Engineering ed: Dealing with failure and the robotic future – Engaging students in multidisciplinary STEM learning

Lawson, F. and Oh, M.

Title: Engineering Ed: Dealing with Failure and the Robotic Future – Engaging Students in Multidisciplinary STEM Learning
Authors: Finley Lawson and Michael Oh
Key words: Engineering, Big Questions, Robotics, Epistemic Insight
Brief description (30 words): The article discusses how robotics workshops can provide a multidisciplinary context for examining the power and limitations of science for secondary school students (aged 11-16) within a Big Questions framework.
Abstract (100 words): This article proposes an alternative (or additional) place for the use of robotics within the secondary school curriculum, Robotics provides a unique opportunity to engage students in genuinely multidisciplinary learning that challenges their misperceptions about the nature of science/technology and engage with Big Questions. After establishing the context and pedagogical framework for delivering Science/Technology and Big Questions sessions within the classroom, this article will provide a practical description of how the session has been delivered with students.

Robotics can be seen an “easy win” for engaging students in cross-curricular work, providing a visible link between the science and computing classrooms and an opportunity to get “hands on” with technology. However, with programming now a part of the national curriculum for Key Stage 1 and 2 (ages 7-11) in the UK (DfE, 2013), and the accessibility of Raspberry Pi’s and Scratch software it can be tempting to feel that hands on basic programming is not complex or engaging enough for students once they reach secondary school (ages 11-16).

This article proposes an additional place for the use of robotics within the secondary school curriculum. Robotics provides a unique opportunity to engage students in genuinely multidisciplinary learning that challenges their misperceptions about the nature of science/technology and engage with Big Questions that address the nature of agency, Artificial Intelligence and the power and limitations of science. After establishing the context and pedagogical framework for delivering Science/Technology and Big Questions sessions within the classroom, this article will provide a practical description of how the session has been delivered with students.

Robotics, Society and the Educational Opportunity

Robots have always been a great topic to get school students interested in Science as they appeal to students’ innate curiosity (Bruder and Wedeward, 2003). Whether it’s through comic books, sci-fi movies, TV shows, or even ads, they are easily fascinated with robotic and remote-control versions of cars, pets, and humans. With robot rovers on Mars and the Moon, self-driving cars already being tested in cities in many countries, and robotic companions are being designed and tested for people with disabilities and the elderly, what was once perceived as science fiction is now looking to become science fact within high school students’ lifetime. Enormous amounts of R&D resources are being spent on this area of technology today, and there is a drive for greater (and more diverse) recruitment to STEM in Higher Education (HE) and careers. The question is how can this expressed curiosity be cultivated in the classroom alongside the existing pressures on staff and curriculum time?

Yet even with the EU discussing the definition of electronic personhood, huge advances in driverless cars and the increase of robots and humans working alongside each other in warehouses and manufacturing our understanding of robotics within society is still only really being dealt with at an overly simplistic level. When even robotics undergraduates see 'current advanced products as "black boxes."' (Nagai, 2001) we have to question how we can develop students understanding of advancing technology so that it is neither seen simply as today's world with robots being a novelty, nor as a futuristic (dystopic) world full of them.

For today's students entering secondary school, the reality for them will not be this black and white - with the current revolution in artificial intelligence and manufacturing, they will likely be the first generation who will see the technology-assisted beings becoming part of everyday society, not just a fantasy or a novelty seen in an amusement park display. Much like today's university students and the smartphone, today's young students will enter into the workforce not knowing a world without robots.

And it is within this gray area that they will have to grapple with some of the Big Questions around robots. How will they be treated by individuals and society as a whole? Will there be widespread resentment of their taking roles away from other human beings (such as autonomous cars taking away the jobs of taxi drivers) or will there be thanks for them filling in where humans are simply unable to (such as fire-fighting or bomb disposal)? It is through the lens of these Big Questions that students can and should be introduced to the power and limitations of science, alongside developing their understanding that whilst science can inform our thinking in many of these areas it cannot provide a sufficient answer, and indeed no single discipline can.

When the media is offering teachers and students alike headlines such as "Robot kills worker" (Guardian, 2 July 2015); "Dallas police used a robot to kill." (Washington Post, 21 July 2016) and "self-driving car kills pedestrian for the first time" (Independent, 19 March 2018), it's jarring to realise that whether or not we prepare the students of today for the big questions of how technology and humans interact, they will have to grapple with these questions- most certainly as observers, but more ominously, as people who will interact with, operate or program them. This brings us to one of the big questions of schoolteachers': how can one take students on a journey that begins to explore these deeper questions within today's heavily regimented curriculum?

