The end of simple problems: Chemistry in higher education.

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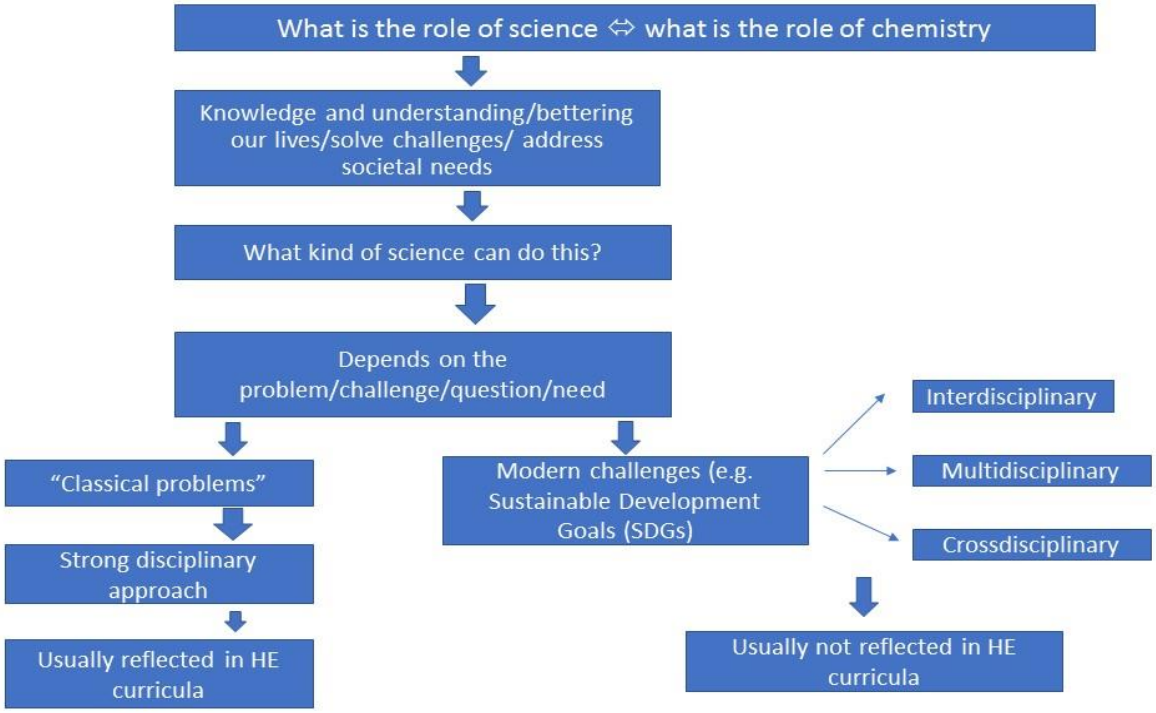
ABSTRACT

The purpose of this paper is to discuss ways that a chemistry course could re-position itself by adopting interdisciplinary approaches based on systems thinking and the Sustainable Development Goals (SDGs) as overarching frameworks, to give an overview of several challenges that chemistry in higher education is facing and discuss how those can be addressed as a result of this re-positioning. We will be discussing the need for a new type of scientist, one who has a deep understanding of their own discipline but also an overview of the links with other disciplines and is equipped with skills that will help them contribute to the solutions of a very complex system; the human-environment interaction system. Chemists should be part of what is described by earth systems' science as 'the new social contract' between science and society. Finally, we will explore how this can be reflected in the curricula of higher education and we will present a University of Bristol educational initiative, Bristol Futures, that attempts to address this.

GRAPHICAL ABSTRACT



KEYWORDS

Higher Education, Chemistry, Systems Thinking, Sustainability

It is widely accepted by many scholars that it was the launch of Sputnik in 1957 that spurred the need to reform higher education and particularly education related to STEM sciences.[1,2] Subsequently, the birth of chemistry education[2] occurred which in September 2013 celebrated its 50th anniversary. During these 50 years, much has changed; from technological advances to the use of the internet and computers, they have all contributed to significant changes in the way we perceive the world. Unsurprisingly, this affected the way we perceive and deliver educational material in higher education but also the way we can teach and assess that material. Emerging pedagogies now include technologically-enhanced learning, online learning, virtual realities, blended learning and asynchronous learning. While chemistry education has taken some steps towards incorporating many of these pedagogies in higher education curricula, there are still significant and important steps that need to be taken in order for chemistry to achieve perhaps the most important goal is has to achieve in the 21^{st} century; to remain socially relevant by which we mean that it must be perceived as being part of the solution of modern, global and local challenges and this needs to be reflected in high education curricula.

