Discover Sustainability

Case Study

Changing focus: making sustainability a major theme in existing university modules

Ian O'Neill[1] · Meei Mei Gui[2]

Received: 29 February 2024 / Accepted: 21 August 2024
Published online: 01 September 2024

Abstract
In this article we report some practical experiences of integrating education for sustainable development into established university teaching modules. The 2021 guidance on Education for Sustainable Development from the UK's standards bodies QAA and Advance HE is an important and urgent motivation for introducing sustainability into university courses. We take as our context a first-year introductory module in Chemical Products and Process in the School of Chemistry and Chemical Engineering and a second-year module in Software Engineering and Systems Development in the School of Electronics, Electrical Engineering and Computer Science, both at Queen's University Belfast. We outline some of the challenges of adding new themes to existing courses. We comment on ways of presenting themes of sustainable development alongside existing module content, and we indicate the type of work students produced. We identify approaches that resulted in good outcomes, and outline changes we have made with a view to improved future outcomes.

1 Introduction

Education for Sustainable Development Guidance published in March 2021 by the UK's standards bodies QAA and Advance HE [1] has added urgency to universities' efforts to make Education for Sustainable Development (ESD) an integral part of their teaching programmes. Recognising the role universities have to play in raising awareness of sustainability among our young generation, Queen's University Belfast has renewed its commitment to ESD in its strategic plan—*Strategy 2030* [2], stating: "Our educational programmes will be increasingly focused on embracing the ethos of the United Nations Sustainable Development Goals at a local, national and global level". This commitment is very much in keeping with the United Nations' own view of the part ESD must play in curricula, from early years to university: "ESD has to be integrated in all curricula of formal education, including early childhood care and education, primary and secondary education, technical and vocational education and training (TVET), and higher education." [3]. Indeed, not only does the United Nations recommend that ESD feature in all curricula, but it also enumerates eight key competencies (systems thinking, critical thinking, collaboration…) that students should acquire if they are to address questions of sustainable development adequately [4]. These competencies feature specifically in QAA/Advance HE's Guidance, and we shall return to them a little later, as they are very relevant to the way in which our students addressed the problem of sustainable design.

While education for sustainable development is now an issue of concern across universities, the way it should be incorporated in subject-specific degree courses is still evolving. That is certainly clear from the advice given in QAA's *Subject Benchmark Statement for Computing* [5], which provides examples that "are intended to be illustrative rather than

✉ Ian O'Neill, i.oneill@qub.ac.uk | [1]School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, Computer Science Building, 16A Malone Road, Belfast BT9 5BN, UK. [2]School of Chemistry and Chemical Engineering, Queen's University Belfast, David Keir Building, Stranmillis Road, Belfast BT9 5AG, UK.

prescriptive". The papers it cites for Computer Science [6] and Software Engineering [7] make positive but modest claims of how a particular approach has improved students' ability to tackle questions of sustainable development. For Chemical Engineering, the element of sustainability has been highlighted by the Institution of Chemical Engineers (IChemE), especially with regard to chemical engineering principles. IChemE's guidelines state:

"Students must acquire the knowledge and ability to handle broader implications of work as a chemical engineer. These include sustainability aspects; safety, health, environmental and other professional issues including ethics; commercial and economic considerations etc." [8].

In this article we relate our experience of introducing ESD on to two of our teaching modules at Queen's University Belfast: *Introduction to Chemical Products and Processes* (CHE1101), a first-semester, first-year module in the School of Chemistry and Chemical Engineering, and *Software Engineering and Systems Development* (CSC2058), a two-semester, second-year module in the School of Electronics, Electrical Engineering and Computer Science (EEECS). The *Engineering for People Design Challenge* [9] from Engineers Without Borders UK (EWB-UK) [10] was the framework we used to introduce ESD. We place the *Challenge* in the context of other approaches to introducing ESD and we mention some of the advantages it brings for educators.