Teaching Robotics Using an Epistemic Insight Pedagogy

The research of Billingsley et al. (2018) at the LASAR Centre at Canterbury Christ Church University propose that through the development of students' epistemic insight, it is possible to equip them with the knowledge and skills to understand the nature of science in real world contexts and have a richer of understand of how different disciplines interact in relation to their preferred questions, methods and norms of thought. In industry and academia robotics is unquestionably a multidisciplinary arena, and yet excluding project such as Cross et al's (2017) Arts and Bots programme students tend to experience robotics only from a coding perspective within the computing classroom. This not only fails to provide an experience that is an accurate reflection of interdisciplinarity associated with robotics, but can also be seen to miss the opportunity for contextualisation and development of students' understanding beyond 'conventional conceptual content' that Allchin (2013) highlight as important for students' motivation and engagement with STEM.

Together with the LASAR team at Canterbury Christ Church University, author *MO* developed a 90-minute interactive robot workshop that takes students on a journey from understanding how robots are designed to considering how a robot deals with failure - a concept that maps out one key difference between human and robot. We challenge the students then to figure out how to bridge this gap, bringing up interesting questions about what really makes humans and robots *that* different. There are a variety of computing specific learning outcomes that can be addressed by this session, but the objectives can be expanded to meet criteria outside the computing classroom from looking at computational theories of mind to investigating the ethics of responsibility for autonomous and semi-autonomous programs. However, for the purpose of this article, we will speak to three learning outcomes from across the epistemic insight curriculum framework (Billingsley et al., 2018):

- Some questions are more amenable to science than others
- Different disciplines have different preferred questions, methods and norms of thought
- Today we ask questions about human personhood and the nature of reality that bridge science and religion

These learning outcomes highlight for students the boundaries placed around disciplines for them to be delivered within a school setting, furthermore by highlighting the distinctiveness of the different disciplines they enable students to understand the power and limitations of science as well as the relevance of other disciplines to our scientific enquiry. These outcomes reflect implicit and explicit aims of the UK national curriculum and the current drive to move beyond a “pub quiz” (concept focused) curriculum.

Dealing with Failure: Robotics Workshop Description

The workshop begins with a short presentation introducing students to science in the real-world context of robots on other planets/ satellites and how they have been designed, search and rescue robots can also be introduced to challenge students’ misperceptions around the social role of engineering careers. A longitudinal study by Barnaby et al. (2008) showed that students’ attitudes to STEM’s usefulness in society remains whilst their attitudes towards school STEM to tends decrease as they move through secondary schooling – actively making links between these two, specifically in lower secondary students may help maintain the view as STEM being “for them”. Then students are provided with a staged process for creating a navigational program moving from a path on paper, then run on a MIND Designer Robot, before finally using their classmates as robots in the same course, to examine the challenges of programming for failure. This begins a key takeaway discussion about what makes robots and humans different and can be used as a foundation for an ongoing dialogue which can even grapple with the biggest of questions: can a robot with artificial intelligence ever be considered as being “alive?”. The staged process allows the for the development of students’ epistemic insight starting from a foundation of transitional curriculum content (that programs execute by following precise and unambiguous instructions; write and debug programs that accomplish specific goals) to move students through lower and upper secondary epistemic insight learning outcomes.

Workshop Description

The workshop has four key parts to the structure:

Materials Required
A1/ A3 sized design maps
Grid Qaudrant (to overlay printed maps)
Full scale cloth map or taped grid on floor
Duck or gaffer tape (to secure the cloth map to the floor)
MIND Designer Robot (only 1 is needed)
Tablet or mobile phone with the Mind Designer app
Small 1”x1” plastic pieces (e.g. bottle caps) to simulate the robot on the design maps
A1/ A3 sized design maps

