AVOIDING THE SCIENCE STUPIDITY TRAP

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Why don't we teach science students how to think?

Why do we only follow people who think like us on social media? Why is this dangerous? What are the risks of having a high IQ in science? Why do 'flat earthers' still exist? Why doesn't scientific evidence always change how people think? Why are fake facts winning in the media? Moreover, why is this relevant to university science students? No one teaches us the foundational elements about how to think like a high quality scientist. Our university science students are often expected to osmotically absorb this knowledge as they spend their time remembering disciplinary facts and theories. An article in New Scientist (2019, No3218) shows that this is not good enough to prevent flawed thinking or 'stupidity'. This course makes explicit to first year science students 1) what a high quality scientist is and 2) practical strategies on how to become a high quality scientist. It teaches students about the full repertoire of different types of scientific thinking and explains where and where not, to use them. A cohesive student-learning journey across the degree means that students apply the theory of high quality scientific thinking, through active learning in second and third year.

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INTRODUCTION

The reality of bias in scientific thinking

Well-publicised psychological research indicates that we have two modes of thinking: one is fast thinking, referred to by Daniel Kahneman (2011) who won a Nobel Prize for his research, as System 1) and the other is slow thinking (referred to as System 2). Fast thinking is an evolutionary response to danger that requires an automatic, unconscious, fast response (e.g., you suddenly see a snake on the path before you and your 'flight' response causes you to turn around and run in the opposite direction). Slow thinking, on the other hand, is effortful, deliberate and takes time. As you can imagine, both types of thinking have their purpose and are required at different times.

When the type of thinking we 'choose' is inappropriate for the context we face, we get a maladaptive response. Kahneman's work (2011), for example, has shown that we often make biased decisions in response to instances requiring us to assess probability. The use of fast thinking over slow thinking in these instances means that the decisions we make are more likely to be incorrect. In many of our day-to-day decisions, this might not be so critical (e.g., we may spend $12.99 on a bottle of shampoo, thinking it much better value than our other option valued at $13); however, when this maladaptive thinking applies to scientific research or practice, the consequences can be very serious.

An article in New Science journal called 'The Stupidity Trap' by David Robson recently drew attention to the importance of robust decision making in science: 'Recent psychological research ……shows that IQ does correlate with many important outcomes in life, including academic success and job performance in many workplaces. But is less useful at predicting 'wise' decision-making and critical thinking' (Robson, 2019, p.30). The reality is that we all have bias in our thinking, but this article tells us bias can be higher in students with higher exam scores! Robson proposes that students with higher grades assume they have less bias compared to others, thus making them less likely to think cautiously. We need to make sure 1) students are aware of such limits to robust thinking, 2) staff are aware of the limits to standard types of assessment at university and 3) curriculum can address limits to robust thinking using evidence based teaching practice. Furthermore, we need to ensure that students are better able to make explicit decisions about when to use slow thinking (using System 2) with effective techniques when they do so.

Empowering students to challenge bias requires them to change their frame of reference (Mezirow, 2000). A frame of reference involves a process of filtering, interpreting and making meaning of new information. This constitutes two dimensions: a habit of mind (i.e., the assumptions that filter information as we interpret information) and the resulting point of view (Mezirow, 2000). Both are critical to addressing bias by questioning assumptions that our thinking is unbiased, making maladaptive habits of mind 'visible' and taking on strategies for robust thinking as alternatives. This is the challenge of a science unit incorporating scientific thinking.

The need to teach scientific thinking

Curricula in science degrees are typically 'crowded' with 'ever-expanding' scientific content (Johnson, 2014). This emphasis on vast disciplinary learning provides students with scientific knowledge that they will need in their careers, but not a sufficient foundation regarding what high quality practice in that scientific discipline is. There are numerous examples of poor practice in professional science (e.g., p-hacking in the disciplines of psychology: Fidler, & Gordon, 2013 and ecology and biology, Fidler, & Fraser, 2018). Poor statistical practices documented in these particular fields does not mean that these practices are absent from other science disciplines. We need to complement the disciplinary learning in science degrees with clear articulation of what high quality practice looks like in the application of science and the scientific thinking skills that provide a foundation for practice.

