Physics Education

DIRECTIONS • OPEN ACCESS

Can a robot be a scientist? Developing students' epistemic insight through a lesson exploring the role of human creativity in astronomy

To cite this article: Berry Billingsley *et al* 2023 *Phys. Educ.* **58** 015501

OPEN ACCESS
DIRECTIONS
Phys. Educ. **58** (2023) 015501 (9pp) iopscience.org/ped

Can a robot be a scientist? Developing students' epistemic insight through a lesson exploring the role of human creativity in astronomy

Berry Billingsley[1,*], **Joshua M Heyes**[1], **Tim Lesworth**[2] **and Marc Sarzi**[3]

[1] LASAR Research Centre, Canterbury Christ Church University, North Holmes Road, Canterbury, CT1 1QU
[2] Simon Langton Grammar School for Boys, Langton Lane, Canterbury CT47AS
[3] Armagh Observatory, College Hill, Armagh BT619DM

E-mail: Berry.billingsley@canterbury.ac.uk

Abstract
Artificial intelligence is transforming the practice of science worldwide. Breakthroughs in machine learning are enabling, for example, the discovery of potentially habitable exoplanets beyond our solar system. The growing role of artificial intelligence (AI) in science raises questions for scientists, philosophers, computer scientists … and educators. How will the scholarship and practice of science education respond to the growing role of artificial intelligence in science? Questions like 'Can a robot be a scientist?' can help stimulate students' epistemic curiosity, about the nature of scientific knowledge, including the value and importance of apparently uniquely human attributes such as creativity. In this article we explain the development and delivery of a science lesson using the question 'can a robot be a scientist?' to explore the

* Author to whom any correspondence should be addressed.

role of human creativity in scientific observation and classification, using resources and activities created for the citizen scientist project 'Galaxy Zoo'.

Keywords: astronomy, citizen science, artificial intelligence, creativity, epistemic insight, nature of science

1. Introduction-the role of creativity in science

The first impetus for this project emerged from a line of questioning regarding the importance of creativity in science education. A significant body of research has acknowledged the importance of creativity in science education and explored various ways that scientific creativity can be taught and assessed. Lubert and Sternberg (1998) define creativity as the ability to produce work that is novel and appropriate' However, this definition may be too broad for the disciplinary specificity of scientific creativity, which has both similarities to and differences from, for example, the creativity involved in the production of works of art. Science operates on values of objectivity, while art concerns primarily subjective matters, even as it might trouble the boundary between objectivity and subjectivity. While art is very different from science in its manifestation of individual experiences, Kind and Kind (2007) argue that science can even manifest a form of personal self-expression, whereby scientific work is sustained by personal commitment to a particular style of understanding and engaging with the world. Further, Massoudi (2003) argues that scientific writing ought to be creative and points out the resonances between the inspiration required to sustain scientific inquiry and the inspiration inherent in spirituality. Despite the apparent focus of science on the establishment of empirically evidenced theoretical knowledge about the natural world, creativity plays an important part in the practice of science as a fundamentally human endeavour.

The second impetus for this project emerged from a series of conversations regarding the expanding role of artificial intelligence in science and how this might be affecting the level of human participation in scientific processes. In concert with recognizing the importance of creativity in science education, we also wanted to engage with whether artificial intelligence could imitate or reproduce human creativity. In her article 'Creativity and Artificial Intelligence', Margaret Boden (1998) distinguishes between combinational, exploratory and transformational creativity, arguing that artificial intelligences are, with varying degrees of success, able to model aspects of all three types of creativity. Scientists are likely to practise some measure of all three forms of creativity set out by Boden. Combinational creativity involves 'novel (improbable) combinations of familiar ideas'. For example, new areas of scientific inquiry are often developed by combining ideas from two different scientific fields or by bridging science and another form of knowledge, creating unexpected or unforeseen connections that enrich the scientific process or aid discoveries while conducting scientific observations.

