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https://www.emerald.com/insight/1467-6370.htm

Received 17 June 2021
Revised 26 October 2021
9 February 2022
Accepted 10 February 2022

Exploring the nature and culture of science as an academic discipline: implications for the integration of education for sustainable development

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Abstract

Purpose – Goal 4.7 of the Sustainable Development Goals (SDGs) explicitly frames education as an enabler of change and a means to achieve all SDGs. This study aims to explore the nature and culture of science as an academic discipline and its capacity for the integration of education for sustainable development (ESD).

Design/methodology/approach – Drawing upon interviews with academics working in a Life Sciences Department ($n = 11$), focus groups with students ($n = 21$) and observations from lectures, laboratory sessions and field trips, the study advances a number of recommendations for the integration of ESD in Science Education programs.

Findings – Findings point to the nature and structure of scientific knowledge and the culture of science as articulated by study participants. The study provides a number of recommendations for the integration of ESD in Science Education programs including a greater emphasis on inquiry-based learning, enhancing ESD themes in science-related modules to teach for sustainability and adopting a department wide strategy that promotes ESD.

Originality/value – This study argues that ESD practitioners need to be cognizant of the nature and culture of the discipline area – as a particular discipline propagates a specific culture – encapsulating ways of being, thinking, acting and communicating, which can have implications for the integration of ESD.

Keywords Nature of science (NOS), Culture of science, Education for sustainable development (ESD), Science, Academic discipline

Paper type Research paper

Introduction

We live in a world marred by inequality and unsustainability. Arising from the drive for globalisation, capitalism, competition and consumerism, societies across the globe face complex and interconnected economic, social and environmental challenges, including poverty and inequality, the exploitation of people, environmental degradation, human migration and political tension (Daly *et al.*, 2016; IPCC, 2013, 2018; Sachs, 2015; Schneider, 2011; UN, 2019). Internationally, the drive to address sustainability issues arising from development has been ongoing for some time (UN, 1973; UNESCO, 1978; WCED, 1987;

International Journal of Sustainability in Higher Education
Vol. 23 No. 8, 2022
pp. 120-147
Emerald Publishing Limited
1467-6370
DOI 10.1108/IJSHE-06-2021-0236

UNESCO, 2002). The United Nations (UN) Millennium Development Goals 2000–2015 identified eight critical areas for international attention. The subsequent UN Sustainable Development Goals 2015–2030 (SDGs) set out 17 challenges to a more sustainable future, including energy provision, climate change, poverty, equality and health. The goals are promoted as being universal (Long, 2015), with their principles, standards and values applicable to all people in all countries, and, as such, all nations are required to take seriously their commitments to addressing them (UNEP, 2015).

The UN recognises the role of education in achieving the SDGs. A sub-target of the ambitious SDG Goal 4 (Education), Target 4.7 emphasises the importance of education for sustainable development (ESD), stating that by 2030, countries must:

> [. . .] ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development (UN, 2015, p. 19).

ESD purports a vision of education that seeks to empower people of all ages to take personal responsibility for creating a sustainable future (UNECE, 2005; UNESCO, 2014a, 2017). Given the interconnectivity and complexity of development issues, educators can play a fundamental role in building the critical consciousness (Freire, 1972) of students and teaching for justice and sustainability. Embracing a cross curricular and interdisciplinary approach to ESD requires that educators recognise the potential within their subject areas and thread together disciplinary and pedagogical strategies to form a comprehensive ESD experience for the learner (Hopkins *et al.*, 2005).

Many of the central concepts and methods in science offer particular lenses through which students can consider the development challenges represented within the SDGs. The study of specialist scientific areas such as ecology, immunology, agriculture and medicine can provide a strong knowledge base through which to explore issues such as global health, biodiversity, environmental protection and food security. Furthermore, scientific approaches to thinking and inquiry such as observation, desk based research, argumentation and experimentation can build important skills for interrogating issues. While science educators have a unique opportunity to support the learner to engage with and reflect upon global development issues, this should be done in a way that is consistent with the culture and nature of science (NOS) as a discipline. Set against this particular context, this study explores the nature and culture of science as an academic discipline, as it is perceived and experienced within the teaching of an undergraduate Science Education program in a Higher Education Institution (HEI). Semi-structured interviews with faculty members were used determine their views on the nature of scientific knowledge, norms and practices associated with science, values and attitudes within science, communication and the transmission of knowledge in science and the place of ethics in science. This is augmented by participant observations and focus groups with students. The research also draws upon literature on ESD as a construct and pedagogical strategy. The authors argue that approaches to embedding ESD in science education must be cognizant of the culture and nature of the disciplinary area, that is the particular ways of being, thinking, knowing, acting and communicating that are distinctive and relevant to science. Knowledge of these nuances are important when planning for ESD to ensure that it is integrated in an appropriate way that compliments rather than contradicts the norms of science and science education. In the next sections, we discuss the culture and NOS as an academic discipline. While these constructs are presented separately in the paper, there is significant complementarity between them with regard to scientific knowledge, processes and relevance to society. We examine literature in the area of ESD. The methodology outlines the particular context of the research and presents the research question that framed the study – how does the lived culture and NOS as an academic discipline, in the context of the Science Education program, support and/or challenge the integration of ESD? Findings are presented and discussed from the perspective of exploring some considerations and implications for the integration of ESD.

Nature of science

Science has been described as the pursuit of knowledge to reliably explain the natural world (Weinberg, 2016) or, an attempt to understand, explain, control and predict the world we inhabit by using distinctive methods of enquiry, including observation, experiments and theory construction (McCain, 2015). Scientific literacy reflects the desired outcomes of science education (Chadwick *et al.*, 2017), and while there are diverse positions, descriptions and interpretations of what it should include, (Millar, 2008; Roberts, 2007), it may broadly be defined as:

> [. . .] an appreciation of the nature, aims, and general limitations of science, coupled with some understanding of the more important scientific ideas (Jenkins, 1994, p. 5345).

The OECD (2016) described scientific literacy as comprising three areas of knowledge: content knowledge, procedural knowledge and epistemic knowledge. Supporting the learner to develop informed conceptions of the NOS and how scientific knowledge is constructed are important aspects of science education and scientific literacy (Lederman *et al.*, 2002; Allchin *et al.*, 2014). NOS may be understood as the epistemological and sociological underpinnings of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). The American Association for the Advancement of Science (AAAS, 2013) describes it as comprising three elements – scientist's views on the nature of scientific knowledge, scientific methods of inquiry that generate knowledge and the interconnectedness of science and society.

Scientific knowledge

Scientific knowledge is the principal product and purpose of science (Ziman, 2004), and the means through which science attempts to explain the natural systems of the world. Scientific knowledge comprises theories, laws, principles, concepts, facts and models and can be acquired in many ways. Scientists develop scientific knowledge from within scientific communities at local, national and international levels, where collective capacity provides the motivation, communication and structure necessary to sustain inquiry (Flick and Lederman, 2006; NRC, 1996). Science represents a vast and cumulative body of knowledge and NOS captures the important features of scientific knowledge arising from the processes through which it is generated (Chang *et al.*, 2010; Lederman, 2007; Lederman and Lederman, 2019). Specifically, science is empirically based, it is derived from observations or experience of the natural world (Morgan, 2011; Kelly and Erduran, 2018) or from inferences based upon observations (Bell, 2009). While scientific claims can become accepted as a valid explanation of a phenomenon, it is not always possible to provide irrefutable evidence and as such, knowledge is considered tentative and may be subject to change (Bell, 2009). The tentative NOS is considered a strength. To work towards reaching legitimate claims requires a degree of scepticism and scrutiny that brings with it the possibility of revision or rejection (Sagan, 1996). There are times when scientific knowledge is modified or discarded if discrepancies between theory and observation are deemed to exist (Flick and Lederman, 2006; Ziman, 2004). Science is objective – it is generated without influence from scientists' guided interests, yet subjectivity in science is unavoidable due to human attitudes and choices in scientific reasoning and inference (Mannan, 2016). Scientific knowledge is created from human imagination, creativity and logical reasoning and is socially and culturally embedded (Kelly and Erduran, 2018).