In introducing ESD we had to meet 3 *basic requirements*:

- Requirement 1: *Acquire* New Knowledge and Resources. The authors had not specialised in ESD previously, so we needed to acquire new *knowledge* and *resources* that we could share with our students in such a way as to encourage their interest and their own critical thinking.
- Requirement 2: *Adapt* Existing Modules. When changes need to be made to the content of modules or the overall make-up of a degree programme, university administration teams often require advance notice of many months. So that we could introduce new sustainability themes quickly, our module specifications had to remain unchanged—for the present at least. (In the course of preparing this article, the module specification for CSC2058 has now been lightly updated to include reference to sustainable development as the context for project work—see Sect. 3.3.8 and ref. [60] also). In adapting our modules we were also establishing new ties between schools and lecturers—appropriate given the interdisciplinarity of sustainable development, and a practical consideration: our Chemical Engineering and Software Engineering modules would be working in sync to prepare student teams to enter the formal stages of the *Challenge*, not as representatives of a particular module or School, but as representatives of the University.
- Requirement 3: *Adopt* New Ways of Thinking. Once we had we established some basic principles of sustainable development, we wanted to give our students the freedom to use their creativity and imagination, their own interests and enthusiasm, to devise sustainable solutions to real-world problems. While the aim was to nurture new ways of thinking in our *students*, encouraging them to grow in the UNESCO key competencies, this would require a complimentary mindset from us as *educators*—being ready to see what ideas would emerge from the student teams, and being ready to examine those ideas constructively and critically with our students.

Given the move towards ESD more generally, we expect that other educators will be faced with the challenge of meeting similar requirements.

We reflect on what were, for us, pioneering steps that helped us establish the theme of sustainable development at module level, and had impact beyond our modules as well. We also show how, encouraged by regular and constructive critiquing of their work, our students began to exercise the competencies required to tackle sustainable development. At the same time, we point out some pitfalls—aims and objectives that students may initially overlook or misunderstand, especially if an existing module (supposedly a 'known quantity' in the module line-up) has begun to shift emphasis towards sustainability.

In our first attempts to introduce sustainability to our modules (a 'first', plain and simple, in the case of Software Engineering, and a first attempt at a detailed challenge-based approach in the case of Chemical Engineering), we did not place a metric against our students' mastery of the UNESCO competencies. That will follow as a next step. We were much more concerned that students would go beyond quite narrow objectives (mastering subject-specific skills) to appreciate and think critically about the wider theme of sustainable development: that we would 'put it on the map' in modules and courses where it had not featured prominently before, if at all. In this, we believe, we have enjoyed considerable success, and we hope this will become clear in the later stages of this article.

Our intention in this experience report is not to propose a template for redesigning academic programmes, but instead report on approaches to ESD that we found to be a good fit for existing programmes. We are acutely aware of the challenges involved in programme redesign, having had experience of it at our own institution. Full academic programmes can involve many modules (over 30 on the Queen's undergraduate Master's programme in Software Engineering and over 20 for Chemical Engineering). Some of these are more obviously relevant to sustainable development than others. Shifting the focus of an established course on to sustainability, while ensuring that subject-specific benchmarks are also met, is a major managerial and pedagogical undertaking that typically involves months of dialogue with the stakeholders involved—not least the lecturers whose modules will be affected. We do not propose a plan of action for this here. Each institution will find the approach that suits it best.

2 Background

2.1 Ways of introducing sustainability on university courses

There is no shortage of printed and online material on the theme of sustainable development. Regulatory documents like [5] set core requirements and recommend approaches. Now there is a growing literature that reflects educators' experience too. Given the magnitude of the climate crisis, many papers in this area, though written by technologists (e.g. [11]), express the need for ESD in direct, engaging, non-technical language.

We begin by looking at some approaches to ESD that have been reported by Peters et al. [12] in their recent systematic review of the literature on sustainability in computing education. Covering 89 primary studies, the review covers the pedagogical methods that have been adopted, and the outcomes that have been reported for students and educational systems. While Peters et al. take Computing (and by extension Software Engineering) as their context, many of their observations are relevant across domains. Indeed, the tensions between specific disciplines and the need to cultivate a more widespread appreciation of sustainability are recognised in the literature from Computing [13]. Different approaches for introducing ESD are espoused, and again readers from non-computing disciplines will be familiar with these. In some cases the ambition is to develop sustainability-themed projects across disciplines [14]; in others vertically though year groups [15], in other cases in a single (capstone) project [16]—in our case the approach was to develop a sustainable design as a project within modules in separate disciplines, but sharing the common resources of the EWB-UK *Design Challenge* (of which more below), and with the respective module lecturers sharing with each other their experiences of using those resources with their students. Sometimes games are the favoured approach for drawing students into an appreciation of questions of sustainability, whether boardgames [17] or even games that require physical passing or throwing of objects [18], to name just two possible formats. As will be mentioned later, the Software Engineering module that is the subject of this article includes a game-based element.

While Peters et al. report many instances of positive outcomes among students as a result of their exposure to ESD in its different forms—for example their increased awareness of, and their increased motivation to tackle questions of sustainable development—there is a note of caution in the review:

> "During the analysis, we found only six studies that considered threats to validity in their research design, which are considered key characteristics of experimental research in education [19]. The general absence of threats to validity raises important questions regarding the research design overall and the reliability and generalizability of the results."