Critical scientific thinking can be defined as 'that mode of thinking — about any scientific subject, content, or problem — in which the thinker improves the quality of his or her thinking by skillfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them' (Paul & Elder, 2010). Inadequate teaching of scientific thinking seems to be a gap in science degrees internationally, not just in Australia. Higher education practice is littered with discussions exploring questions such as 'Why do science students get taught so little about the scientific method?' (Foreman, 2014). A report on science college graduates in the USA (Impey, 2011) articulates the gap in foundational science literacy in science graduates and in science education. A number of highly troubling educational outcomes are well described by the following quote from the report (on page 37):

> '*About 40% [of graduating science students] believe that the positions of the planets affect everyday life, and the same percentage think some people have psychic powers. About one in six believe that aliens visited ancient civilizations, one in four think that faith healing is a legitimate alternative to conventional medicine, and a quarter think that some numbers are lucky for some people, half of all science majors say that astrology is either "sort of" or "very" scientific'*.

It is noteworthy that a high proportion (one third) of science graduates in Australia also find work outside of the science workforce (McInnis, Hartley, & Anderson, 2000). The ability of science graduates to think like scientists – their ability to undertake evidence based enquiry that supports innovation - is the critical element valued by employers outside of science (Kirkup & Johnson, 2013; Office of the Chief Scientist, 2016). For example, the four most important STEM based skillsets related to scientific enquiry that are not typically found in non-STEM graduates (but are particularly valued by non-STEM employers) are active learning, critical thinking, complex problem-solving and creative problem-solving (Delloites Access Economics, 2014). These highly desired STEM skills are transferrable to other professions (Marginson, Tytler, Freeman, & Roberts, 2013). Given the large number of science graduates working outside of science, science training needs to train students for this expanded job market.

A note about general science units

Anecdotally, and ironically, general science units in which scientific methodology and the philosophy of science are taught, are disliked by students and are seen to take up space in curriculum that could be used for disciplinary learning. 'General science' units may fail to articulate why this knowledge is important and how it is going to be relevant to them as students and as scientists. Alternatively, the employment focus of students may mean that students are not aware that industry value these skills. As a result, students leave these types of courses with very little understanding about the risks and common characteristics of poor quality science that they should avoid. They also leave without a cohesive understanding about the significance of scientific thinking and its departures from other types of thinking in their lives. Without relevance, engagement is difficult from the outset.

A SCIENTIFIC THINKING UNIT AT THE UNIVERSITY OF NEWCASTLE

Context - revision of the Bachelor of Science

We revised the Bachelor of Science (BSc) at the University of Newcastle using a highly collaborative curriculum design process starting in 2017. More than 200 multidisciplinary stakeholders actively participated in decision-making including 1) science academic, professional and technical staff, 2) BSc undergraduate and post-graduate students, 3) school students, 4) industry, 5) University of Newcastle staff from other faculties, 6) University of Newcastle STEMM leaders, 7) University of Newcastle transferrable skills and pedagogy experts and 8) TAFE.

The eight-stage, broad disciplinary and sectoral involvement in the revision of the BSc supported both the high quality of the curriculum and its ownership by the science community. The success of engagement is confirmed by 1) an internal Faculty award for collaborative curriculum development, 2) pedagogic approaches that align with and anticipated a University of Newcastle mandated New Education Framework that guides best-practice teaching at the University of Newcastle, and 3) the selection within the University of Newcastle, of the BSc, as an exemplar of innovative curriculum and pedagogical approaches to guide review of other degrees in the institution.

One spine of the degree

The redesign process highlighted gaps in teaching in the degree. In response six new core courses (see Figure 1) were planned in the degree, two each year of the three-year program. This spine sits alongside the varied disciplinary and professional specialisations offered to students in the degree.

Figure 1. The new core courses in the BSc at the University of Newcastle

A cohesive narrative describes the journey students take through the core courses.

In the first year, the curriculum supports a transition to university learning & the development of university academic success skills. Pedagogy focuses on lower learning (Bloom's 'remembering' and 'understanding') (Anderson, Krathwohl, & Bloom, 2001). Active learning is prioritised but is heavily scaffolded by teaching staff. Students build an internal student and staff community. There is an emphasis on clarifying the teaching strategies for students. The pedagogy emphasises multidisciplinary problem solving. Prior science and mathematics knowledge is not presumed. Curriculum is structured to engage both those with and without a science background.