Scientific inquiry processes

Scientific knowledge is generated through scientific inquiry processes (Lederman *et al.*, 2014b) in the "pursuit of coherent, mechanistic accounts of natural phenomena" (Hammer *et al.*, 2008, p. 13). Scientific methods of inquiry rely on gathering evidence, generating hypotheses and theories, merging logic and imagination, explaining, predicting and identifying while maintaining a non-biased stance. They include:

> [. . .] making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results [. . .] identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (NRC, 1996, p. 23).

NOS includes an understanding of such scientific means of inquiry. Although there are different approaches to scientific inquiry, some rules of scientific process apply. These include using empirical data to construct explanations, avoiding bias and presenting explanations for "skeptical review" (Bybee, 2006, p. 2). Science has its own ethical principles that are crucial for the proper conduct of science and insuring integrity, including open-mindedness, accuracy in data collection and reporting, suspension of judgement, intellectual honesty and a self-critical attitude (Ratcliffe and Grace, 2003; Kretser *et al.*, 2019). While scientific inquiry refers to the broad range of non-linear activities involved in science practice, scientific method refers to a linear step-by-step process that is undertaken to investigate phenomena and to answer a scientific question. Scientific method can guide investigations; however, there is no single, universal step-by-step scientific process to follow. Scientists explore research questions using approaches deemed most suitable to the research context (Kelly and Erduran, 2018).

Science and society

A third aspect of NOS refers to science as an enterprise, located within institutions, adhering to ethical principles and contributing to society through various means, including public debate (AAAS, 2013). This perspective of science supports the learner in understanding and evaluating controversial scientific arguments and situations. It scaffolds them to critically read science-related reports and media texts and enables citizens to use scientific information to form evidence-based opinions in debate on socio-scientific issues (Neumann, 2011). The National Council for Curriculum and Assessment (NCCA) in Ireland described scientific literacy as enabling the learner to contribute to "political, social and cultural life as thoughtful and active citizens [. . .] who appreciate the cultural and ethical values of science [. . .] [and can therefore] make informed decisions about local, national and global challenges (NCCA, 2015a, p. 5). Some interpretations of scientific literacy reflect the development of social values required for responsible citizenship (Holbrook, 2008; Holbrook and Rannikmae, 2007), supporting the learner to engage in community initiatives (Roth and Lee, 2004), and the application of scientific knowledge in decision-making (Lederman *et al.*, 2014a).

Culture of science as an academic discipline. Drawing on social perspectives, academic disciplines are distinguishable by the identity and social culture that develops within the group (Becher, 1989; Becher and Trowler, 2001). Being part of a disciplinary group involves personal commitment and a sense of identity; it represents a way of being in the world, and implies taking on "a cultural frame that defines a greater part of one's life" (Becher, 1989, pp. 24-25). The existence of separate scientific sub disciplines, branches or specialist areas such as geology, meteorology, mineralogy, botany evident (Anthony, 1958) consider science from a particular perspective, with their own language and reporting infrastructure (Ziman, 2004). In social terms, culture may be described as the cultivated behaviour of a group of people, embodying inherited ideas, behaviours, beliefs, values, symbols and knowledge that constitute a shared enterprise for social action, which are then reinforced and transmitted by group members (Geertz, 1973). Science as an academic discipline can be viewed as a culture with particular language, values, beliefs and practices (Anderson, 2007; Roth and Lawless, 2002). It may be seen as a complex way of life that has evolved within a particular group of people with shared traditions being transmitted and reinforced by members of the group (Ziman, 2004). Within the culture of science, there are particular ways of knowing, acting and communicating that members of the group conform to (Bruner, 1996).

Being socialised into the culture of academic science involves entering the "tribe" of the sub-discipline or discipline and conforming to the implicit norms, rules or traditions (Ziman, 2004). These are not sustained by specific sanctions, rather they are assimilated as an ethos by the institution (Ziman, 2004, p. 30). In terms of communication in science, scientific knowledge is reported with an explanation of how it was obtained, and the reasoning used to reach conclusions (Valiela, 2009). Scientific research is communicated through written publications, such as academic journals and books, and information dissemination events, such as conferences, symposia and exhibitions. In addition, engagement in scientific communities facilitates greater interaction among scientists, resulting in shared expertise and a sharing of values (Schneider, 2009). In many ways, the communication of advancements in science is what builds and maintains the scientific community (Holliman *et al.*, 2009). As science is increasingly interdisciplinary, scientists also need to be able to communicate more effectively across disciplines, to foster collaboration and innovation. Rewards for academic scientists who communicate their research results to the communal archive include increased social standing, visibility, citations and professional progression by gaining tenure and promotion within the discipline (Achinstein, 2004; Ziman, 2004). Publication is a formal principle and expectation in the scientific production process (Schneider, 2009). Academic scientists are expected to conduct original research, publish, be experts in their field, supervise students, be willing to be reviewed by peers, serve on committees and editorial boards, seek funding, attend conferences and meetings, and engage in academic discourse (Ziman, 2004).

Education for sustainable development

ESD sets out to empower learners to make informed decisions and take responsible actions for environmental integrity, a just society and economic viability, for present and future generations (UNESCO, 2002, 2005, 2006). ESD seeks to enhance knowledge, skills, attitudes and values that enable individuals to lead healthy and fulfilled lives, make informed decisions and respond to local and global challenges to bring about a more sustainable and just society (UNESCO, 2016; Leicht *et al.*, 2018). ESD comprises local and global dimensions to its knowledge base, thus requiring the learner to approach complex, interrelated issues from a sustainable perspective (Leicht *et al.*, 2018). Issues relating to ESD straddle environmental, economic, cultural and social spheres and include environmental degradation, wasteful consumption, health, poverty, urban decay, conflict, gender inequality and the violation of human rights (O'Flaherty and Liddy, 2018; UNECE, 2005). Many of the issues central to ESD are echoed in the UN SDGs (UNESCO, 2020).

ESD emphasises the development of skills such as critical thinking, communication, information processing and systems thinking, thus supporting the learner to explore responses to local and global development issues (McCormack and O'Flaherty, 2010; O'Flaherty and Liddy, 2018). In its publication *Education for sustainable development goals – learning objectives*, UNESCO (2017) draws on the work of Rieckmann (2012) and Wiek *et al.* (2016), when defining key competencies for sustainability including: self-awareness, critical thinking, systems thinking and integrated problem solving. ESD stresses a learner-centred, active and participatory approach, where students have the opportunity to reflect on their experiences to develop their knowledge on sustainability issues and are exposed to methods that empower and motivate them to change their behaviour and to take action for sustainable development (Baily *et al.*, 2017; Barth, 2015; Leicht *et al.*, 2018; Tilbury and Cooke, 2005; UNESCO, 2002). Particular pedagogical approaches are used to facilitate social critique and promote critical thinking and analyses of local contexts (UNESCO, 2012; Ubuntu Network, 2019). Andreotti (2006, 2011) warns that if educators do not adopt deep, critical and challenging approaches to ESD, they risk reproducing belief systems that reinforce the very practices that perpetuate inequality. Thus, students may seek out easy or un-complicated solutions to global problems that do not require systemic change. Such approaches to teaching and learning can be challenging in some formal education settings, particularly in higher education, where the traditional lecture format can restrict pedagogical choices (O'Flaherty and Liddy, 2018).

