachers between 2016 and 2018 and designed for secondary school science lessons focused on UK Key Stage 3 (KS3) National Curriculum. They are available as a free online download and as a booklet. The resources have combatted 'the lack of space in the current curriculum for considering societal and cultural influences on science and pedagogical approaches in schools that are focused on "direct instruction" and "exposition" by teachers' **[5.1]**.

The resources have been endorsed by trusted science education organisations, including the Association for Science Education (ASE) – the largest subject association in the UK; STEM Learning – the UK's largest provider of education and careers support in science, technology, engineering and mathematics; and Scientix – the European Hub for Science Education. This has secured the resources' reputation and helped increase their reach.

The resources received an excellent review from the ASE's *School Science Review* journal, which is widely distributed in the UK and has a sizeable overseas readership. ASE quoted 'every now and again a resource appears that just makes you stop and wish that you could find more of them; this is one of those resources… This is a very good resource for starter activities to stimulate discussions at the beginning of lessons and get the pupils motivated to learn. It could also be used to develop thinking skills in pupils… Overall, this is an excellent resource.' **[5.2]**.

After presenting at three consecutive ASE national annual conferences between 2016-2019 (the largest science education conference in Europe), Ladyman and colleagues in University of Bristol's Public Engagement team were invited to contribute an article for the journal to reach the wider ASE audience (6,500 educators in the UK and 500 overseas) **[5.3]**. The team were also invited to contribute to STEM Learning CPD for teachers in 2019; 88% of attendees rated the *Thinking Science* session as the most useful element of the CPD **[5.4]**.

The *Thinking Science* project has had the following impacts:

1. Transforming curriculums in a Multi-Academy Trust and other UK schools
2. Improving teacher practice, specifically teacher questioning
3. Improving school students' engagement and learning in science
4. Improving the education of trainee teachers in science
5. Inspiring the development of new teaching resources

1. Transforming Curriculums in a Multi-Academy Trust and Other UK Schools

The *Thinking Science* resources have been embedded in the curriculum at the Cabot Learning Federation (CLF), a multi-academy trust with 20 primary and secondary academies in the Bristol area with 11,000 students on roll and a high proportion of students from socioeconomically disadvantaged backgrounds, and Rainham School for Girls, a non-selective academy in Kent with 1,600 students on roll.

The CLF were partners on the project with science teachers collaborating to co-produce the resources. The CLF's Senior Network Leader for Science was appointed as the teacher consultant throughout the project. Between 2017-2020, training based on *Thinking Science* was delivered to over 60 teachers at the CLF. As a result of their collaboration, the CLF have considerably redeveloped their science curriculum across all 20 academies, to frame topics around philosophical questions **[5.5]**. This has led to better engagement from students and more inclusive lessons **[5.6]**. The Senior Network Leader for Science is also better able to support other teachers to use philosophical questioning techniques in their lessons **[5.5]**.

At Rainham School for Girls, teachers have used *Thinking Science* to redevelop curriculum content around "big questions" and philosophical enquiry **[5.6]**. This has positively impacted student learning, with teachers reporting that their 'students are so much more engaged in Science and this is also having a positive impact on their attainment' **[5.6]**.

2. Improving Teacher Practice, Specifically Teacher Questioning

Since 2017, 380 teachers and trainee teachers have received training based on the *Thinking Science* resources and methodology. The online resources have been downloaded over 850 times and 900 hard copies have been distributed nationally. The training sessions were rated 4 or 5 stars out of 5 by 99% of teachers and 100% found the training useful for improving confidence in using philosophy in the science classroom **[5.4]**. The Senior Network Leader for Science at the CLF noticed an improvement in teachers' use of questions as a result of using the resources **[5.5]** and teachers themselves have reported that the resources have helped them improve their questioning skills, in turn giving students access to higher-order ideas **[5.6]**.

3. Improving School Students' Engagement and Learning in Science

Improving teacher practice has led to an improvement in student engagement and learning in science. Teachers have reported that the resources:

- Engage those not normally engaged in science **[5.6]**

- ‘Students who are often disengaged with science will tend to get involved in the activity’ (Head of KS3 Science, Launceston College, Cornwall)
- ‘The ideas are accessible to all levels, which means everyone can get involved. What has been nice is seeing some of the less engaged learners furiously leap to disagree with a classmate and thereby involve themselves in lessons’ (Science Teacher, The Ridgeway School, Wiltshire)
- ‘Pupil engagement was high… One of the best moments was when I gave a selective mute pupil the role of scribe, and so he had the chance to develop his group's ideas in a tweet. He felt confident enough at the end to read it out to the class! It was awesome’ (Science Teacher, Bristol)