Table 1 Materials Required for the Workshop

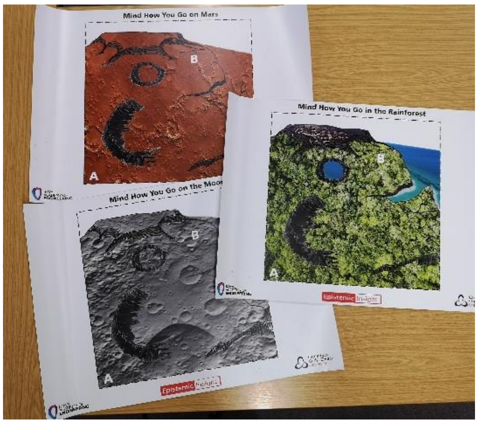

Figure 1 The maps were printed at A1 on coated paper to ensure they were durable across multiple sessions. The shared obstacles are clearly visible on all three maps

Figure 2 MIND Designer robot used for the programming

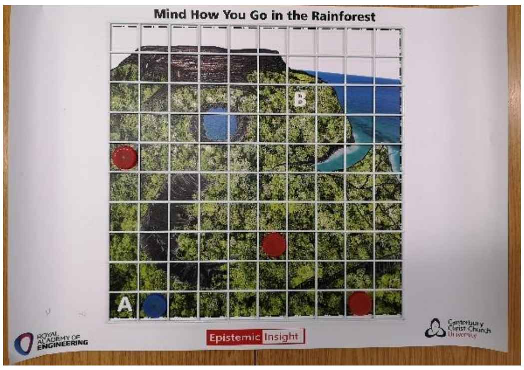

Figure 3 A quadrant can be placed over the maps to support the coding process for less confident students. Additional counters (red) can be added to provide "unexpected" obstacles and raise the question of planning for failure.

The Programming Design Challenge reinforces (or introduces for those outside the national curriculum) earlier computing outcomes that ‘programs execute by following precise and unambiguous instructions’ (DfE, 2013). Students are presented with an (un gridded) map of a landscape (moon, rainforest or mars) featuring obstacles and a start and end-point. Students are asked to write a “program” to move their robot (counter) from A to B.

Figure 4 Students planning the original route for coding

Students are provided with a map and a plastic piece to represent the robot, placed on the starting point They are then instructed - using the basic programming steps available to them of forward, turn left, turn right, reverse - to write down a program that got them from the start to the end, whilst avoiding the obstacles on the way. Depending on the confidence of the students they can either be provided with a quadrant grid from the beginning or this can be introduced after students have written code based on the plain map. The comparison of un-gridded versus gridded code writing reminds students that there is preferred method within computing that requires universalisable instructions that can be compared to a “program” narrative from an English disciplinary perspective that requires a different norm of thought.

To encourage full participation from all students within a group team, members can be allocated different roles (programmers, control engineers or “checkers”, robot operator, code writer etc.). Once written the program is then tested using the map and plastic robot. With the majority of the teams, some changes were needed in their program before they could implement it – these changes often related back to the need for greater specificity, as students often assumed a 90° turn or that the robot was facing North/ East at the start of the program.

Figure 5 Students entering the code using the mobile App

The test run with the MIND Design robot requires students to enter their coding via the mobile/table application. Using the “advanced coding” option students are able to specify angle degrees and length of a single “step” forward this provides the additional opportunity for students to translate their un-gridded instructions into a program that moves beyond 90o turns. For students who are more confident with coding it would be possible to draw on the introductory discussion to program for the path a human might take in comparison to the “robot path”. One of the essential parts of this process was to determine how far the robot would need to go in order to go one step on the map. In our workshops, one grid space on the map was around 30cm on the canvas grid, which was the maximum amount that the MIND Designer robot could do in a single step. Making the canvas map at a larger scale could bring in more complex maths such as the idea that a single step on the program could require multiple steps on the app program (e.g. a 35 cm forward would require two steps of 30 cm and 5 cm in sequence). Depending on the outcome of the test run, teams (time permitting) could go back to adjust their programs and do other test runs. This iterative process matches the iterative process of software and hardware development in engineering.