In conversation with Marc Sarzi from Armagh Observatory, we noticed that aspects of Boden's 'combinational creativity' can be seen in the discovery of extremely star-forming 'Green Pea' galaxies during a citizen science research project conducted by Armagh Observatory. Citizen science refers to the voluntary participation of citizens in different phases of the scientific process, often data collection or analysis, of projects run by scientists (Jordan Raddick *et al* 2013). Volunteers typically provide their support via web-based and mobile technology. They can choose between a vast number of projects that in many cases come with detailed explanations, instructions and additional educational materials. In many instances, volunteers also have to chance to report or discuss their findings with the scientists running these projects through public forums or similar platforms.

While undertaking galaxy classification tasks, a citizen science participant reported an image resembling 'green peas' and wondered if anyone else had noticed the same. When others reported similar observations, astronomers at Armagh Observatory examined the images in greater detail and realised this was an entirely new class of galaxy, now referred to as 'extremely star-forming' galaxies (Cardamone *et al* 2009, see below). The observation of the image of the extremely star-forming galaxy resonates with Boden's concept of 'combinational creativity'—in this case, the importation of an 'everyday' system of meanings into a formal scientific process of classification, creating a shared understanding that led to a significant breakthrough. While neither observation/classification nor creativity are unique to scientific methods of investigation, we see here that creativity and observation/classification can go hand in hand.

While Boden argues that artificial intelligences can *to some extent* imitate or participate in elements of all three aspects of creativity, there are also limitations. In further conversations with Marc Sarzi, we learned that these limitations are highly relevant for astronomers who are now dealing with advanced astronomical instruments that gather volumes of data (e.g. photographs of galaxies) so vast that they cannot be stored efficiently and need rapid processing before proceeding to further studies. While a machine learning programme could in theory be used to perform classification of galaxies, the 'green pea galaxy' discovery may not have happened without the capacity to make a novel connection with a different system of meaning. We thus began to engage in the question of whether this capacity for novel connections across divergent systems of meaning is 'uniquely human'.

In this way, we were eventually led to consider what a science lesson might look like that engaged in tandem the questions of (a) what role creativity might have in science and (b) what might be the power and limitations of artificial intelligence for reproducing and/or supporting scientific creativity. In initial piloting of the lesson, we found that the question 'Can a Robot be a Scientist?' to be effective in engaging what we call *epistemic curiosity* (see below) about the nature of scientific knowledge and in enabling discussion of the 'uniquely human' elements of scientific investigation. This lesson attempted to give students some opportunities for thinking that might provide them with access to these questions by working at the intersection of scientific observation, creativity and artificial intelligence. One of our aims was thus to help students notice that while many of the central features of observation can be performed by artificial intelligences, perhaps even more effectively than humans, we might want to question whether certain aspects of science, like creativity, are indeed unique to humans. The lesson was co-created by education researchers (Berry Billingsley and Joshua Heyes), a head teacher of science (Tim Lesworth) and the Head of Research at Armagh Observatory & Planetarium (Marc Sarzi).

2. Introduction to the lesson 'Can a Robot Be a Scientist?'

2.1. Use of 'Galaxy Zoo' materials

In developing the lesson, we drew on preparatory materials provided for a citizen science project, 'Galaxy Zoo' (zoo4.galaxyzoo.org). Citizen science volunteers prepare by studying the shapes of some different galaxies as they appear in images of the night sky. They can then join with other volunteers, identifying and analysing as yet-uncategorised images. While citizen scientists are apparently only 'doing science' in a very limited and restrictive way through the task of classification, citizen scientists are also *informally* engaging in other aspects of scientific inquiry, including hypothesis forming and testing as they work out how best to classify images. The proposal that citizen science projects can meaningfully develop a range of scientific inquiry skills was investigated by Aristeidou and Herodotou (2020). The authors reviewed empirical studies that examined the impacts of participation on volunteers via instruments that measured attitudes to science, scientific knowledge and more. Their review suggested that taking part can cultivate citizens' knowledge and skills, however the authors also note that there are limited studies into the educational benefits and in particular of empirical studies set in formal education settings. In this way, the lesson and our small-scale study of its impact builds on the work of Galaxy Zoo and previous studies into the educational potential of citizen science.