Education for sustainable development and science education

Addressing issues of sustainability and citizenship are considered an important element of science education and are increasingly included in science curricula (Gresch, *et al.*, 2013; Vesterinen *et al.*, 2016). Some authors suggest that teaching for sustainability requires a paradigm shift in education, whereby education systems, policies and practices are reoriented to facilitate learners to engage with issues of sustainability and to make decisions for action that are locally relevant and culturally appropriate (Sterling, 2001; UNESCO, 2002; Wals, 2011). To integrate sustainability in a comprehensive way requires considerable organisational change and as such can be challenging (Sterling and Thomas, 2006). ESD advocates that development issues transcend disciplinary boundaries and so cannot be understood entirely within any one discipline. What is required is an interdisciplinary approach (Barth, 2015; UNESCO, 2015), which draws on the natural sciences, social sciences and humanities (McKeown, 2002). Increasing awareness of sustainability problems does not in itself imply behavioural change (Jenkins, 1999; Sterling, 2001; Vare and Scott, 2007; McCann and McCloskey, 2009). Ethical values are advanced as principal factors in social cohesion, thus enabling change and transformation. As such, ESD has an ethical and moral dimension, which influences the individual's sense of responsibility for action. It is about instilling an ethic for sustainable living that also nurtures values of justice and fairness, and a sense of common destiny (UNESCO, 2002). This aspect of ESD aligns with approaches to exploring science and society (for example socio-scientific issues) in science education. While many issues addressed within ESD draw upon scientific knowledge and understanding, Holbrook and Rannikmae (2007) express a need to move away from content-led teaching in science and move towards teaching approaches that develop reasoning skills, draw conclusions, develop argumentation skills and make decisions by drawing on scientific ideas.

Methodology

This study set out to explore how the nature and culture of science as an academic discipline, in the context of the Science Education program, supports and/or challenges the integration of ESD. The study is embedded in the interpretivist paradigm and employed qualitative data collection methods to explore perceptions and experiences of reality that may be varied and in flux (Bryman, 2008; Creswell, 2013). Dumas and Anderson (2014) argue that interpretive methodological designs facilitate thick descriptions and complex nuanced findings. Ethical approval was granted from the relevant Institutional Research Ethics Board and is in compliance with ethical protection for human subjects' research. Informed consent was received from all participants involved and pseudonyms were used to anonymise the data.

Methods and participants

Semi-structured interviews. Faculty members in the Life Sciences Department at a HEI in the Republic of Ireland were invited to volunteer for interview. A total of 11 lecturers/teaching assistants who lead biology-related modules on the Science Education program (Biological Science) agreed to participate. Semi-structured interviews provide systematic direction for participants, yet the format of the interview remains mainly conversational (Cohen, *et al.*, 2017). To mitigate the use of leading questions, Bell (2010) advocates that interview protocols and questions need to be carefully planned. The interviewees "voice" needs to be authentically reflected to enhance the validity of the interview and avoid distortion (Punch, 2001). Semi-structured interviews were used to yield an insight into how participants perceived or experienced science (biology) as a way of being, thinking, acting and communicating, as well as determining what participants' valued in relation to science, their work, and their research. The interviews also explored participants' views on the relevance or inclusion of ESD in the Science Education program. A thorough examination of national and international literature in the area of ESD aided with the research design process and the selection of questions for inclusion in the guide which is presented in Table 1. The questions selected for inclusion reflect Schein's (2004) levels of culture and existing literature related to the NOS, understanding culture and disciplines. Question categories included, knowledge in science, norms and practices in science; and values and attitudes associated with science. Interviews lasted approximately 45 minutes and were audio recorded for accuracy. Member-checking facilitated improved accuracy and interpretation of the data.

Table 1.
Interview guide and prompts

	Sample questions and prompts
Knowledge in Science	How would you describe your discipline? How is knowledge formed? What knowledge do you consider fundamental? Are science disciplines/sub disciplines changing? What approaches to thinking are important in science?
Norms and Practices in Science	What do biologists do in the laboratory and/or in fieldwork? What instruments do you use? What are the practices and techniques that you use? What skills do you develop? How are these skills developed? How do you communicate in your discipline?
Values and Attitudes	What do you value as a scientist? What makes a good biologist? What do you enjoy about your discipline? How valuable are scientific findings to society? How do you see science as influencing/being influenced by society?
How is science communicated and learned	How do you publish or share your work? How do students of science learn? How do they develop skills? What is the contribution of lectures, labs and field trips? Is the material to be learned in biology strongly framed? Do students have flexibility in what they choose to learn? How important is assessment?
Ethics in Science	What is the place of ethics in biology? Where does responsibility lie? Is there an onus on scientists to respond to sustainability issues that are emerging? Does biology contribute to the overall good?

Focus Group. Focus groups engage a small number of individuals in an informal group discussion, centred on a particular topic (Wilkinson, 2004). Three focus groups (n = 21) were conducted with undergraduate students registered on the four-year concurrent science teacher education program. Participants were selected using convenience sampling. This type of sampling occurs when the researcher identifies convenient cases that meet a prescribed criteria and then selects participants who respond on a first come first served basis until the sample size is reached (Robson, 2011). Focus groups comprised six to eight students in the third year their program. Each lasted for 35–40 min and were audio recorded for accuracy. Questions were open-ended and invited students to share their experiences. The purpose of the focus groups was to explore student attitudes and perceptions of the Science Education program in relation to content and delivery. Questions focused on three areas: their experiences of the science program (for example, why do you think science is important as a subject? How do you experience the program?); their experiences of learning science on the program (for example, what kind of contemporary issues does science relate to? What issues are you particularly interested in? Why are you interested in these issues?); and their views on ESD as it relates to science education (for example, what is your understanding of ESD? What is your view of the role of ESD in science?).

Participant Observation. Participant observation was used to gain an understanding of the culture and experiences represented in the teaching and learning environments in which faculty members and students occupied. Four lecturers agreed to facilitate access to lectures, laboratory sessions and field trips, for observational data to be collected. A total of 11observations were conducted in these settings. Drawing upon Morrison's (1993, cited in Cohen *et al.*, 2017, p. 457) four levels of observation a framework for observation was developed, encompassing the human setting, interactional setting, physical setting and programmatic setting. The framework also included elements from Spradley's (1980) descriptive question matrix including actors, space, activities, objects, acts, time, events, language and goals. The observation framework constituted across various models facilitated the researcher to capture experiences in the teaching and learning spaces. Note-taking was completed concurrently with observation, and were subsequently used as a source of data (Bryman, 2008).

Data analysis strategy

Inductive thematic analysis was used to analyse data from interviews, observations and focus groups, facilitating the identification of themes, patterns and categories that transcend and emerge from the data (Lewis, 2009; Merriam, 2009). Such an approach to making meaning implies that the researcher, through a variety of triangulated data-collection processes, actively engages in constructing meaning with the support of the participants (Silverman, 2006). Transcripts from interviews, focus groups, and participant observation notes were studied and themes were identified. Segments of text were indexed, coded and organised in line with emerging themes (Creswell, 2013). Codes were generated by means of bottom-up coding, which enabled openness to new codes emerging from the data (Lewins, 2008). After the initial coding scheme was developed it was piloted using a random sample of the data. Multiple coders facilitated for the coding scheme to be applied in a reliable way. Categories and codes emerging from the data and data analysis are listed in Table 2.