- Improve oracy, literacy and scientific literacy skills **[5.6]**
  - ‘They provide fertile ground for class discussion, which gives me an opportunity to promote their oracy skills such as answering in full phrases and referring to ideas their other classmates have said. This skill then makes their writing in exams more coherent and nuanced’ (Science Teacher, The Ridgeway School, Wiltshire)
- Highlight student misconceptions in curriculum content **[5.5]**
  - ‘[The resources] reveal the depth of [students’] understanding – including misconceptions - which allow teachers to re-teach certain areas’ (Senior Network Leader for Science, CLF)

4. Improving the Education of Trainee Teachers in Science

The project has delivered training on secondary science and primary PGCE programmes nationally: at the University of Bristol since 2016, at the University of York (2018) and at Bath Spa University (2020), reaching 243 PGCE students. In addition to the benefits to teacher practice outlined in 2 above, *Thinking Science* has improved the education of trainee teachers in science by ‘combat[ting] the simplistic views that student teachers often bring to the PGCE course – that there is one right way to teach and that teachers should be able to answer all pupils’ questions and offer the right solutions’ **[5.1]**.

At the University of Bristol, *Thinking Science* is now embedded into the PGCE curriculum and has become a significant framing for the course **[5.1]**. Students have been using the resources from their first placement and many continue to use them **[5.1]**. One former student wrote a blog post for the STEM Learning website (reaching thousands of teachers) about her experience with the resources, writing ‘I first came across *Thinking Science* as a PGCE student. I use this resource endlessly’ **[5.7]**.

At the University of York, *Thinking Science* has given student teachers a deeper understanding of their discipline. ‘There is little attention to the philosophy of science (even less to philosophical inquiry) … in initial teacher education, but I believe this is an important component of critical, reflective teachers who understand their discipline well. The University of Bristol resources fill a gap…’ **[5.8]**.

The effectiveness of *Thinking Science* in teacher training, teacher practice and for students is summarised in this statement from York: ‘*Thinking Science* is very clearly influenced by teachers and the realities of demands in school. The associated professional development demonstrates how teachers can use the resources little and often, which is important for many teachers who do not see philosophy as a priority. At the same time, the workshop provides a strong rationale for why it *is* a priority. The pedagogical strategies that go alongside promote learning through reflective dialogue and correspond well to what is known about how science learning works. I have implemented many of these strategies into my teaching. *Thinking Science* will continue to be used at York for the foreseeable future’ **[5.8].**

5. Inspiring the development of new teaching resources

The success of *Thinking Science* has inspired the production of other teaching resources. In 2017, Dr Genevieve Liveley, Reader in Classics at University of Bristol, developed ‘Science of Stories’: (http://www.bristol.ac.uk/classics/hub/resources/) based directly on the design and concept of *Thinking Science*. Supported by the national charity Classics for All, ‘Science of

Stories' has been distributed to over 600 schools across the UK for use in school science lessons, cross-curricular lunchtime and breakfast clubs, gifted and talented groups, debate groups, storytelling societies, and extra-curricular Classics clubs. One teacher reports that the 'cross-curricular thinking' that Science of Stories inspires has 'changed teaching practice'; another that the school has 'used the science of stories resources as a way to enrich the teaching practice of the science department, using it as a form of extension and differentiation' **[5.9]**.

5. Sources to corroborate the impact

5.1 Statement of impact (December 2019) – PGCE Science Coordinator, University of Bristol

5.2 Review (December 2018), *School Science Review,* **100:371**, p.94 (Association for Science Education, ASE) https://www.ase.org.uk/system/files/SSR_December_2018_091-098_Reviews_0.pdf

5.3 ASE Annual Conference (June 2019) – Philosophy for science education, *School Science Review*, **100:373**, pp.22-24. See also: https://www.ase.org.uk/resources/school-science-review/issue-373/annual-conference-2019-philosophy-science-education

5.4 Feedback from workshops (2018-2019) including STEM Learning CPD course

5.5 Statement of impact (December 2019) – Senior Network Leader for Science, Cabot Learning Federation

5.6 Testimonials from follow-up interviews with teachers (July 2018)

5.7 STEM Learning blog – *Thinking Science: provoking thought and generating discussion* [accessed 25 January 2021]

5.8 Statement of impact (January 2020) – Lecturer in Science Education, University of York

5.9 Excel reports evidencing school data on Science of Stories (anonymised) – (October 2020)