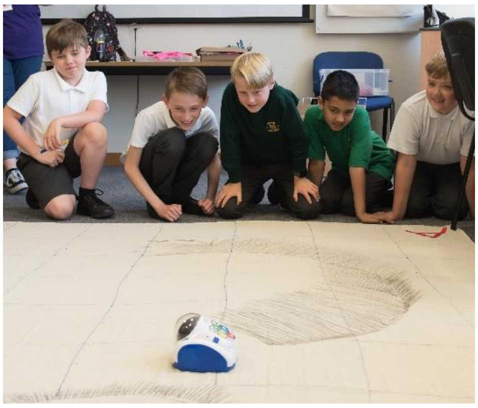

Figure 6 Students testing their code on the "full-scale" floor map

The final part of the session – the test run with a "human robot" serves to draw out the outcome of "today we ask big questions about human personhood and the nature of reality that bridge science and religion". This is done by inviting one of the students to be the "robot" and they will be commanded to do the same steps in the program as the MIND Designer robot - including any previous version of the program that didn't work. This creates an interesting prospect for the student - do they "dumb" themselves down or do they use their additional sense of distance and sight to avoid obstacles (this can be encouraged through the addition of extra "obstacles" within the map). Either case is fine - as at the end of this test run you can discuss with the student what made things different between the robot and "human robot" runs. Of course, in many cases, the student will use their basic skills of adjusting their step distance and sight to have a successful run, without even really thinking about why they could perform the task better than a robot. It is advised to make this process explicit by asking students "what was different?" to draw out students learning in relation to the "nature of reality" and the Big Question what really makes humans and robots different.

In workshops with more time and appropriate safety measures e.g. a sighted "guide", we can even provide an additional variation on the theme - by blindfolding the human robot to remove the sense of sight and degrade their sense of distance. This allows us to have even more of an interesting discussion about how the different parts of the robot (eyes/cameras; brain/computer) need to work together in order to make the robot more human like, and highlight the instinctive adjustments that humans make to pre-empt failure that can be problematic for programming (particularly within the capacity of the MIND robot).For students with more coding experience, or as part of a longer project, students could extend the activity by programming a robot with sensors and building in a "failure" program (i.e. instructions for encountering an obstacle).

A final, and crucial part of the workshop is to allow time for exploration of the questions that sit at the boundary of science and other disciplines (such as the question of language around technology). Students should be drawn back to the opening questions and examine how different disciplines interpret and investigate the questions raised. The concluding exploration can bring many of these concepts introduced and revisited during the workshop together into what hopefully translates into one of many "aha" moment possibilities for students.

Techniques for Broader Participation

The workshop description emphasizes a computing disciplinary perspective. However, it's important within these workshops that we don't solely engage those students who are interested in robots - and perhaps those with some programming or science experience.

Revisiting the epistemic insight learning outcomes through the workshop and drawing students' attention to the multidisciplinary nature of the Big Questions raised aims to engage students who may not be reach by traditional coding projects. The questions around exploration, curiosity and programming for the unexpected can also link to students' interest in the wider social concerns such as the practicalities and requirement for "assistive" robots and robot "companions".

The Engineering Ed project was designed to challenge students' misperceptions about the nature of engineering. As part of this aim we used a variety of different techniques to engage students who may have had more interest in storytelling, collaboration, or art than in the programming and science.

- Narrative creation: Students were asked to create a team name and craft a story around their design challenge. This had to go along with their chosen location (rain forest, moon, Mars, etc.) but it was up to the students to determine why their robot had to get from point A to point B. This provided an additional opportunity to discuss the powers and limitations of science – what *could* science equip the robot with to support the "mission" and what was beyond the capacity of science at the moment.

- Design their own robot: Because in all of our sessions, there was only one robot, but multiple teams - so there was always some downtime for teams while one team was programming and doing their test runs. One activity that was created by a teaching assistant during one of our workshops was for team members to design their own robot, either as a team or individually. This introduces students to the concept of design engineering, and provokes students to think about the similarities and difference between robots and humans – for example cameras may give "sight" for a remote operator but is this enough for an autonomous robot on mars?

- Roles in the Test Run: Having different roles for students in the test run gave the students who were less engaged with the programming aspect of the design process something to "own." During the test run in particular, we gave certain students who were not as engaged in the design session to role of being the "referee" - to tell us when a robot had run into a mountain range or fallen off the end of a cliff. Also, in the final test run with the human replacing the robot, we frequently picked the least engaged member of the team. This allowed them to become the center of attention but also forced them to think about the biggest question of the workshop: what made the human and the robot really different in how they navigated the full-scale world.

- Physical separation of the design and test run phases: The separation of the design and test run phases gave students with differing skills the opportunity to provide vital input to the process. Some students understood the concept of working on a small scale better than others; some understood angles and measurements better; and others could more easily follow the robot at full scale

Our Results

Implementation of the session within schools highlighted a number of students' misperceptions and curriculum opportunities around using robotics to develop students' understanding of the Nature of Science. Many students were not aware of robots “in real life” and how to really view their role in their world today however even those with limited understanding of of what makes a robot function on a faraway world could easily comprehend the parallels between humans and robots in terms of what they needed to have and do to survive.