Findings

A number of themes emerged from the data in response to the primary research question. Two key themes are presented here. The first, scientific knowledge includes two sub-themes: the nature of scientific knowledge and the structure of scientific knowledge. The

Category	Codes
1 Knowledge in Science	1.1 The nature of scientific knowledge in science 1.2 Scientific knowledge is building and changing 1.3 Hard, factual aspects of scientific knowledge 1.4 Application of scientific knowledge 1.5 Curriculum as a selection of knowledge
2 Structure of Science as a discipline	2.1 Discipline, sub-disciplines and specialist areas 2.2 Changing sub-disciplines 2.3 New emerging areas and links with other disciplines
3 The Ethics of Science	3.1 Ethical issues in science 3.2 Science is value neutral
4 Culture of Science (Ways of talking, thinking)	4.1 The language of science (ways of talking) 4.2 Ways of thinking in science
5 Culture of Science (Ways of doing, being)	5.1 The working environment of a scientist 5.2 Ways of being a scientist (norms and practices) 5.3 Ways of doing as a scientist (e.g. lab work, investigations) 5.4. Motivations/Goals of a scientist
6 Culture of Science (Ways of becoming)	6.1 The novice undergraduate science student 6.2 The postgraduate science student 6.3 The graduate expert scientist
7 How Science is communicated	7.1 Building a knowledge base 7.2 Building skills and mastering techniques 7.3 Becoming good at scientific method 7.4 Reading in science
8 The Student (Learning Experience)	8.1 Supporting students to think scientifically 8.2 The scaffolded nature of teaching on the programme 8.3 Students' independent work (e.g. reading, assignments) 8.4 Translating learning (between modules, between lectures and labs)
9 ESD in the programme	9.1 ESD in existing modules 9.2 Other opportunities for ESD in the programme 9.3 Obstacles to ESD in the programme 9.4 Departmental support for ESD

Table 2.
Thematic categories and codes

second theme, the culture of science, includes a number of sub-themes: ways of being, ways of thinking, ways of acting and ways of communicating.

Scientific knowledge

Nature of scientific knowledge. Within this theme, interview participants described the knowledge associated with science as vast, expansive and continually building. Participants spoke of the sheer scale of scientific knowledge associated with their research areas and the need to keep abreast of developments. In discussing how to organise modules for students, many participants noted that the process of selection of material focused on providing the basics of the scientific area in sufficient depth as to provide students with an understanding of the key concepts:

> It's about getting across the fundamentals, the core ideas while also giving them a feel for the scope of the area, and basic techniques [. . .] it's difficult to get the whole subject encapsulated in 12 weeks [. . .] We're trying to give a little bit on how it [microbiology] impacts on health, food, the environment and the industrial applications, which is the other side of it [. . .] it's a science that touches on a lot of things (Faculty 5).

These sentiments were echoed by undergraduate students with one noting "I often think [that] maybe in first year [. . .] they should start with more basic stuff, well I know myself I didn't do chemistry or physics [in second-level] and I was in first year, at the point of pulling my hair out" (Student 1).

Reflecting the changing nature of the knowledge base of science, one educator noted how her module reflects change from year to year, "I say here's the dogma on this and I say next year I'll be teaching a different dogma [. . .] because someone will discover something new in this process and I have to update the dogma (Faculty 4)". Another interviewee described how the practice of microbiology has changed over the years from knowledge on a few select microbes to assembling complete genomes from single cells. He noted how technology has contributed to this, and described how textbooks and publications have changed to reflect this, "books are being constantly published on this [. . .] if you go back to an older textbook you'll find that really it is invariably very out of date in comparison to the modern stuff" (Faculty 5). Another participant explained that change is particularly common in biology-related areas of science. She noted that there are more absolutes in physics and chemistry, where things are largely measurable and predictable, but that "in biology, there's a softness because things are in flux and knowledge is in flux and we only know the tip of the iceberg" (Faculty 4).

In science education, scientific knowledge is communicated through the formal structures of lectures, laboratory sessions and field trips. From observations in labs and lectures, modules offered to students were strongly framed. Lectures formed the basis of theoretical input. These took place in lecture halls, with the lecturer presenting PowerPoint slides and other visuals. Faculty members controlled the sequencing and pacing of information transmitted, what was to be learned and what was to be examined. Lecturing styles varied, but for the most part they were didactic. Interaction was minimal, with lectures following a traditional transmission format, that sought to build layers of knowledge that facilitate a deeper level of understanding about the scientific concepts, principles, techniques and procedures in question. Describing his lectures, one faculty member stated that the students should:

> Have fundamentals, let's say in terms of soils – soil composition and function, how they do what they do [. . .] Once you have that right, you can take steps forwards based upon it (Faculty 6).

Lecture notes and handouts provided a scaffold for theoretical aspects of the module. Students were expected to refer to key prescribed texts and conduct further reading to substantiate this information. Students were also provided with a reading list of core texts, containing the technical knowledge relevant to the module.

In laboratory sessions, students were supported in learning and using practical skills. From the seven laboratory sessions observed with students, labs tended to be prescriptive and highly scaffolded. Students were provided with instructions or procedures to follow with one faculty member noting, "they get a handout when they come in and they get an overview of what's happening in the lab and they just literally start through the procedures (Faculty 1)". In one laboratory session, a brief assessment was conducted at the start of class to gauge learning from the previous laboratory. This suggests a focus on building competence in the theoretical components of the program. Data from both interviews and observations identified that some students were more concerned with getting the correct outcome in scientific procedures than engaging in genuine scientific inquiry. One faculty member explained the fear and frustration that she observed from students as they grappled with unexpected results, stating:

> All the first years want to do is write up their lab report. They'd ask 'What is the answer supposed to be?' You know [. . .] the biuret test, it goes from blue to purple. One person got a funny colour, and was saying 'Oh my God, it's not the right answer,' but I tried to work with her and said, 'But why did you get that colour?' [. . .] She said, 'But it doesn't matter, I just want to get it right' (Faculty 7).

During laboratory observations, students engaged in a range of procedures including: examining microbial cultures (e.g. Ascomycetes) using a microscope; weighing soil samples accurately using electronic scales and identifying the internal organs and components of the arterial system of a rat through dissection. Where specialist equipment or techniques were required, these were demonstrated by the lecturer from the top of the laboratory. Students were organised into groups of three or four and were given autonomy to work at their own pace. Some groups were more engaged than others. Students used specialised equipment (e.g. scalpels, pins, test tubes, centrifuges, microscopes) and substances (e.g. iodine, sucrose). They worked with samples from the natural world (e.g. rats, frogs, soil, fungi, plants). They referred to textbooks, overhead projections and lecture notes for more information. They referred to prescribed procedures to guide their work. Results were captured, charts were labelled and graphs were drawn.

Field trips enabled students to see real-life applications of what was learned in the classroom. For example, in Field Trip 2, students visited different agricultural sites – an organic farm practising permaculture, an intensive tillage farm, a farm growing *Miscanthus* for biofuels and a commercial orchard. The lecturer encouraged students to examine the soil at different sites, suggesting:

> Take some soil in your hand and smell it [. . .] What can you tell from the smell? (Observation Notes).