In the second year, there is a transition from an internal university focus to a focus on future employment and careers through ‘internal’ WIL/RIL opportunities (e.g., university staff posing real life University of Newcastle institutional challenges that students work on). Students are supported to extend their networks beyond university. Students begin to understand career skills and attributes. There is a pedagogical focus on mid-level learning (Bloom’s ‘applying’ and ‘analysing’) (Anderson, Krathwohl, & Bloom, 2001). There is an expectation of greater autonomy in active learning compared to first year. There is an inter-disciplinary problem solving pedagogy.

The third year shifts focus to the students’ transition from university to the workforce. The consolidated ‘workforce lens’ (external WIL/RIL e.g., industry pose real life industry or research challenges that students work on) means that students become fully engaged in solving complex, real-world industry and/or research problems. There is a focus on higher learning (Bloom’s ‘evaluating’ and ‘creating’) (Anderson, Krathwohl, & Bloom, 2001) and an expectation of autonomous active learning. Course curricula enable students to articulate the skills and attributes they need for the workforce in line with industry expectations. There is a transdisciplinary problem solving pedagogy.

First year core course – Scientific Thinking
The focus of one of the first year core courses called ‘Professional Scientific Thinking’ is how to think and be a high quality scientist. The main weekly themes in the course include:

- Adjusting to the university life and an outline of how the course works
- Pseudoscience, Fake Facts and Science Denial - the challenge for science
- What is science and where did it come from? - an alternative to non-science
- What makes Science Special? - philosophy and practice of science
- How do Scientists Think? - contrasting ways of thinking scientifically
- That Eureka Moment – why creative thinking is so important in science
- Hang On! Really? – the power of critical thinking
- Lies, damn lies, and statistics! – the importance of data and its sound interpretation
- Bias, Quackery and the Irrational - identifying poor scientific thinking
- Doing the Right Thing – ethical practice in science
- Science Can’t Provide All the Answers - The Limits of Science
- Meeting Some Real Scientists – testing course theory in practice

This course is blended or flipped. Online pre-class preparation material and post-class consolidation material support a two-hour face-to-face workshop where students deepen the learning they engaged with prior to class. The decision to implement a blended course came from observations by Faculty teaching staff noting declining attendance to lectures. At the University of Newcastle this is likely a response to all lectures being recorded and shared with students online; however, reduced student learning outcomes from such forms of learning were concerning.

The decision to use a blended course format came also from responses from students themselves. Focus groups indicated that students were often unable to attend lectures. Their reasons for not attending were not necessarily ‘laziness’ or ‘disengagement’. In the BSc at the University of Newcastle, nearly half of the students who enroll in the degree are non-school leavers who are mature aged – and balancing study with jobs and family. A third of students studying the BSc come from lower socio-economic backgrounds, many of them needing to work in order to be able to study. We endeavored to make study as flexible as possible, by allowing these students to engage asynchronously with significant parts of the course content online, at times when they were able to and requiring only two hours of attendance on campus each week.

The online learning is not something that students passively engage with, as you would in a lecture. Students are required to interact and extract meaning and insights from the curated online content. For instance, they may be required to summarise information and bring it to class, to reflect on what they have learned and articulate what they find interesting or challenging.

The course explores eight characteristics of scientific thinking including causal, critical, creative, reflective, emotional, ethical, quantitative and resilience thinking. Three central themes show students:

- what high quality science looks like
- how to identify poor science or non-science and
- how to become a high quality scientist

Students learn about the important role of science in contributing new knowledge and finding solutions to societal challenges. Critically, they find out both how science creates value to society and how it sometimes fails to do so. Engagement is encouraged with the curation of rich media resources (YouTube clips, TED talks, excerpts of TV shows, 3d visualisations) that are engaging as well as informative. Students communicate at least one element of the course content that intrigued them back to staff via a multimedia assessment task – encouraging students to synthesize and articulate their understanding concisely.

Students start to build a picture of what a successful scientist looks like (i.e., their skills, attributes). They learn about the importance of scientific literacy (of which scientific thinking is a subset), through rich examples where science was misused (e.g., poor reporting of science, bias in analysing data) and where non-science was used (e.g., pseudoscience). Students describe these important skills and attributes by writing a Nobel Prize nomination assessment task for their ‘hero’ scientist (e.g., someone they saw in the media, staff within the University of Newcastle Faculty of Science, a scientist doing a TED talk etc.). Articulating the skills and attributes of high quality science and seeing it in a ‘real’ scientist deepens learning.