As we move to the next stages of analysing the effect of introducing sustainability on to our modules, we shall be careful to design robust analytical instruments, aware that there is much merit in the clichés "What gets measured gets done" and "We measure what we value" [20].

There has also been much interest in the literature in the way sustainability is being introduced on Chemical Engineering courses at university. Again, the format of the approaches will be applicable to other disciplines as well. Since the emergence of the concept of 'sustainable development' in the 1980s and its definition in the Brundtland Report [21], the chemical manufacturing industry has increasingly focused on sustainable processing. This has led to the demand that ESD should not only be included in Chemical Engineering degree programmes [22], but that it should be embedded in each programme at multiple levels, if it is to be delivered effectively [23]. Often, this means redesigning existing courses to include new course materials, or developing elective modules to be taken in the later stages of a course [24]. The increased focus on sustainability has led to the emergence of new engineering concepts, which now also have to be covered in the curriculum—for example, green engineering [23, 25]; green chemistry; and sustainable chemical engineering [26]. There is also a stronger emphasis on engineering project management and control, requiring that students have knowledge of environmental management systems, lifecycle analysis, and process integration and optimisation

[27]. (There are analogies here with the emergence of 'green computing' and the Green Software Foundation's efforts to help developers audit the environmental impact of their software [28]—we expect that such developments will have to become part of our Software Engineering programmes too, sooner rather than later.) Several teaching strategies have been reported as being effective. For instance, Glassey and Haile [29] describe use of a concentrated programme of lectures and teambuilding in the first week of teaching for first-year students: during the week the students tackle a simple design problem, one aspect of which is sustainability. Several key modules (some optional in the latter stages of the programme) then support a "progressive development of [the] sustainability theme" across a range of topics during the four years of the undergraduate Master's programme. As an example of a very focussed learning experience, suited to introduction of an important sustainability-related concept or technique, Othman et al. [30] report a favourable reaction to an intensive one-day lecture on 'sustainability assessment and selection' (SAS—a methodology for selecting best process design, supply chain, etc.): the one-day lecture was offered to a small group of final-year undergraduate and Master's students as part of a Chemical Engineering course on Computer-Aided Plant Design. With a 'crash course' approach of this kind, an already high level of background experience in the target audience is critical.

2.2 The Engineering for People *Design Challenge*

2.2.1 Some background to the *Challenge*

Sustainability may be a headline topic, and its integration into formal curricula increasingly an area of pedagogical practice and academic analysis. Nevertheless, finding ready-to-use or easily adapted resources for use in the classroom or lecture theatre remains difficult. EWB-UK's *Engineering for People Design Challenge* provides examples of real-world problems for students to investigate and resolve—not least through critical thinking. Our decision to take on the *Design Challenge* was certainly not without justification. The *Challenge* has already reached over 60,000 undergraduate students across Cameroon, South Africa, UK, Ireland and the USA [31].

We ourselves bring a sizeable cohort of students to the *Challenge*. In the current academic year (2023–24), CSC2058 had 52 teams of 6 or 7 members, totalling over 320 students; CHE1101 added nearly 60 more students, divided into 10 teams of 5 or 6 members. Numbers in 2022–23, our first year of participating in the *Challenge*, were similar.

2.2.2 The form of the *Challenge*

The *Engineering for People Design Challenge* is an example of challenge-based learning (CBL) [32]. Though this term is much used, and though the approach has many variants (sometimes overlapping with and used interchangeably with project-based learning (PjBL) or problem-based learning (PBL)), some useful, distinguishing characteristics of CBL are identified in one of its early definitions (also cited in ref. [32], and quoted below). The *Design Challenge* exhibits these characteristics—particularly in that it encourages students to confront problems and formulate solutions that go beyond the boundaries of their own discipline:

"A challenge-based learning [CBL] experience is a learning experience where the learning takes places [*sic*] through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable" [33].

2.2.3 Reactions to the *Challenge*

Despite having had so many student participants, the *Design Challenge* has not been the subject of many independent academic reviews. A recent report from Strathclyde University [34] finds the experience positive, but emphasises the importance of making clear what will be assessed [an echo perhaps of our initial difficulty in establishing that software engineers had to base their gamification on a proposed real-world solution (Sect. 3.2.3)] and that weekly meetings with students were essential [seminars in the case of Strathclyde; weekly lab-based advisories the case of our Software Engineers (Sect. 3.3.8)].