In the interview, he explained:

> Agriculture and soil are a field-based science so it's important that they get exposed to it and that they get some appreciation for it [. . .] By just taking soil in your hand and feeling it and smelling it [. . .] you can tell quite a lot about it (Faculty 9).

A notable element from observation notes was the absence of opportunity for students to dialogue, converse or discuss topics pertaining to science. The factual nature of relevant information, coupled with the emphasis of development of practical laboratory skills, suggests limited opportunity for talk-based activities. Another aspect that emerged through observations is the modalities of assessment used. Undergraduate students are required, as part of their program to complete science-related assignments independently. This may include laboratory reports, assignments and the development of materials associated with teaching science, that require additional reading and independent research. However, students indicated that, given the high level of contact hours, the time available for this was limited. One student noted:

> 'Oh, it's only one more assignment.' Each lecturer says that and, 'Yeah, fair enough, but multiply that by six and then you're stressed out and everyone is stressed out from it' (Student 6).

Structure of scientific knowledge. Within this theme, study participants described the structure of scientific disciplines, explaining that science has numerous sub-disciplines, fields of study and specialist areas and that specialising is the norm in science. One participant observed:

> The study of science has become narrower and narrower, and there is a greater tendency to put labels on those narrowing disciplines: are you a biologist, or are you a zoologist? Are you a biochemist, or a biologist? Are you a food scientist, or a biologist? Or a botanist, or biologist? (Faculty 3).

Faculty spoke of the development of new sub-disciplines within science, and how new and emerging technologies have allowed for greater exploration of natural systems. One interviewee noted "molecular ecology didn't exist years ago and now there are entire journals devoted to it" (Faculty 10). Another participant indicated the degree to which scientific applications are impacting society and development, noting:

> There are whole new areas in biology relating to health, biotechnology, the microbiology, the gene manipulation and also the prospect, the real serious prospect is that enzymes are going to gradually begin to replace the silicon chip (Faculty 3).

Topics and areas of study in science can be independent, or they can be interrelated. Interviewees spoke of the importance of seeing links between different aspects of science:

> Soils link with many things like engineering, climate change, hydrology, geology, biodiversity perhaps, biometric quality. Agriculture is closely linked with food science, water issues as well, and to environmental issues, economics of course and human health (Faculty 9).

The combining of science with social sciences and humanities was also mentioned as forging new career paths for scientists. Such interdisciplinary expertise is necessary for the development of policy, to ensure that science is accurately and appropriately considered. One interviewee recalled attending a conference describing the "socio-biologists" that he met as "guys in suits who don't go in the lab anymore, but they have to be able to look at the implications of practice to inform science policy" (Faculty 5). Agriculture was specified as an area that has expanded into other specialist areas, as noted in the following statement:

> Agriculture has moved far more into the area of food science and technology. It has moved into the areas such as rural and environmental protection, organic production, forestry, recreation [. . .] we have to look at the alternatives to agriculture in terms of the old model (Faculty 3).

Culture of science

Ways of being. Participants emphasised the importance of being passionate about their area of work. One interviewee spoke of their excitement at observing microbial growth in agar plates, stating "when I go down and see a plate with antibiotic in it and growth levels are almost the same as the one with no antibiotic, then I get fairly excited, because this tells me there [are] a lot of antibiotic resistant bugs in there (Faculty 5)". Another interviewee spoke about seeing science in the natural world around them:

> Science principles are taking place around us [. . .] from the lawn to the potted plant, to the acre of grounds, to the 30 acres outside in maize, to the farmhouse, to the budgie cage: this is where biology is (Faculty 3).

In the laboratory spaces, participants dressed in lab coats and protective goggles. Laboratories were equipped with microscopes, weighing scales, Bunsen burners and centrifuges. Extractor fan units were in place. Skeletal models were suspended from hangers. Safety notices and illustrative charts hung on the walls. Stations were set up for students to conduct their work, for example one lab observed focused on identifying the internal organs and physiology of a rat specimen.

When asked in interviews what they valued as scientists, some spoke of the prestige of being recognised as a contributor or expert in their field, nationally and internationally:

> I think that most of the scientists are driven by their own ego. They're really looking to prove something [. . .] You write it and you submit it and it becomes part of the shared knowledge out there [. . .] and then you see if referenced in later work, and that's rewarding (Faculty 6).

> We're interested in what we do first and foremost and I think it would probably be quite a selfish interest. It feeds our egos. The research we do, we like to think we're one of the best in that particular area of research in, let's say initially Ireland, then Europe, and then the world (Faculty 5).

Others noted that seeing the positive impact of their research in society was also a motivator for their work, "seeing your work being successful [. . .] seeing disused land reclaimed and turned into a safe green area is a really good feeling (Faculty 6). When asked what might constitute a good day in the laboratory, answers included: "getting a funding application in", "seeing something unexpected happen in the lab", "seeing my students making progress", "making progress on a paper" and "being invited to present at a conference". Some faculty members, particularly those who had completed doctoral and postdoctoral work spoke of the additional experiences that they gained through postgraduate studies. They described this experience as being pivotal to their development as scientists resulting from increased responsibility, and a clearer focus on a career trajectory in a particular area. Engagement with post-graduate studies supports the student to draw on the expertise, connections and publications of their supervisor and delve into a specialist area:

> You go from working through prescribed experiments to being part of a bigger research project where the answers aren't apparent, and you're not really sure if what you're doing is the right thing (Faculty 2).

> [Being] a postgrad can be a lonely experience [. . .] you have your own project, and while you have a supervisor you still have to work on your own, and you have to become a lot more independent, you rely on yourself (Faculty 8).

Ways of thinking. Interview participants described characteristics that are important for how biologists think and view the world. They indicated that they need to "be logical thinkers and be reflective" and to "have critical abilities". They need to be "methodical", "organised and good at planning microbiology is like cooking". They need to "learn from their mistakes", "gain intellectual independence" and "develop confidence in their knowledge and arguments". Interviewees noted that a scientist must "have a natural curiosity", "enjoy working with difficult puzzles", "enjoy working with gadgetry", "want to become specialists in [their] field" and "must be problem-solvers".

One faculty member described wanting his students to:

> Have a taste or appreciation [. . .] for what's necessary to carry out good science [. . .] In the labs, you know, it's about rigor and application and patience [. . .] and to have critical abilities [. . .] I wouldn't go so far as to say sceptic[al], but critical you know, the ability to stand back from things; [not to] accept information as a given; be prepared to look at it, you know (Faculty 9).

Some lecture content observed during this study evidenced an alignment with sustainable development themes. In particular, a lecture on Soil Science examined links between land use and climate change and the potential for carbon sequestration. Similarly, in an Agriculture module, students were introduced to themes relating to sustainability, including the growing use of biofuels and intensive versus organic farming. Interviewees also alluded to links between their module content and ecology, biodiversity, health, water, energy and food security. However, some faculty shared that sustainable development was not relevant to the focus of their module, for example, biochemistry. This educator highlighted that:

> A large portion of what I teach is chemical structure, the nearest I get to a whole organism is looking at an organ or muscle or a nerve [. . .] and so it's really quite remote really from saying to a student, 'Well we need to develop a new process for recycling plastic,' or something (Faculty 4).

During focus groups, students suggested that the inclusion of ESD themes was a positive experience:

> It's important to make pupils aware of the more global context, rather than just thinking about what happens in their own country like. To bring up, make them aware of just the issues (Student 16).