Our analysis indicates that the learning outcomes for students are high (i.e., high distinction and distinction grades) with more than 72% of students able to incorporate many key elements of the course content to identify the key skills and attributes of a high quality scientist. Only one percent of students could not adequately demonstrate this ability and failed this component of the assessment task. At the end of the course, students meet a Q&A panel working in science at the university. They have the opportunity to test the validity of what they have learned by asking panel members questions. It also allows students to connect what they are learning with science occurring on the global stage.

The core characteristics of professional science thinking are connected to student’s personal experience through a reflective journal assessment task. Students are tasked to reflect on their current skills and attributes and use course content to identify where further learning is required (through the use of Gibbs reflective cycle) (Gibbs, 1988). The bigger picture of the course explores the public responsibilities of having scientific understanding. As you might expect, student experience is highly divergent. Many reflections, however, provided windows into the impact of the course content for many students:

> *“I quickly noticed how the materials and skills I was learning in the course were starting to impact my experiences outside of the course. It was like everywhere I looked, especially on TV, I was searching for things like confirmation bias or traits of pseudoscience. I began electing to integrate critical thinking more and more into my daily life. It has also come to my attention that, after learning what traits make up a great scientist, how funny it is now when seeing scientists portrayed so inaccurately in TV and film”.*

Finally, this course engages students with one another and with academic staff to begin the process of 1) building a learning community and 2) building an understanding of what it is to be a scientific professional within a cohort of scientists. Students learn that science is not an individual activity. The success of science relies heavily on working with others. This requires emotional maturity. The active, collaborative group learning in face-to-face workshops gently guides students on how to work together to produce and refine knowledge. Understandably, many students enjoyed the collaborative learning experience and others found it uncomfortable. For instance, one student noted that:

> *‘I don't find the workshop type of learning helpful I would prefer more note taking, less in person than online’.*

Whilst another student noted:

> *'What kept me the most engaged in this course was teamwork and being able to have a group discussion, which allowed me to discover a different perspective and brainstorm ideas. Each tutorial was very interactive, the discussion of any past work experience by the lecturer gave an insight into the reality of how it is to be a scientist in my future career'.*

Connections with subsequent learning

The learning in this course would be entirely theoretical if it were not for the second and third year core courses in the BSc and further learning in disciplinary majors. In second year, for example, students are required to undertake a second year core course called 'Interdisciplinary Challenge'. In this course, interdisciplinary student groups receive a 'real' issue faced by various staff at the university. Teams are challenged to produce recommendations through project-based learning in the course. The course provides a foundation of entrepreneurialism, defined as the production of 'value' for others (Lackeus, 2015). The pedagogical framework for the course is described well by this author as follows:

> '*Surface learning defined as memorization and acquisition of facts, and deep learning defined as abstraction of meaning and interpretation of experience (Jarvis, 2006). Surface learning informs action, and deep learning is the result of the shared inter-action. Deep learning is therefore by definition meaningful to learners, which leads to increased motivation. If the artifacts created become valuable to a wider community it will also trigger even higher levels of motivation and engagement. In essence, learning-by-doing can be regarded as an emotional and motivation laden process, where motivational levels depend on (1) what actions are taken, (2) what learning occurs and (3) what value is created'* (Lackeus, 2015, p 28)

This learning framework embedded into the institution (i.e., using the campus as a learning laboratory) is an opportunity for students to use the scientific thinking skills they gain in practice. For instance, creative thinking (divergent and convergent) is used to explore 'challenges' by using 'out of the box' thinking (mostly through interactive workshop activities). Critical thinking is applied to narrow down a range of plausible and robust solutions recommended for prototyping. Reflective thinking guides students to explore what worked and what did not, to develop personal resilience and to develop the high emotional maturity and interpersonal skills that is required for interdisciplinary teamwork.

Entrepreneurial learning-by-doing in the second year Interdisciplinary Challenge course serves as a practice run for undertaking a WIL/RIL based Transdisciplinary Capstone in third year. Instead of requiring students to provide value to internal university 'clients', students work with industry or researchers to provide value for an external 'client'. This is an opportunity for students to showcase the skills they have developed as high quality scientists. For industry, it is an opportunity to scope out employees they might like to attract to their workforce in the future.

CONCLUSION

The first iteration of the course indicates that learning how to think scientifically is a skill that is valued by, and valuable for undergraduate students. Active learning to develop an understanding of what high quality science is and how to develop it can be successfully demonstrated by first year BSc students.

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