2.2. Grounding in epistemic insight

Epistemic insight is, broadly speaking, 'knowledge about knowledge', including knowledge about disciplines and how they interact (Billingsley *et al* 2018). Research and

Figure 1. The epistemic insight curriculum framework (Billingsley *et al* 2018).

development into epistemically insightful approaches to education emerges from research exploring the epistemological landscape of the science-and-religion dialogue. In relation to the wider field of literature on the nature of science, epistemically insightful approaches assume that while there may be no universal and essential definition of science, scientists do have distinctive preferred questions, methods and norms of thought that have varying levels of convergence and divergence with those of other disciplinary perspectives.

The epistemic insight curriculum framework (figure 1) elucidates three aspects of epistemic insight which develop progressively through an educational journey. The framework is intended to help students to navigate the borders between different subjects in their timetable with ever increasing epistemic insight (understanding of how knowledge works). This version was designed in the context of schools in Engand, where Religious Education (RE) is a compulsory subject in the state education system. Students in England sometimes encounter Big Questions that draw on scientific knowledge in these lessons. The framework an be adapted for use in other contexts. This lesson focused on the central column 'nature of science in real-world contexts and multidisciplinary arenas'. Epistemic insight recognizes and builds on research critiquing the compartmentalization of science education from other areas of knowledge and an excessive focus on 'recipe investigations'. Both compartmentalization and recipe investigations have the unintended consequences of suppressing students natural epistemic curiosity and creativity and override their capacity for epistemic agency. Epistemic curiosity—that is, a curiosity about the multidisciplinary and interrelatedness of knowledge—is core to developing an epistemically insightful pedagogy. We found that the use of 'Big Questions', such as the one used in the title of this lesson, can effectively stimulate epistemic curiosity, helping students to engage in activities and thinking that builds capacity for thinking across disciplinary perspectives (Billingsley and Nassaji 2020). In addition, 'Bridging Questions' (e.g. 'Why did the titanic sink?') can be used to create a bridge between science and another area of knowledge,such as history and the history of art.

While this lesson was not designed explicitly to create these cross-disciplinary 'bridges', it is inspired by the resonance between epistemic insight and 'combinational creativity' (in Margaret Boden's terminology), that is, novel, unexpected connections between areas of knowledge that can arise in the course of making scientific observations (Boden, 1998). In this way, the question of human/machine differences is used to develop students' awareness of the importance of creativity in science. Exploring this boundary also supports and buttresses the development of epistemically insightful approaches to science education. The lesson does this by bringing students closer to the 'cutting edge' of how science is practiced in the 'real world'. Students are encouraged to appreciate the excitement of scientific discovery available to 'ordinary people' like those involved in the 'Galaxy Zoo' project. They also learn that this was a discovery that was made possible by the importing of a non-scientific set of meanings to establish a shared understanding that led to a significant breakthrough.

2.3. Evaluation of lesson effectiveness

In order to evaluate the impact of the lesson, we designed a pre and post-questionnaire for students to complete. While we did include some Likert-style statements to measure effectiveness, the drop-off in completion of questionnaires from pre to post made meaningful analysis of this data almost impossible. However, we did included qualitative statements in the post-questionnaire which provide some indication of the lesson's effectiveness and are presented following the description of the workshop. Follow-up work to this study will include safeguards to ensure a higher completion rate.

2.4. Availability of lesson and resources

We present this lesson as an available resource for other science teachers to take, adapt and use. We would be very pleased to hear suggestions from other scientists and educationalists about how these activities could be taken forward. The lesson draws on activities and resources supplied on the Galaxy Zoo website, including 'training' materials for beginner citizen scientists. Slides for the session can be found on the epistemic insight open science community area on Zenodo (https://doi.org/10.5281/zenodo.6546829).