> Open your eyes a bit as well to see what's going on in other countries, and know the effect of what we do here has on them (Student 15).

> The world is becoming a smaller place and you know going back to the concept of like global village, I think it would be important from that aspect that pupils get to know like other countries, cultures, what's going on for people (Student 1).

Ways of acting. Interviewees described that working in science is multifaceted and involves reading, planning experimental design, sampling, measuring, manipulating, observing, analysing and interpreting. It uses a range of equipment, techniques and practices, and involves recording, documenting and writing. Work in the laboratory setting involves a range of techniques and procedures that support the inquiry NOS. Specialist instruments and equipment appropriate to the scientific area are used. In this regard, one interviewee noted:

> If you were testing soil, you'd be using your AAS [Atomic Absorption Spectroscopy] machine continuously; if you were testing food and enzymes, you'd be using your HPLC [High-performance liquid chromatography] and your gas chromatography [. . .] I am on PCR [polymerase chain reaction] all the time, extracting DNA [deoxyribonucleic acid] (Faculty 7).

Others spoke of the problem-solving nature of their work, whereby scientific methods or processes are devised to address a problem or question at hand. One interviewee described his work on finding appropriate and safe uses for the by-products of agricultural production, including compost remains from mushroom growing. He also described his involvement in a research project on the restoration of mine wasteland. The problem was posed as 140 acres of toxic land that was contaminated from the by-products of mining that occurred in the 1970s. The land was unfit for use and posed a health and pollution threat. He stated:

> There were millions of tonnes of residue or waste being produced and so when the mine closed, the problem was how to nudge this back into the landscape to have a beneficial use or basically not just be exposed potentially (Faculty 6).

He explained that approaches taken to address a scientific problem and the resulting experimental design are influenced by what is already documented and published in the area. He also noted the preparation work in the laboratory, and the observation and sampling tasks on site:

> The literature part, has it been done before? What's the best procedure to follow and mistakes to avoid? That's the first stage really, to give you the background and give you an idea what to look for, because if you look for everything you'd be there all day or be there forever, you know. So, it's maybe fine-tune exactly what you're looking at. [. . .] It's about representing, getting samples of the soil and taking it back to the lab and seeing what it's like, chemically and physically [. . .] then setting up a greenhouse with the samples to see if grass type I grows or type II or type II (Faculty 6).

Ways of communicating. Interview participants identified a number of discipline specific methods of communication including the discourse of the discipline and dissemination of scientific processes and research. One interviewee noted, that "biology is notorious for jargon" and explained how language can be unique to a specific scientific area of study. She noted, within her sub-discipline:

> We're often talking different language [. . .] biology more than any area is notorious for jargon, so every sub-discipline has its own jargon, its own way of looking at the world, and thinking about it (Faculty 8).

Interviewees explained the proliferation of scientific terminology. They explained the detail involved in naming individual components within the structure of living organisms, whether they be plant, animal or micro-organism. They elaborated that reactions and cycles are named, technical terms are used to describe processes, and machines and equipment have their own names. They explained taxonomy and the names assigned to plants and animals to include a kingdom, phylum, class, order, family, genus and species. They also noted that Latin or botanical names are used to provide information to distinguish one plant type from another. One lecturer explained her incremental use of technical terms in the learning environment, to ensure that students become familiar with them, "I would say to them, go get the coleopteran, rather than go get the beetles (Faculty 5)". Participant observations completed in the "Diversity of Organisms" laboratories reaffirm the common use of language relating to the discipline, with technical terms used to describe procedures and Latin names to describe specimens.

In terms of academic communication, significant findings and developments are shared across the scientific community, through academic publications and conferences. These also serve to inform the students and emerging scientists. Reading builds knowledge and informs scientific practice, this was reiterated in the interviews with faculty members with one noting, "I carry papers around with me all the time so whenever there's time, I read, you know, half a dozen papers on the way up to [X], another half a dozen on the way back down" (Faculty 5). Interviewees noted the enormity of keeping on top of publications and adopting techniques to identify strategies to efficiently assimilate useful knowledge. They noted that review journals bring together vast arrays of research into one paper, which is useful, while also providing links to other relevant material. "Review journals in particular have huge literature lists which will lead to you reading another 20 or 30 papers" (Faculty 5). Faculty members also spoke about the importance of working in scientific communities to expand their scientific career, both in terms of knowledge and recognition. Peer dialogue is key to enhancing knowledge. One interviewee noted:

> You'll find interesting things by talking to colleagues who have read something that you didn't see, and this will give you the basis for a bit more work (Faculty 3).

Equally, scientists seek to publish research, to share their work and to become more visible in the field, marking their scientific outputs. Academic papers and journals with high ranks and visibility are targeted by faculty members – in terms of both raising their research profile and also attracting funding, "you have to publish to be seen [. . .] If you don't focus on getting papers out as well, your funding will dry up (Faculty 5). Opportunities to be involved with other academics in the field also serve to share knowledge and developments in science. A range of actives were flagged as important in terms of raising profile and sharing learning in science. Conferences were named as particularly useful:

> People go to conferences because you get to present your work, and see what others are doing, you make contacts at a conference, and you get recognised as a contributor to your niche area (Faculty 3).

Discussion

The findings presented here reflect the lived nature and culture of science as an academic discipline in the context of an undergraduate Science Education program in one HEI. Results reflect scientific knowledge as hard and technical, extensive, expanding and cumulative, subject to change and highly specialised. The science content/experience reflected here is "hard", "packed", technical, factual and complex - results suggest a strong focus on content knowledge and transmission of information. When exploring procedural/practical knowledge, we note that this experience is hugely scaffolded and educator-led, thereby negating enquiry approaches to student learning. Students are therefore not experiencing significant "inquiry-based learning experiences" with opportunities to hypothesise, question, and devise inquiry processes including collecting, analysing and interpreting evidence (Harlen, 2015). When ESD themes are included in course content, they are presented in a factual manner, therefore reflecting education *about* sustainability rather than to education *for* sustainability. This approach lacks the explicit focus on building learner capacity in critical thinking and informed decision-making that is central to ESD. When considering the results of this study from the perspective of the epistemological and ontological positions that inform science as an academic discipline – a clear focus emerges, to create and facilitate learning experiences that support the exploration of sustainability issues, active engagement with the issues, and informed decision-making drawing upon scientific decisions/research – the core concepts underpinning ESD. These findings provide a useful lens to science as an academic discipline in a particular context and have significant implications for how ESD might be included within the delivery of a Science Education program. Both formal and informal ESD practitioners need to be cognizant of the culture and NOS as a discipline, as a particular discipline propagates a specific culture - encapsulating ways of being, thinking, acting and communicating. Therefore, pedagogical approaches for ESD in science education must be aware of the norms associated with the culture and NOS. This discussion interrogates the findings in lieu of relevant literature pertaining to science, and ESD, and in doing suggests three recommendations regarding the integration of ESD in science education. At the micro level, we advocate for the adoption of inquiry-based learning approaches such as problem-based learning (PBL). At a meso level, we discuss the packaging of content for modules that includes an ESD focus. Finally, at a macro level, we advocate for the adoption of a department-wide commitment to ESD.