We theorize that in order for chemistry and chemistry education to remain socially relevant it needs to not only incorporate these new pedagogies into the various curricula but also to align itself with three main themes: systems thinking, sustainable development and the Sustainable Development Goals (SDGs) and interdisciplinary work.

In their literature review 'Factors affecting Curriculum Development in Chemistry', Mbajiorgu and Reid (2006)[3] present evidence from their research that can be summarized under four headings: (a) Chemistry for whom? (b) What Chemistry? (c) How to be taught? (d) How to be assessed? We will be using these four headings as starting points and throughout this paper we will offer our thoughts on what some of the answers might be.

Two critical points are made in the same report by Mbajiorgu and Reid.[3] The first relates to problem-based learning which we will be discussing from the point of view of 'problem-based thinking'. The second relates to the fact that only a very small number of chemists actually become bench chemists and, the report continues, it is critical that chemistry education moves away from 'simply producing lab chemists'.

We will discuss that it is perhaps time for chemistry, as has been the case with other STEM disciplines, to aim towards producing graduates that have both a deep understanding of chemical phenomena as well as an appreciation of how chemistry relates to other disciplines. This should encompass global and local challenges with an emphasis on how the discipline can critically contribute to addressing these challenges. We will also present a University of Bristol educational initiative that we believe can enhance the experience of undergraduate chemists by adding the much-needed interdisciplinary approach, systems thinking and sustainable development in the curriculum.

SYSTEMS THINKING

The term 'systems thinking' is attributed to Barry Richmond (1987) and since then, the term has been defined and redefined.[4,5] For the purpose of this paper we will be borrowing parts of Senge's definition as well as Sweeney and Sterman's definition[6,7] and we will define systems thinking as 'a holistic approach that enables simultaneous analysis of the parts as well as the whole itself, their evolution, overlaps and dynamic interactions'. Using this definition, it is very useful, before we examine chemistry in higher education in isolation, to first examine it as part of a larger system. The role of chemistry within higher education cannot be discussed separately from the role of chemistry within science which in turn cannot be discussed separately from the role of science in relation to society.

Science for whom?

As early as 1938 J.D. Bernal published an essay on 'The Social Function of Science'[8] where he discusses the role of science as both an outcome of social forces but also as a social force itself:

> "Science, conscious of its purpose, can in the long run become a major force in social change. Because of the powers which it holds in reserve, it can ultimately dominate the other forces. But science unaware of its social significance becomes a helpless tool in the hands of forces driving it away from the directions of social advance, and, in the process, destroying its very essence, the spirit of free inquiry."

According to Bernal, science further to contributing to our understanding of the natural world has a social role to play which in essence, is applying this knowledge in order to make our lives better. The demand for greater 'social relevance' of science and academic programs reappears frequently in the literature.[9–14] As discussed in detail in the Dalhem Workshop Reports 'Earth System Analysis for Sustainability' (2004)[15] it is possible that we all together need a new 'social contract between science and society'. It becomes clear that the answer to the question 'what is the purpose of science' and the answer to the question 'science for whom' have both the same answer and that is 'society'.

What science?

Answering these questions, unavoidably raises the question 'which science' or 'what kind of science' is equipped to achieve these goals? Over the last few centuries different disciplines have generally evolved in isolation from each other to the extent that we now speak of over-specialization in some areas[16]. From 1959 when C.P. Snow introduced the 'two cultures' theory, to 1962 and Kuhn's suggestion that devotion to a scientific paradigm can prevent absorption of new facts and knowledge and the work of MacKinnon, Hine and Barnard (2013), there are ample critiques in the literature that no one science alone is equipped enough to solve every challenge we are facing.[17–19] The societal demand for greater 'relevance' of science and academic programs appears in the paper by Swora and Morrison (1974) 'Interdisciplinarity and higher education' while MacKinnon, Hine and Barnard (2013) reach an excellent conclusion where they describe interdisciplinary work not as a means to an end, but a natural progression in the scientists' quest to answer a question and solve a problem.[9,19]

"The movement toward the interdisciplinary mode facilitates this restructuring in that disciplines are not demolished but are made to focus on their relationships with one another and with the problems of society."