3. Description of lesson

3.1. Part 1-introduction and inquiry question

In this first part of the lesson, we pose the following introductory question for students to keep in mind during subsequent activities:

(a) Imagine we could create a robot that was virtually indistinguishable from a human.
(b) Imagine we could train this robot to conduct scientific experiments.
(c) Regardless of whether or not you think this robot would be 'human'… Could we say that this robot was doing science?

This question is designed to stimulate epistemic curiosity, an essential aspect of the development of epistemic insight. We leave this question open for the time being, to be revisited at the end of the session.

3.2. Part 2-introduction to citizen science

The lesson was embedded in a timetabled science lesson with 30 students aged 14–15. We began the lesson by observing that AI is playing a growing role in science, giving a brief explanation of Google's 'AlphaFold' project which provided breakthroughs in protein folding prediction. We note that despite all these breakthroughs, much of science still seems to require the human touch—and that citizen science projects are evidence of this.

We then introduced the Galaxy Zoo project. We explained that the project is predicated on the idea that 'anyone' can learn enough about different types of galaxies to be able to help to classify them. We then gave students exemplars of spiral and elliptical galaxies and invited them to experience carrying out classifications using resources provided by Zooniverse classroom (see https://classroom.zooniverse.org/#/astro-101-with-galaxy-zoo/educators/). Students input their answers into a Google spreadsheet that allowed us to track their agreement or disagreement. This activity creates excitement and gets students involved in the activity of classification.

3.3. Part 3-programming a computer to observe

We then tell students that citizen science project directors set this up while wondering whether, with enough examples of human classification, some of the task going forward can be carried out by a machine. We asked students to consider—what would be involved in designing a computer programme to take on this task of distinguishing between a spiral and an elliptical galaxy. Students produced some insightful responses, such as describing how the programme could scan the colour of individual pixels on the image and analyse various patterns of distribution to make a decision.

3.4. Part 4-merging galaxies

We then introduce students to another type of galaxy—merging galaxies. Merging galaxies are interesting because they provide a snapshot of how we think the largest, rounder and redder galaxies are formed.

We then set this as a new challenge for the students' computer programmes. How might they programme their computer to detect a merging galaxy? We also ask them to consider while doing this, what advantages a human has over a programme for recognising a merging galaxy. For example, in the discussion we mentioned that the shape and distribution of patterns in merging galaxies is more chaotic and unpredictable, making it harder to a computer to accurately recognise a pattern that would distinguish a picture as one of a merging galaxy.

The activities and subsequent discussion of why the categorisations of merging galaxies are more challenging sets up one of the key points made in the lesson. We remind students that when we 'observe' the world, we draw on our understanding of how the world works to help us to make sense of what we see. Observation and classification are evidently not unique to science—they are important methods in a range of non-scientific disciplines. However, it is the embedding of observation within science's distinctive norms of thought that makes *scientific* observation unique. For example, scientists attempt to achieve objectivity in their studies—meaning that as far as possible they do not rely on who is making the observations. Even so, for human observers, objectivity and prior experience are not mutually exclusive. We add the understanding we bring from our everyday experiences and beliefs to our scientific understanding. Scientists, like all humans, work within the constraints of human language when 'labelling' what we see—the best labels are those that reduce detail and emphasise what makes sense to us (e.g. Enfield *et al* 2006). Building on this idea, we ask students to think of other examples they know of 'things that merge'. We then display images of 'merges', such as roads, raindrops and lava lamps. We point out that we have an understanding of what 'merging' might look like from our prior experience which positions us to apply that understanding to the new task of galaxy categorisation.

We then ask students to consider whether this prior knowledge makes us different, better or worse to an AI for categorisation tasks like this one. We introduce here the idea that humans are able to creatively draw on seemingly unrelated 'background knowledge' in novel ways when faced with apparently procedural tasks like categorisation.

3.5. Part 5-artificial general intelligence and science

The next part of the lesson introduces some questions to consider when evaluating whether and how an AI could carry out the task of analysing images to look for examples of merging galaxies. We distinguish between artificial intelligence, in which we programme machines to perform tasks that we deem valuable, and artificial *general* intelligence, which is able to come up with valuable tasks to perform by itself. We note that artificial general intelligence has not yet been achieved, though it is at the forefront of some of the most cutting-edge technological developments.