Towards an inquiry focus for education for sustainable development

Observations conducted as part of this research indicated that students' laboratory and field-based work tended to be highly prescriptive and scaffolded. Module content was fixed and the curriculum was strongly framed (Bernstein, 1971), with little self-directed learning or autonomy provided to students. The culture of science, as articulated by faculty members, is one in which the scientist develops skills of inquiry, reflection, organisation, problem-solving and critical thinking. Scientists develop practical skills, including experimental design, sampling, measuring, manipulating, observing, analysing and interpreting. They think scientifically, use scientific terms and adhere to safety procedures in the practice of their work. They develop arguments based on evidence and communicate, defend and alter these, as appropriate. They read scientific publications, engage in scientific communities and publish their work to contribute to the scientific knowledge base. To this end, science education should reflect real-world scientific practice, so that students experience the genuine, uncertain nature of processes associated with scientific inquiry. Grinnell (2009, p. 19) critiques approaches to science education that do not replicate the everyday practice of science. He draws attention to textbooks that "divorce facts from understanding", and do not represent the "erroneous observations, misleading generalizations, inadequate formulations, and unconscious prejudice" that are central to the everyday work of scientists. Cavagnetto (2010, p. 339) explains that science instruction is lacking when it does not replicate actual scientific practice. He describes some approaches to science teaching as overly prescriptive, and as attempting to "replicate the science process using cookbook-style labs that serve as verification of ideas rather than construction and critique of ideas". Gilbert (2004) claims that science education should be as authentic to the discipline as is possible, under the conditions of formal education structures. Holbrook and Rannikmae (2007) advocate moving away from content-led teaching towards the development of skills such as reasoning, argumentation and evidence-based decision-making. To reduce the focus on content and to enhance skills development would be consistent with post-primary curriculum reform in Ireland, pointing to key skills development (NCCA, 2015b). In particular, it resonates with the emphasis of the new Junior Cycle science specification on the NOS, scientific inquiry, communication and cross-thematic strands (NCCA, 2015a).

Inquiry-based learning is a pedagogical strategy that is considered effective in the teaching of science, through scientific investigation (Lunetta *et al.*, 2007). Such participatory methodologies are core to ESD. Successful implementation of inquiry-based learning in a science environment is not without its challenges, as the pedagogical strategies required are more complex than the transmission of knowledge (Barron and Darling-Hammond, 2010). For successful inquiry-led outcomes, the learner must be highly motivated, competent in appropriate scientific techniques, have sufficient scientific background knowledge, and the capacity to manage the extended activities required for the investigation. In addition, the educator must be competent in overcoming the constraints of the traditional learning environment and skilled in managing the multitude of challenges that can arise during the process (Barron and Darling-Hammond, 2010; Edelson *et al.*, 1999). While a high level of scaffolding and support may be beneficial in guiding students to reach stated learning outcomes within class time, findings from this study indicate that practical experiences do not mirror the culture and NOS as an academic discipline, or expose students to the myriad of experiences of real-world scientific practice. This leads the researchers to question the extent to which students develop the mindset of a scientist, and the skills of true inquiry associated with NOS within the program (AAAS, 2013; Kelly and Erduran, 2018; Lederman *et al.*, 2013; Neumann, 2011). This has implications for considering how to embed ESD. To address this in part, we propose developing inquiry-based pedagogical approaches for exploring scientific and SDG/ESD-related themes and topics. This would incorporate authentic inquiry processes (Asay and Orgill, 2010) such as reading, desk based research, observation and experimental design into modules, supporting the learner to ask scientifically oriented questions and seek out and arrange scientific knowledge and evidence to advance their learning and structure their thoughts (NRC, 2000). Problems may reflect the SDGs and have a local and global focus, as is consistent with ESD. This may result in a reduction of the "content" delivered in programs, however it would result in benefits to the learner in understanding scientific processes and NOS. In science education, the inquiry process provides students with the structures necessary to enable them to understand scientific knowledge production and, as such, its limitations, thereby better equipping them to take part in decision-making on issues relating to science and the wider world (Flick and Lederman, 2006). For example, students may explore aspects of climate change, biodiversity loss, water quality or disease prevention in a scientific manner. Engaging in such processes would support students to think and act in a scientific manner while also addressing sustainability issues.

Faculty members spoke of the problem-based elements of their work both in terms of research and practical science applications. Wiek *et al.* (2016) emphasise that teaching and learning experiences should support the learner to apply problem-solving frameworks to complex sustainability problems and focus on developing viable solutions. PBL is appropriate to science education (Akınoğlu and Tandoğan, 2007; Gallagher, 2015) and is an effective pedagogical tool for ESD (Bessant *et al.*, 2013; Cörvers *et al.*, 2016; Wiek *et al.*, 2014). The benefit of PBL in the context of ESD is that the learner is presented with an engaging and relevant real-world problem pertaining to an aspect of sustainability and learning is supported through authentic inquiry. To engage in PBL, the learner must use an iterative process of assessing what they know, determining what additional information they require, collecting that information, and collaborating on the generation and evaluation of hypotheses in light of the data they have collected (Stepien *et al.*, 1993; Gallagher, 2015; Torp and Sage, 2002). Engaging in PBL requires skills on the part of the educator to facilitate the flow of discussion and to intervene only when necessary to advance students' thinking and informed decision-making (Wilkerson and Hundert, 1997).

Given the findings of this study on problem-based science and the appropriateness of taking a problem-based approach to teaching science and ESD, the authors advocate for the inclusion of a Science PBL Experience (SPBLE) in the Science Education program, similar to that described by Gallagher *et al.* (1995). This would be particularly relevant in the latter stages of a module, with the problem being posted early in the module and some contact time devoted to the lecturer facilitating an exploration of the problem. Students would be required to conduct desk-based inquiry independently, including seeking out relevant evidence based articles and papers, and take responsibility for engaging in scientific processes to investigate aspects of the problem at hand. Laboratory sessions would be more loosely framed to allow students to determine an appropriate approach to support their investigation. During problem resolution, students would use their data and other evidence to formulate a solution, or a solution set, for the problem posed. Some opportunity for scaffolded discussion would be provided to allow for sharing and debriefing. Many of the problems associated with science and sustainability draw upon societal considerations, as such they are socio-scientific issues that require a degree of ethical or moral reasoning (Zeidler and Sadler, 2011; Zeidler *et al.*, 2019). Some opportunity for argumentation and discussion of these issues may be incorporated into SPBLE pedagogical approaches (Erduran and Jimenez-Aleixandre, 2007). To communicate findings, present outcomes and defend viewpoints is an important part of the culture of science as well as aligned with ESD.

Teaching for sustainability

Interviews with faculty members highlighted that some modules reference a range of sustainability themes. Within these modules, students were exposed to ideas on sustainability through core science-related content. In focus groups, students also recalled a range of ESD-related topics that they addressed in their program. However, many of the examples offered aligned with technical and hard scientific knowledge on the issue, rather than to cultural, social or economic considerations. Only a small number of faculty members spoke of the human or societal implications of their work or the sub-discipline that they teach. This finding resonates with Eilks (2015), who suggested that science teaching in tertiary education, tends to limit the focus of sustainability-related issues to the subject matter content and/or scientific background, rather than extending the discussion to consider other factors. A key characteristic of ESD is its capacity to reflect social, economic and environmental considerations, while also being cognisant of political and cultural perspectives.