Additionally, as described in 'Interdisciplinary science research and education' (P.J. MacKinnon, D. Hine & R.T Barnard, 2013) p. 411:

"For the scientists in our vignettes (case studies), interdisciplinarity was a natural progression in their scientific quest. They did not set out to engage in interdisciplinary science, rather they focused on solving a problem."

Earth systems science and the science of sustainability or sustainable development are directly and indirectly trying to answer the question of 'which science' by introducing methods, approaches and frameworks which are deeply interdisciplinary, and use systems thinking in order to examine, as we defined, both the parts and the whole of the system. So far, we have presented some key interactions in the system we are attempting to describe. Science (apart from advancing our knowledge and understanding) needs to address societal needs and problems and in its effort to do this it needs to be flexible enough to adopt either strong disciplinary-focused practices or strong interdisciplinary practices.

GLOBAL CHALLENGES

The point highlighted in the extract from P.J. MacKinnon, D. Hine & R.T Barnard (2013)[19] is very important: it is the problem (challenge or question) the scientist is trying to address that will define the appropriate approach (or the appropriate kind of science). This leads us to the next question: What are the current problems, or as we call them, global challenges? We now live in the era of the Anthropocene[20] where humans are a globally significant force capable of reshaping the face of the planet. In the case of the human-environment interaction system, the myriad ways that humans have been changing the planet are a side-effect of our 'learning about global change by doing global change'.[21] In 2015 the UN, moving from their Millennium Goals, introduced their 17 Sustainable Development Goals (SDGs)[22,23] (box 1); a framework whose purpose is to map the challenges humanity must solve in order to keep living on this planet. Each goal addresses one global challenge but every goal has several targets that need to be addressed. In total the 17 SDGs have 169 targets. These goals and targets were agreed by 193 member-states.

Box 1. The Sustainable Development Goals (SDGs)

1. End poverty in all its forms everywhere.

2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

3. Ensure healthy lives and promote well-being for all at all ages.

4. Ensure inclusive and quality education for all and promote lifelong learning.

5. Achieve gender equality and empower all women and girls.

6. Ensure access to water and sanitation for all.

7. Ensure access to affordable, reliable, sustainable and modern energy for all.

8. Promote inclusive and sustainable economic growth, employment and decent work for all.

9. Build resilient infrastructure, promote sustainable industrialization and foster innovation.

10. Reduce inequality within and among countries.

11. Make cities inclusive, safe, resilient and sustainable.

12. Ensure sustainable consumption and production patterns.

13. Take urgent action to combat climate change and its impacts.

14. Conserve and sustainably use the oceans, seas and marine resources.

15. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss.

16. Promote just, peaceful and inclusive societies.

17. Revitalize the global partnership for sustainable development.

We, humans, decided that these are currently the most pressing issues for its future and survival. Unlike the problems and challenges we faced 20 years ago, or even 10 years ago, it is becoming increasingly obvious that the human-environment interaction system is potentially more complex than we thought, making the challenges we are facing more complex which implies that the solutions needed to address these challenges are also likely to be complex. There are no simple, single solutions to climate change much like there are no simple solutions to poverty; we are potentially witnessing the end of simple problems in science. It is critical that this realisation is not only reflected into higher education curricula but, in the case of chemistry education, is reflected explicitly in the core content, learning outcomes, and skills the graduate needs to develop.

CHEMISTRY AND CURRICULA

Chemistry has been defined as 'a science that deals with the composition, structure, and properties of substances and with the transformations that they undergo'. This definition, reflected in the structure and content of several higher education curricula, begs one very simple question: "in the era of the Anthropocene, the age of technology, the internet and information, is this all chemistry has to offer?". And while the answer to this question is 'of course not' this is not explicitly reflected in several higher education curricula. In their 'Report of a Literature Review', Mbajiorgu and Reid (2006)[3] state that:

> "When faced with the question, 'what chemistry?', the temptation is to list the topics and themes to be included in a syllabus. These are usually defined by the logic of the subject as well as the needs of later stages of learning. This approach must be resisted. (…). There needs to be a massive paradigm shift in thinking and the willingness to jettison much traditional chemistry."

An excellent alternative is described in the work of Matlin and co-workers (2015); (2016), and Mahaffy and co-workers (2016)[14,24–26], where the links of chemistry in a sustainable future are described, followed by the introduction to 'one world chemistry' and eventually calls for the reorientation of chemistry through systems thinking. This approach to chemistry and chemistry education reflects a large part of the educational initiatives we will be describing; this 'new chemistry' has a very important role to play in most of the global challenges and it is uniquely placed to play a leading role in addressing several of the SDGs. Below, we are presenting those SDGs that have a direct link with chemistry and the chemical sciences (box 2a) and those SDGs that would be indirectly influenced by the advancement of the former (box 2b). We are basing this classification on the UN's targets and indicators related to each SDG.