A report on earlier challenges under the auspices of EWB-UK's sister organisation, EWB Australia, reports an overwhelmingly positive reaction from the student participants—students giving strong indication that they felt their understanding of the issues and their personal skills had been enhanced [35]. As an account of the experiences of two academics who have introduced the *Design Challenge* in their own modules, this article supplements such reports.

3 Meeting our *basic requirements* in the context of the *Challenge*

3.1 Fulfilling Requirement 1: *Acquire* New Knowledge and Resources

Intended specifically for first- and second-year university students, each year the *Design Brief* for the *Engineering for People Design Challenge* describes a different geographical location and its cultural and historical background. In the *Design Brief*, people who live in the location describe the problems they face, whether these are to do with food, transport, digital systems and connectivity, the built environment, waste, energy, water or sanitation. It is up to the students to identify a problem (or group of closely related problems) from these 'challenge areas', and then begin to design a sustainable solution.

The *Design Brief* offers students—and educators—insights into places that may be very unfamiliar to them (for example, *Challenge* participants from Ireland and the UK learning about Lobitos and Piedritas on the northern coast of Peru; or about Cape York, a vast peninsula largely owned and managed by indigenous people in northern Queensland, Australia; and, in 2023–24, Pu Ngaol, a rural village of just 547 people in Mondulkiri province, eastern Cambodia).

Sometimes, though, the place will seem very familiar. For example, in 2022–23, participants from Belfast, a city once renowned for its shipbuilding industry, were tackling problems faced by people living in Govan, an area in Scotland that is itself facing the challenges of deindustrialisation after shipbuilding.

Beyond the *Design Brief*, Engineers Without Borders provide a chat facility in the form of a Discord forum, a way for students to discover information that might not be covered in the *Brief*, especially as they start to consider the fine detail of a sustainable solution for a particular community. In 2022–23 members of the community in Govan answered the students' questions; in 2023–24 questions were answered by staff and volunteers of EWB-UK and EWB Australia. Primarily intended for use by the students, educators are also welcome to enter the forum: the information posted there helps inform the discussions that educators have with their students about viable sustainable solutions.

Likewise, and new for 2023–24, an interactive map, with ground-level views of Pu Ngaol, provided valuable insights into the reality of life in the village—the state of roads, the distances between main buildings, the layout of a schoolroom—knowledge that could normally only be acquired by actually being there.

As well as setting the real-world context, the *Design Challenge* brings with it a set of assessment criteria which apply to the real-world solution and emphasise *appreciation of the context*, *justification of the solution*, and *reflection on the learning journey*. *Appreciation of the context* includes the economic, environmental and social implications of the proposed solution: sustainability is, in other words, built into the design exercise. Again, for lecturers new to the theme of sustainability, these marking criteria provide an appropriate checklist of points to consider when evaluating the students' work.

Much or what we write here is based on our experience of accompanying our students as they worked on EWB-UK's Govan *Design Challenge* of 2022–23, but we also make observations about progress and latest outcomes on the 2023–24 *Challenge* set in Pu Ngaol, Cambodia.

3.1.1 Other useful resources to supplement the *Design Brief*

For scene-setting background, the UN itself provides extensive information on its 17 Sustainable Development Goals (SDGs), including the very detailed *2030 Agenda for Sustainable Development*, adopted in 2015, which enumerates the 17 SDGs and their many subgoals [36]. This is likely to be off-putting for many first-timers, who need an easier introduction to the 17 SDGs. For them, the UN's booklet *Software Development Goals* [37]—which devotes a one-paragraph description to each of the 17 goals—provides a very accessible starting point: an invaluable aide-mémoire for educators and students alike.

Other organisations have developed presentations that show how the SDGs translate into practical solutions in their own area of expertise. One example is the International Telecommunication Union's 'backgrounder' [38], illustrating how IT devices, services, configurations of equipment, and community initiatives can be used to further different SDGs. Again, these are practical examples that students can emulate in their own sustainable solutions, rather that attempt to assimilate the aims and objectives of the SDGs directly from the densely written *2030 Agenda*.

3.2 Fulfilling Requirement 2: *Adapt* Existing Modules

3.2.1 Before the introduction of the *Design Challenge*

In the case of our Chemical Engineering module, CHE1101, introducing a sustainability challenge meant changing the theme and adjusting the focus of a single assessment on process design. For some years the module had been delivered in a conventional 'one-way' teaching approach, in which students were introduced to the fundamental concepts in lectures. More recently, in a move towards collaborative working, a two-hour workshop and briefing sessions were used to provide guidance on the key tasks of the group assignment that was used to assess learning outcomes, and that the students 'took home' to work on in their own time.