We wonder with students whether an artificial general intelligence *could* draw on examples of 'merging' from other aspects of nature and apply them to the challenge of identifying a 'merging' galaxy. This leads us back to the initial question regarding whether we could conceivably create a 'robot scientist'.

3.6. Part 6-revisiting the initial inquiry

We now give students the chance to respond to the initial inquiry session—if we created an artificial general intelligence indistinguishable from a human and 'set it loose' in the world—if we taught it do scientific experiments, could we say it was doing science? The purpose of the subsequent discussion was to lead students to be curious and think insightfully about the nature of science, rather than only form and present their opinions about a complex question about AI and humanity.

3.7. Part 7-green pea galaxies

Beginning to draw the lesson to a close, we tell students about the 'green pea' galaxies discovered through the citizen science project. On the Galaxy Zoo message forums, one volunteer became curious about something unusual that they observed and could not explain. The volunteer posted a question to ask whether anybody else had encountered a galaxy that looked like a green pea. Other users confirmed that they had; and this was flagged to the project leaders. On closer inspection of the 'green pea' images, scientists realised that these galaxies were an entirely new type of highly star-forming galaxy (Cardamone *et al* 2009, see also Jennett *et al* 2016).

Explaining this to the students, we notice with them that this discovery was enabled by the volunteer's curiosity combined with the use of shared prior experiential knowledge to draw other people's attention to the quest. These interactions in turn led to conversations between citien scientists and experienced astronomers in forums provided with the site. And the outcome was a significant new discovery. This reinforces the idea that human cultures and experiences provide a wealth of background knowledge that enables creativity, insight—and even naming—in the practice of science.

3.8. Part 8-conclusions

We finished the lesson by noticing with students that observation is central to 'what makes science science' (the nature of science). We ask students to consider:

(a) What is involved in the process of scientific observation?
(b) What do we need in order to be 'good observers'?
(c) How might artificial intelligence aid human observation?

The intention here is for students to see that humans and robots should not necessarily be thought of as 'in competition' for the essential scientific task of making observations. Distinctively human qualities such as creativity and curiosity are central to scientific methods of observation. We can be curious in asking questions regarding whether artificial intelligences could be creative or curious—and whether we would even want to create such a machine. However, there are benefits to gain by being open to machines providing something valuable and supplementary to human observations—for example one of the distinctive contributions of AI to science might be in sifting through large quantities of data unmanageable for humans, distinguishing that which can easily be classified from that which 'does not compute'. Some noteworthy differences between artificial and human intelligence emerge when the activity involves novel and unusual images. In these case, a person engages with the problem imaginatively and draws on a wealth of 'background knowledge' gained from the real world. This contrasts with the programs, historical recordings and data sources that AI uses to synthesise its discourse.

4. Evaluation of pilot lesson

We ran a pilot of this lesson with a class of students aged 14–15. The class teacher and a researcher each evaluated the session and concluded separately and then in conversation together that it had successfully stimulated students' interest and understanding around the nature of science and what 'working scientifically' means. We also administered a survey which asked students a number of questions, including 'what makes a question a good one for science?' Students gave a range of responses to this question, including:

(a) 'It can be experimented with'
(b) 'One that brings up more, complex questions'
(c) 'Any question is good if people are interested'
(d) 'One in which the answer will benefit someone'
(e) 'An unexplored area'

In the course of the discussion, we drew students' attention to characteristics of science described in the curriculum. With this said, these comments by students introduced aspects of science that we can also examine when considering what, if any, are uniquely human elements of scientific inquiry. For example—could we design a robot that could judge whether a question was 'interesting' or not? What about whether it was beneficial to someone? How do we begin investigating totally unexplored areas? It may also be interesting to compare students' answers with answers given by professional scientists to the same question.