Box 2a. The SDGs where Chemistry can play a leading role and address specific targets and indicators directly

2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

3. Ensure healthy lives and promote well-being for all at all ages.

6. Ensure access to water and sanitation for all.

7. Ensure access to affordable, reliable, sustainable and modern energy for all.

9. Build resilient infrastructure, promote sustainable industrialization and foster innovation.

11. Make cities inclusive, safe, resilient and sustainable.

12. Ensure sustainable consumption and production patterns.

13. Take urgent action to combat climate change and its impacts.

14. Conserve and sustainably use the oceans, seas and marine resources.

15. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss.

Box 2b. The SDGs where Chemistry can play an indirect role; to help improve without addressing a target or indicator directly

1. End poverty in all its forms everywhere.

4. Ensure inclusive and quality education for all and promote lifelong learning.

5. Achieve gender equality and empower all women and girls.

8. Promote inclusive and sustainable economic growth, employment and decent work for all.

10. Reduce inequality within and among countries.

16. Promote just, peaceful and inclusive societies.

17. Revitalize the global partnership for sustainable development.

Curriculum change, or curriculum reform has never been an easy task, nor are we implying that it can be done without a lot of resources spent, as well as invested energy and time that academics often don't have.[27–30] However, aligning the curriculum with systems thinking, interdisciplinary thought and the framework provided by the SDGs, we believe can transform the content provided to undergraduate students while the simultaneous use of new and exciting pedagogical approaches, such as online, blended and asynchronous learning can help with both timetabling and workload concerns. Below we are presenting two parts of the same educational initiative that we believe can offer just that and we provide a map of how we believe this initiative can enhance the student experience of the undergraduate chemist.

A UNIVERSITY OF BRISTOL EDUCATIONAL INITIATIVE: BRISTOL FUTURES

The United Nations (UN) General Assembly declared a Decade of Education for Sustainable Development (DESD) (2005-2014) and invited all educational institutions to contribute to education for sustainability.[31,32] The University of Bristol is a member of the Global Action Programme (GAP) and Sustainable Development Goals (SDG) Accord partner institution.[31,33,34] In response to these initiatives, it has developed Bristol Futures, a creative and integrated approach to curriculum development which aims to develop student skills and values in sustainable futures, global citizenship and innovation & enterprise.[35–39] Bristol Futures is one of the University of Bristol's strategic projects that seeks to equip all students with the skills needed to be informed, engaged citizens and scientists in a changing world and will be completed in three phases. Additionally, the University of Bristol has developed a skills framework, the Bristol Skills Framework.[40,41]

Bristol Futures is not an initiative targeting chemistry students only, but, because it is offered across the University it gives undergraduate chemists the possibility to (a) interact with global and local challenges, (b) explore the relevance of their degree to these challenges, (c) interact with young scientists from other disciplines, and (d) explore their discipline and degree in relation to other disciplines, degrees and approaches.

The core of Bristol Futures is formed by three ‘pathways’, defined as:

- Sustainable Futures (SF) - equipping students to engage with the challenges of globally improving the quality of life for humanity while sustaining the natural environment and finding ways of living with the environmental change that we cause.
- Global Citizenship (GC) - fostering the critical self-reflection and understanding students need to negotiate the challenges of energy and resource management and food security, tackle international insecurity and engage with culture and heritage in an increasingly globalised world.
- Innovation and Enterprise (IE) - enabling students to act on their ideas, use their initiative, and shape change in diverse sectors.

In this work we will only be discussing the Sustainable Futures pathway.

THE SUSTAINABLE FUTURES ONLINE OPEN COURSE

The first phase of this educational initiative is the Sustainable Futures massive online open course (MOOC).[42,43] This is a non-credit bearing course open to everyone, however University of Bristol students are offered additional incentives in order to join and successfully complete it.