The questions around the nature of reality and human personhood reflected common misperceptions around the appearance of agency in technological devices, for example. Some students, when asked about the difference between a human brain and a robot’s computer were confident that robots could think whereas others related the requirement for programming to a lack of agency.

The techniques for broader participation also developed as we ran numerous workshops, and we found that the activities around storytelling and designing their own robot were very successful. Stories such as “Amazon explorers who were trying to go to a place where there was a report of a new species” to “A robot who needed to deliver essential parts to a broken down spacecraft” helped to engage student interest in the activity - and by using these stories in the test runs, we were able to get the students excited to see the outcome of their programs. On the test run, the biggest challenge was getting across the idea of failure being an acceptable outcome. Much of the experience of students learning is binary - good vs. bad; pass vs. fail. So when the robot failed to reach its objective, some students became dejected - so it was important to prepare them for the prospect of failure (in our workshops at least a ⅓ of the teams failed to reach the end) and to use that as an opportunity to say “what would you do differently next time?”

Conclusion

Many of the opportunities for further development have already been mentioned. However, the important development opportunity rests in the chance to developed students’ understanding of the Nature of Science (and engineering), and the relationships between science and other disciplines. Whilst not all students came away an “aha” moment, most students found something of interest and engagement in the process. Furthermore, we believe that even if no “aha” moment was reached during the workshop, the activities create an epistemic framework for future opportunities for students to understand some of the essential concepts: the role of failure in engineering; what makes humans “intelligent;” and an expressed curiosity around the Big Question arising from technological advances.

<u>Word Count: 3922</u>

Acknowledgements

The authors would like to thank The Royal Academy of Engineering for funding the Engineering Ed project through an Ingenious Award grant in 2018/19 (Grant reference Ing1718\12\93).

References

Allchin, Douglas. “Problem- and case-based learning in science: an introduction to distinctions, values, and outcomes.” *CBE life sciences education* vol. 12,3 (2013): 364-72

Barmby, P. and Kind, P. and Jones, K. (2008) 'Examining changing attitudes in secondary school science.', International journal of science education., 30 (8). pp. 1075-1093.

Billingsley, B., Nassaji, M., Fraser, S., Lawson, F., 2018. A Framework for Teaching Epistemic Insight in Schools. *Research in Science Education* 48, 1115–1131. https://doi.org/10.1007/s11165-018-9788-6

S. Bruder and K. Wedeward, "Robotics in the classroom," in *IEEE Robotics & Automation Magazine*, vol. 10, no. 3, pp. 25-29, Sept. 2003.

J. L. Cross, E. Hamner, L. Zito and I. Nourbakhsh, "Student outcomes from the evaluation of a transdisciplinary middle school robotics program," *2017 IEEE Frontiers in Education Conference (FIE)*, Indianapolis, IN, 2017, pp. 1-9

DfE National curriculum in England: computing programmes of study - key stages 1 and 2 (2013)

K. Nagai, "Learning while doing: practical robotics education," in *IEEE Robotics & Automation Magazine*, vol. 8, no. 2, pp. 39-43, June 2001.

OECD (2019), OECD FUTURE OF EDUCATION AND SKILLS 2030 Conceptual learning framework A SERIES OF CONCEPT NOTES, https://www.oecd.org/education/2030-project/contact/OECD_Learning_Compass_2030_Concept_Note_Series.pdf

Finley Lawson is a research Fellow at LASAR (Learning about Science and Religion) and completing a PhD in science informed theology. He joined LASAR in 2017 having previously worked in schools for 10 years as an educational support worker and Religious Studies specialist. He works with primary and secondary schools delivering CPD, widening participation and outreach events, and curriculum design on large scale informal science learning programmes. Email: finley.lawson@canterbury.ac.uk

Michael Oh has a Bachelor’s in Aerospace Engineering and Electronic Engineering from MIT. He started his company TSP whilst a first year in university and continues to run it as an owner/founder 26 years on. He has two eight-year-old girls and regularly does “Science Club” with them to not only keep them interested in science and technology, but to give them essential skills in understanding technology in the future.

Corresponding author email: oh@tsp.me