In concert with piloting the lesson, writing this presentation and responding to reviewers' recommendations, we sought additional feedback and guidance from astronomers, science teachers, an astronomer who is also a teacher and an Initial Teacher Education specialist in physics education. Comments we received included the recommendation that we sharpen the focus of the lesson on the nature of science rather than becoming sidetracked with questions around the potential of human-like machines in general. We are grateful for their contributions in strengthening what we have offered here. Going forward, we hope a version of this lesson can become a springboard for schools. undergraduate, doctoral and professional scientists and other stakeholders to engage with the roles of humans and AI in scientific research.

5. Conclusions

Technological development is revolutionising the practice of science and is already playing a part in changing how science is conducted in classrooms. Artificial intelligences can effectively perform 'observations' and categorise images, supplementing scientific methods. However, questions remain regarding the extent to which qualities that are apparently unique to humans, like creativity, are essential to scientific processes such as observation. Teachers can use this session to stimulate students' epistemic curiosity and encourage them to question what 'working scientifically' means. Students have the chance to build their scientific curisoity and epistemic insight into the nature of science as they consider how science is conducted in real-world contexts and participate in a scientific activity through engaging in 'citizen science'. There are also opportunities to better appreciate the power and limitations of science as students begin to see the alignment between the power and limitations of humans themselves with the forms of knowledge we create and apply. Findings from students' comments during the session, feedback by the class teacher and data drawn from their questionnaires indicate that some students did develop their ability to think about the nature of science, how it is practised in the real world, and what (perhaps unexpected) uniquely human capacities are involved.

Data availability statement

Data from the supplementary questionnaires used in this study is available upon reasonable request.

Acknowledgments

The intervention study described here was created for the Epistemic Insight Initiative. We thank the Science and Technology Facilities Council (STFC) and the Templeton World Charity Foundation (TWCF 0225) for funding that has enabled this research.

Students and their parents/guardians gave their informed consent to participate in the study, including permission for the results to be published. The research was carried out in accordance with the principles outlined in our ethical policy, Ethical approval given by the Canterbury Christ Church University research ethics committee.

Conflict of interest

No conflict of interest between the authors is reported.

ORCID iDs

Berry Billingsley https://orcid.org/0000-0002-7974-4904
Joshua M Heyes https://orcid.org/0000-0002-8035-3353

Received 30 June 2022, in final form 31 August 2022
Accepted for publication 24 October 2022
https://doi.org/10.1088/1361-6552/ac9d19

References

Aristeidou M and Herodotou C 2020 Online citizen science: a systematic review of effects on learning and scientific literacy *Citiz. Sci. Theory Pract.* **5** 1–12

Billingsley B and Nassaji M 2020 Perceptions of the relationships between science and religion held by upper-secondary school students in Church of England schools *Int. J. Christ. Educ.* **24** 153–78

Billingsley B, Nassaji M, Fraser S and Lawson F 2018 A framework for teaching epistemic insight in schools *Res. Sci. Educ.* **48** 1115–31

Cardamone C *et al* 2009 Galaxy Zoo Green Peas: discovery of a class of compact extremely star-forming galaxies *Mon. Not. R. Astron. Soc.* **399** 1191–205

Enfield N J, Majid A and van Staden M 2006 Cross-linguistic categorisation of the body: introduction *Lang. Sci.* **28** 137–47

Jennett C, Kloetzer L, Schneider D, Iacovides I, Cox A, Gold M and Talsi Y 2016 Motivations, learning and creativity in online citizen science *J. Sci. Commun.* **15** A05

Jordan Raddick M, Bracey G, Gay P L, Lintott C J, Cardamone C, Murray P, Schawinski K, Szalay A S and Vandenberg J 2013 Galaxy zoo: motivations of citizen scientists *Astron. Educ. Rev.* **12** 1–41

Kind P M and Kind V 2007 Creativity in science education: perspectives and challenges for developing school science *Res. Sci. Educ.* **43** 37

Lubart T I and Sternberg R J 1998 Creativity across time and place: life span and cross-cultural perspectives *High Abil. Stud.* **9** 59–74

Massoudi M 2003 Can scientific writing be creative? *J. Sci. Educ. Technol.* **12** 115–28