Development and Delivery

The main goal of the Sustainable Futures Online Course (SFOC) is to take sustainability beyond its obvious and most frequently used links, to connect sustainable development to challenges like homelessness and resilient cities, personal happiness and wellbeing and a sense of purpose in life.[44–47] It introduces learners to interdisciplinary challenges related to several sustainable development goals as well as the three pillars of sustainability (environment, economy, society).[32,48,49] For the SFOC access is not restricted to University of Bristol students, or just students. Therefore, in this case we are discussing about the ‘learner’ instead of the student. This course was designed by a core, interdisciplinary team and an extended team of online and e-learning experts and is delivered online, through the platform FutureLearn.[50] This course was fully co-developed by (a) a large, interdisciplinary group of academic members of staff, (b) students (c) a large team of external partners and (d) industrial partners. Co-development of the course particularly in collaboration with students ensured that delivery of the course would address student concerns (e.g. related to timetabling and workload); particular consideration was given to making explicit and direct links throughout the course to different disciplines, as well as using language and context that would be accessible and understood by both social and natural science students. Access to this course is free of charge and it runs over four weeks, with three hours of interactive and self-directed content per week, requiring a total of 12 hours of commitment from the learner while no previous in-depth understanding of such challenges is expected.

Three main overarching themes are used across the course; sustainable development, systems thinking and interdisciplinarity. Learners are given the chance to explore several themes in the form of case studies of individuals and organisations that engage in some way with the SDGs and the challenges we are presenting: personal and professional wellbeing and purpose, food and food waste, energy and energy use, homelessness, climate change and greenhouse gases, plastics and microplastics, sustainable development abroad (Albania), personal challenges and mental health. We adopted three different scales of examining modern challenges through the lens of the SDGs; from the personal to the local (Bristol), from the local to the global and from the global back to the personal. These case studies were used as a tool for the students to engage with more than just the theory and develop a deeper understanding of the complexity of the interactions in the human-environment system. It provides the students with role models and real situations that they can relate to, thereby enhancing their deep, long-term learning. By engaging with these case studies learners engage with several experts all representing a different aspect of either the challenge or the solution. This gave us the opportunity to explore research-led teaching in an online environment.[51–55]

Finally, discussion points throughout the course give the learner the opportunity to engage as an active contributor in a dialogue between the learner and the academic.[56] The discussion points facilitate interactions between the learners which have several benefits such as (a) the cohorts develop interaction and consistency between them, (b) facilitating social learning and sharing, (c) allowing the learner to explore different aspects of the case study[57,58] and (d) promote overall deep learning[59,60] through social learning as the amount of content that could be explicitly delivered online was limited. Learners are given information on how to join local initiatives, ways to contribute and interact as well as spaces and events where they can engage with others.[45,58,61] Additionally, and in order to give the learner a sense of the bigger picture, there are also challenges not strictly local to Bristol. This showcases the scale of modern global challenges and the need for collective action beyond the University, and the City.

Assessment and Feedback

We provide feedback in two ways: (a) participate in the discussions; there we comment in writing and answer questions that are either content specific or contextual and (b) for the end of every week we provide feedback in the form of a video; after going through every week's comments we address the most important questions on video, reward the students that were very engaged by pointing out how much they have helped their cohort and thank them for their participation but also to encourage the ones that are not commenting and participating in the discussions to do so. The benefits of filmed feedback are that the students feel there is an interaction with the lead educators, they can see that the core teaching team has read and interacted with their comments and it promotes further interaction with the discussions in the course. The response we have from the video feedback has been extremely positive. Overall, the learners are assessed through the percentage of the course they have completed. In the specific course we have not added additional assessment through online quizzes. For the assessment, we are not using online quizzes and the only form of assessment is the completion rate of the course as defined by FutureLearn guidelines (successfully complete 80% of the course).

Benefits specific to Chemistry and Chemistry Education

We believe that overall, the undergraduate chemistry curriculum should explicitly and specifically include those sustainable development goals that chemistry and chemical sciences could, and is, having a direct impact on (box 2a). Furthermore, we strongly believe that the interdisciplinary nature of case studies presented in the SFOC can provide these links between chemistry and the SDGs as we will be discussing below.

There are five key points we believe this online course can help improve within the undergraduate Chemistry curriculum:

1) The student interacts with several of the SDGs and explores links specific to chemistry through the case studies and the filmed feedback.
2) As this course offers research-led teaching in an online environment giving the student the flexibility to control the time and duration of their learning.
3) The students engage with interdisciplinary, international, transgenerational cohorts thereby gaining not only the different perspectives of other disciplines but the experience of different age groups and different cultures.
4) Each case study is presented by several different experts who not only discuss the challenge they are presenting from their expert viewpoint, but they also discuss how they got to where they are in their lives and careers.
5) The skills an undergraduate chemist can develop during this course are: Creativity, intellectual abilities, self-management, personal well-being, personal effectiveness, engagement and communication.