While some promote the importance of social issues in scientific literacy (Lederman *et al.*, 2013; NCCA, 2015a; Sadler, 2011; Vesterinen *et al.*, 2016; Zeidler, 2014), others suggest that the issues are overly complex for the classroom and that time should be devoted to teaching and learning important fundamental scientific concepts and practices instead (Millar, 2008). While the occurrence of sustainability-related themes in existing modules bodes well for the inclusion of ESD, the focus on scientific knowledge remains a concern. Results from this study demonstrate an emphasis on imparting large quantities of hard, technical knowledge and the "fundamentals" of the sub-discipline in order to enhance the learners' repertoire of scientific content knowledge. This finding causes the researchers to question the extent to which modules, in their current form, have the capacity to explore economic and social perspectives on global issues, while also maintaining the nature, culture and integrity of science as an academic discipline. Yet, this multi perspectival approach to teaching is central to ESD. Many of the development issues that we face as a global community require this multidimensional view (Leicht *et al.*, 2018; UNESCO, 2006). Taking climate change as an example, if science education teaches purely about the scientific underpinnings, without teaching about human contribution and impact, as well as approaches to reducing impact and mitigating the effects of climate change, then arguably it does not fulfil the remit of ESD. This might be achieved through PBL as discussed above or through class discussion. Opportunities may also exist to work with students from other disciplinary areas, hence exposing students to new academic cultures and ways of acting and thinking. We question if science is too strongly classified (Bernstein, 1971) to adapt to the interests of the learner or the needs of society. Given the nature of the scientific knowledge and acknowledging the natural gravitation towards teaching technical aspects of science, we question the extent to which science education is open to the discursive, skills-based and transformative nature of ESD (DeHaan, 2010; UNESCO, 2005, 2014b). Without these learning experiences, any educational provision might be considered "education about sustainability", rather than "education for sustainability" (Hargreaves, 2008). If this is the case, learners will acquire new knowledge, yet they are less likely to experience behavioural change or value changes (Sterling, 2001, 2013, 2014). Given the positive disposition of module leaders involved in this study, with regard to integrating sustainability into their teaching, it would be beneficial to conduct an audit of modules to identify where ESD and the SDGs are currently represented, and how they are incorporated. Specifically, such an audit would identify how environmental, economic and social considerations are addressed in the content and pedagogy. This could serve for the basis to establish ESD as a cross-cutting theme of the program. Furthermore, efforts could be made to maximise and expand such curricular areas to better reflect an ESD disposition to teaching, learning and assessment.

Adopting a department-wide commitment to education for sustainable development

While faculty members generally spoke positively about incorporating sustainable development in their teaching, they did not reflect a department-wide recognition of or commitment to ESD. Rather, they described sustainability in the context of overlapping themes within existing modules. While participants noted the importance of learning about and for sustainability, it was not a prevalent or consistent theme across the program. ESD has been described as a "paradigm shift" (Sterling, 2004), and not merely the addition of sustainability to curriculum. This is an ambitious endeavour – as Smith and Watson (2019, p. 1) argue that science education, amongst others, is situated within a neoliberal ideology and therefore may be "inherently unable to provide the type of deep transformational education that is needed to live sustainably". The structure, form, history and politics of education are deep rooted in serving the multiple roles of education from academic rationalism to humanism, social efficiency and social reconstruction (Luke *et al.*, 2013; Nussbaum, 2010). HEIs, in particular, must support the learner to generate and acquire knowledge, to reflect on the effects of their behaviour and decisions on the future, and to take responsibility for bringing about more sustainable ways of living and working (Rieckmann, 2012). This vision of education challenges educators to critique existing educational structures and question the dominant discourses. To seek to reorient policies, education systems and practices to facilitate sustainability shifts the emphasis to ameliorating social problems and engendering social reconstruction above all else (McGarr and Lynch, 2021; Schiro, 2013; UNESCO, 2002). For ESD to be transformative, the educational institution as a whole must reorient towards sustainability, involving a rethink of the curriculum, organisational culture, campus operations, leadership and management, student participation, community relationships and research. Framed by this approach, the institution itself operates as a role model for learners (UNESCO, 2014b). For sustainability to be effectively integrated into higher and tertiary education, it must be part of the culture of the establishment, embodied in research initiatives, teaching and professional practice, and reflected in management and operational parameters (Barth, 2015). A recommendation from this research is that ESD be specified as a central component of the Science Education program, thus explicitly including ESD as a learning outcome. A commitment to sustainable development would be reflected in the behaviours, ideas, beliefs, values, symbols and knowledge transmitted (Geertz, 1973). Messages on sustainable development would be to the forefront of the physical environment, as well as in curriculum and activities or events associated with the program. The onus would be on faculty members to identify, where appropriate, how their module would address and refer to science in society, sustainability in local and global communities, and aspects of the SGDs. ESD would become integrated into what students see, hear and experience on a daily basis – it would be part of the culture of the learning environment. Ultimately, this would require consensus from course directors, course boards and module leaders, and a commitment to position ESD within the program aims, outcomes, teaching, learning and assessments experiences. Importantly, this explicit focus implies a series of actions for the management and implementation of the program including: mapping of ESD as a cross-cutting theme in the program; consideration of the professional development needs of educators to support this vision; support materials/infographics/online applications reflect this department-wide vision; learning outcomes relating to ESD/SDGs would be included in module outlines, and reflected, where appropriate, in teaching, learning and assessment modalities; and finally educators could explore the potential for students to log their engagement with ESD in a portfolio entry-type activity across their program, with an expectation of ESD entries at regular intervals.

Limitations

While exploring the nature and lived culture of science as an academic discipline contributes to our understanding of science as a discipline and opportunities for integration of ESD, some caution is required when interpreting the results. First, the sample was recruited from one biological science program in Ireland. Therefore, replications of the present study are required and caution is needed when generalising to the wider population of science programs or cross culturally. Second, while qualitative studies provide a depth of data reflective of the particular case, by themselves they do not allow for a sufficient level of causal inference. To strengthen validity/reliability a structured questioning and observation framework was employed to capture the participants' views. This involved a scheme for data collection, analysis and interpretation that involved iterative cycles of collection, analysis and feedback. Participant validation was supported via member-checking. During this process, participants were consulted to seek confirmation of the data recorded and the accounts generated. Such co-construction of ideas is an important tenet of ethnography and aligns with a constructivist approach to research. Method triangulation was also used in the research (Denzin, 1970;

Silverman, 2006). This involved an examination of data from different data collection methods – interviews, focus groups and participant observation. To enhance reliability multiple researchers analysed the data and identified similar codes and themes (Silverman, 2006). Finally, a limitation of the direct involvement of the researcher in data collection and analysis is their own subjectivity and the potential for bias. Merriam (2009) notes that rather that attempting to remove the bias, the researcher should identify and monitor how they may influence the collection and interpretation of data. To this end, the research employed reflexive practice in the research process including recording (in research diaries) their thoughts, feelings, impressions, motivations, interests and attitudes at various stages of the research and reflected on how these might impact the research process (Finlay and Gough, 2003; Flick and Lederman, 2006).

Conclusion

Science is a long-standing academic discipline with a distinctive nature and culture. It has particular ways of viewing, generating and working with knowledge. It has associated inquiry processes that include questioning, observing, hypothesising and deriving theories. It requires a particular way of thinking, acting and working. It demands rigour and creative scientific attitude. It has language and terminology specific to the discipline or sub disciplines. Its evolution over time contributes to and is influenced by society's needs and demands. Approaches to embedding ESD, a more recent and sometimes abstract construct, must complement the culture and nature of the disciplinary area. These approaches must also align with the pedagogical approaches and strategies that reflect the epistemological and sociological foundations of science. Failure to do this may result in offerings that are inappropriate and ineffective and that contradict rather than complement ways of knowing, acting and doing in science. To facilitate integration of sustainability themes in science education – a move towards inquiry and problem based approaches are recommended, within a context that supports education for sustainability and that demonstrates a department wide commitment to ESD.

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