Figures 1a and 1b summarize the content delivered in weeks 2 and 3 of the course, mapped against the SDGs discussed in that week and relevance to the chemistry undergraduate curriculum. We have assigned a high (H), medium (M) and low (L) value to describe how relevant is the content presented within SFOC in relation to education of the 'new chemistry' we have discussed above (and the 'One world Chemistry' as defined by Matlin (2012)[14]) and we are using the same values to describe skills that can be developed that are relevant to the needs of undergraduate chemists. In this work, as skills we define the skills presented in the Bristol Skills Framework.

	Introduction to week 2	**Food**	**Energy**	**Homelessness**
Week 2	• The roles we take • An introduction to the themes and case studies in week 2 • Introduction to food	• Case Study: The origins of Fareshare • Case study: Just eat it • Case study: FoodCycle • Food: What do you think?	• Introduction to energy • Case study: Geneco • Case study: The energy efficient home • Case study: Smart energy management at the university of Bristol • Different perspectives on the same problem	• Introduction to homelessness • Case study: Saint Mungo's • Case study: Understanding homelessness • Case Study: Political initiatives to support the homeless
SDGs	1: No poverty 2: Zero hunger 3: Good health and wellbeing 4: Quality education 5: Gender equality 7: Affordable and clean energy 9: Industry Innovation and infrastructure 10: Reduced inequalities 11: Sustainable cities and communities 12: Responsible consumption and production			
Relevance to Chemistry Education				
Content	L	M	H	L
Skills	M	M	H	M

Figure 1a: Overview of the content presented in week two of SFOC in relation to the SDGs presented in this week of the course and relevance to chemistry education regarding content and skills developed.

Figure 1a presents a brief overview of the content presented in week two of the SFOC in relation to the SDGs this week's content discusses either directly or indirectly. We have assigned a value of medium for both skills and content for the case study of food and food waste as this case study was designed to focus several bottom-up, student-led initiatives regarding food and food waste instead of an 'academic' or 'expert' approach. This case study was designed to work as an introduction to numbers and facts related to food and food waste, invites the learner to think critically and discuss with others and most importantly presents to the learner what students are doing to address this issue. Regarding energy consumption and production, we assigned a value of high for both skills and content as this case study discusses in depth the chemistry behind the technologies presented and presents research and career opportunities more suitable for an undergraduate chemist. Finally, in the case study of homelessness we assigned a value of low for content relevance as this case study is not directly linked to chemistry or chemical sciences. However, we assigned a value of medium for the skills as this section discusses different career paths of different people which can give perspective to the undergraduate chemist and can help them reflect on skills acquired during their degree and future career pathways.

	Introduction to Week 3	Microplastics	Greenhouse gases, industry and climate change	Sustainable Development in Albania
Week 3	• Change mechanisms and roles for Global Change • An introduction to the themes and case studies in week 3	• Introduction to Microplastics • Case study: Understanding microplastics • Case study: CodSteaks • Case study: Ellen MacArthur Foundation • Can you avoid using plastic?	• Introduction to greenhouse gases, industry and climate change. • Understanding CF4 emissions. • Case study: Edwards. • What roles have people played?	• The situation in Albania and how it links to sustainability • Case study: Sustainable development in Albania • Sustainable Development goals in Albania
SDGs	6: Clean water and sanitation 9: Industry Innovation and infrastructure 11: Sustainable cities and communities 12: Responsible consumption and production 13: Climate action 14: Life below water			
Relevance to Chemistry Education				
Content	M	H	H	L
Skills	M	H	H	H

Figure 1b: Overview of the content presented in week two of SFOC in relation to the SDGs presented in this week of the course and relevance to chemistry education regarding content and skills developed.

Figure 1b presents a brief overview of the content presented in week three of the SFOC in relation to the SDGs this week's content discusses either directly or indirectly. For the case study of microplastics we have assigned a value of high for both the content and skills in relation to relevance to chemistry and chemical sciences as for this case study we are presenting expert academic work done by academics of the University of Bristol who discuss both the challenge of microplastics, the science and field work behind this challenge. For the case study of greenhouse gases, we assigned a value of high for both content and skills as we are presenting the challenge of climate change from an atmospheric chemistry, and industrial point of view. Finally, for the case study related to sustainable development in Albania we have assigned a low value for the content but a high one for the skills as this case study examines scales and timescales of change, stakeholders and different approaches to solving a problem.

The Sustainable Development Optional Unit (20 credit points)

The second phase of the Bristol Futures educational initiative is the introduction of an optional, 20 credit point unit offered to students across the University of Bristol who have suitable optionality within their degree programmes. The Sustainable Development Optional Unit (SDOU) was built using the same overarching themes: sustainable development, systems thinking and interdisciplinarity. The unit is currently completing its first run (teaching block 2, 2019) and has been selected as an optional unit by more than 250 students across most faculties and disciplines of the University.

Development and Delivery

For this unit we are using a blended learning approach that consists of:

(a) online delivery of the core learning materials presented in the forms of briefs and blog-like articles and (b) six, two-hour compulsory workshops of approximately 50 students each where the students interact with the core team and the extended teaching team (consisting of 6 teaching assistants).

The unit is structured in the form of 6 blocks of different content: introduction to sustainable development, science and understanding, behaviour and organisational change, economy, policy and law, equality and justice, technology and innovation. The different content was designed to align with the majority of disciplines and schools within the university of Bristol and guide the students through early concepts of sustainability and simple systems to more elaborate thinking, frameworks and complex systems. Overall, the purpose of this unit is to explore the links of different disciplines to sustainable development, emphasize the need of systems thinking in order to address global challenges and introduce interdisciplinary work early in the undergraduate studies. This unit focuses on developing skills more than retention and repetition of information taught; during the two-hour workshops the students must engage in different activities which require them to develop their critical and analytical thinking, negotiating skills, leading a team and being part of a team, presentation and researching.

Assessment and feedback

This unit is a pass/fail unit and the students are assessed based on a portfolio they must produce. The students are required to pass all assessments in order to pass the unit. The portfolio consists of:

a) A group project (wiki project).

A central part of the Sustainable Development unit is the production of a wiki which accounts for 40% of their assessment. Working in groups, students choose one of four case studies to cover in their wiki project and will be assigned to a group that includes people from other disciplines. They conduct guided research on the chosen case study during the second hour of the workshops. In their group, they create a wiki that provides a briefing on a specific case study for a given Sustainable Development challenge. The briefing should be directed at an identified audience (e.g. a city authority, a company executive, a government department, a community organisation, an international campaigning NGO, etc.). The challenges offered in the case studies are fairly wide-ranging. They may choose to focus on evaluating the role of a particular technological innovation; the impact of alternate water provision policies on poor and marginalised members of a community; or potential behaviour change strategies to encourage people to eat less meat. The wiki exercise is designed to encourage students to think about how sustainable development involves the interplay (sometimes harmonious, sometimes not) of different components derived from different academic backgrounds.

This sort of group learning activity may be new to students in two ways: (a) Active learning as a group activity: being able to work in interdisciplinary teams is an essential skill in any future career but is particularly important to sustainable development and (b) Writing for the web: we get lots of practice at reading electronic resources. Here students get a chance to think about the creation of web resources. How do we show authority when writing for the web? What are the particular challenges of writing brief but accurate web pages? How do we link ideas together differently when working electronically?

b) Online contribution and reflective writing

The students are expected to participate in online monitored discussions where they are required to both start a discussion themselves but also comment on discussions started by others. Additionally, they are expected to produce a reflective piece of approximately 300 words. This accounts for 60% of their assessment.

Overall, the online and offline activities which generate content for the portfolio, together with the final reflective writing piece, are intended to:

- Develop their ability to creatively apply ideas and concepts drawn from a number of disciplines to specific Sustainable Development challenges and scenarios.
- Engage with others (both online and face-to-face) in constructive debate and critical discussion regarding Sustainable Development challenges and potential ways forward.
- Reflect on the application of the ideas and concepts learnt in the unit to challenges facing those trained in your own discipline – either within academia or in professional careers beyond – and therefore how they may impact their own future.

Benefits specific to Chemistry and Chemistry Education

Overall there are five key points we believe this online course can help improve within the undergraduate Chemistry curriculum:

1) It allows the student to interact with deeply interdisciplinary content, in a blended learning environment and explore links specific to chemistry.
2) Systems thinking and sustainable development are embedded in the online and offline content as well as the personal and professional practice of the core and extended teaching team offering the students an excellent environment to engage with these concepts and ideas.
3) It helps the student develops critical and analytical thinking regarding global challenges while exploring solutions for these challenges as part of a larger interdisciplinary team.
4) It allows the students to develop critical skills: knowledge, creativity, intellectual abilities, self-management, personal well-being, personal effectiveness, engagement, teamwork and communication.
5) It advances the students' personal and professional development.

Figure 2 summarizes the content delivered in every block of the course, mapped against skills developed as part of the workshops' activities and relevance to the chemistry undergraduate curriculum.

	Block 1: Introduction to Sustainable Development	Block 2: Science and Understanding	Block 3: Behaviour and Organisation Change	Block 4: Economy , Policy and Law	Block 5: Equality and Justice	Block 6: Technology and Innovation
Online content	• Exploring Sustainable Development • Introduction to the Anthropocene • Systems thinking and Interdisciplinarity	• Science, understanding and Sustainable Development • Qualitative methods • Quantitative methods • Uncertainty in a changing world	• Behaviour and Organisation Change • Promoting Pro-environmental behaviour • Case study: The sea • Case study: For Ethiopia • NGOs and civil society	• Policy • Climate change and Policy • Sustainability and the Law • The limits of the law • Economics – costing the Earth	• Reintroducing the social pillar of sustainable development • Inequality, ethics and sustainable development • A history of environmental movements • Environmental racism	• Innovation and purpose • Biodesign • Storing energy with hydrogen • Sustainable Buildings • Innovation and responsibility
Workshop activity	Group work, voting, arguments in small and large groups, role playing	Group work, online research, voting, negotiation arguments large groups, role playing	Online research, working from small groups towards a large group, group presentation	Mock trial, flipped classroom, online research, group work, group arguments, negotiation	Decision making, critical thinking, critical analysis, online research, group work	Group work, online research, elevator pitch, group presentations
Relevance to Chemistry Education						
content	H	H	H	H	M	M
Relevance to required skills	H	H	H	H	H	H

Figure 2: Overview of the online content presented the Sustainable Development Optional Unit in relation to the offline content (workshop activity) and relevance to chemistry education regarding content and skills developed.

The SDOU online content was designed to take the student (in this case, the undergraduate chemist) on a journey; block one introduces basic concepts, frameworks and ideas, block two discusses science and our understanding of the world while introducing qualitative and quantitative methods and approaches, block three introduces the student to behaviour and organisational change, block four addresses issues related to law, equality and policy , block five addresses issues of equality, justice and racism and finally block six discusses technology and innovation. In every block the undergraduate chemist has the opportunity to identify how chemistry fits into the content discussed under the specific block, reflect on this and discuss it online with his cohort. Additionally, the workshops and the intensive activities will give the undergraduate chemist the opportunity to actively work on developing their skills, their personal and professional development in a safe environment moderated by a team of expert teachers.

CONCLUSION

We live in a rapidly changing world. And while the function of science has always been to help us understand the natural world around us and to improve our lives using this knowledge and understanding, we are now facing urgent challenges on a global scale that could prove fatal for our species very survival. These challenges have been mapped according to the UN under the Sustainable Development Goals. Chemistry has a pivotal, leading role to play in addressing these challenges, but this leading role needs to be reflected in high education curricula including the core knowledge, skills, values and ethos we cultivate in our chemistry graduates. The Bristol Futures educational initiative is attempting to incorporate the themes of Sustainable Development, Innovation and Enterprise and Global Citizenship across the University of Bristol. This paper focused on the Sustainable Development theme and how this theme can help incorporate sustainable development, systems thinking and interdisciplinarity specifically to the chemistry curriculum. We are presenting both the Sustainable Futures Massive Online Open Course (MOOC) as well as the Sustainable Development Optional Unit (SDOU) and we discuss how each of these can help the undergraduate chemist to understand and embrace interdisciplinarity and systems thinking, to 'think' beyond their disciplines, backgrounds and experience and understand that addressing global challenges requires collaboration across the traditional silos of academia and policy-making. To stimulate this engagement, we designed the SFOC and SDOU to ensure that the Sustainable Development Goals covered are presented and discussed under broad headings. Throughout, the content provided students are encouraged to both reflect upon their own contribution to the SDGs, the role of their home-discipline and the importance of engagement with other disciplines, communities and organisations in addressing global challenges. The successful launch of Sputnik required the expertise of many, and the Sustainable Development Goals are no different. It is by stimulating such a process of reflection, collaboration and dialogue that a new generation of chemistry graduates can be equipped with the skills necessary to address global challenges.

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