Before the introduction of the *Design Challenge*, the assignment focussed on renewable energy. Students were given a problem statement and were tasked to provide a critical analysis of the background to the problem and likely future trends. They then had to propose a suitable renewable energy strategy for Northern Ireland that included a chemical engineering design solution—for example, generation of renewable fuel from gasification of biomass. In the biomass project, students were asked to propose suitable types of biomass gasifier, applying their own innovations, and then analysing the operation of the gasifier and its impact on the environment. Already then, in this first-year module, key engineering skills and environmental awareness were being assessed: (1) the ability to generate/understand a process flow diagram; (2) the ability to perform environmental analysis; (3) the ability to apply appropriate waste reduction and management.

However, a rather conventional approach to the assignment was characterised by only limited interactivity (between the students, and between the students and their educators), while the chemical process that had to be applied was predetermined by the educators.

The position for the Software Engineers was similar: there the theme of the software game to be developed was set by the module lecturer: no particular set of case studies was proposed, and often the students' general knowledge of the subject matter of the game (e.g. 'protecting the environment'), was (rightly or wrongly) assumed.

3.2.2 After the introduction of the Design Challenge

Embedding the EWB-UK *Design Challenge* changed the conventional assessment structure by creating a more interactive, realistic and open-ended group project, facilitated by collaborative workshop activities that helped students formulate their own design ideas. In the *Design Challenge*, students were being specifically encouraged to overcome the barrier between acquiring knowledge and applying it to solve the problems faced by an actual community—in 2022–23, the community in Govan, Scotland.

For all our students, whether Chemical or Software Engineers, the challenge areas (see Sect. 3.1) were very different from the subject-specific examples normally presented in class, shifting the focus towards a complete system solution with a discipline-specific element, rather than a very narrow problem for which good lecture-based knowledge of a discipline-specific topic would be sufficient for devising a passable solution. Consequently, at the beginning of the project, students sometimes found it difficult to pinpoint a starting point. However, through interactive discussions guided by educators, in workshops and advisory sessions, we started our students on the path of thinking critically and creatively about the problem, helping towards their first draft of a design.

Through their experience of developing a solution to a real-world problem, the students' awareness of the engineer's role in society gradually increased. Now they were doing more than applying lecture-based learning uncritically to narrow problems as an exercise in 'functional design'. Instead they were widening their focus to 'sustainable design'—economically feasible, environmentally friendly and technically sound, of benefit to the community in which it is deployed, and protective of the planet and its inhabitants more generally.

3.2.3 A game-based approach, and the 'cold (sustainability) start' at the beginning of second year

Apart from the very different subject matter, *Software Engineering and Systems Development* (CSC2058) differed from *Introduction to Chemical Products and Processes* (CHE1101) in at least two significant respects: it was a second-year module rather than a first-year module, and it had a game-based element: in recent years the Software Engineering students (on CSC2058 and its predecessor modules) had used their practical software development skills to design and code a game.

Game-based learning is recognised as a valuable means of encouraging students to explore ideas and experiment in an engaging and non-threatening context—things might not quite work out as initially planned, but even that is a valuable learning experience. In their *Education for Sustainable Development Guidance*, AdvanceSE/QAA say:

"Use play-based approaches, including game-based learning and simulation, to provide an environment for students to explore alternative scenarios and practice and develop alternative ways of thinking, allowing students to take risks, experiment with new approaches and learn through failure" [39].

Although the details of the game in the Software Engineering module changed from year to year (sometimes taking on an educational, a technological or an environmental theme), the emphasis for the Software Engineering students was on creating a functioning game in software, using their abilities in the programming language Java and applying the tenets of object-oriented software development. The loosely formulated real-world theme merely provided a context for this, to make the game more interesting and coherent.

Now aligned with the EWB-UK *Challenge*, the game in its latest form served at least three purposes. Firstly it provided a context in which student software engineers could exercise a full range of software engineering skills and adopt an appropriate development methodology, to create a robust, well-specified software artefact. Secondly it encouraged them to investigate the real-world problem to ascertain its objectives, tasks and steps—as a preliminary to developing the game, but also during the development of the game: if the game did not seem true to life, then what elements of the real-life solution were missing; what aspects of the real-world solution should be examined more closely? And lastly, as it reached completion, the game became a showcase for the steps to the real-life solution—potentially an awareness-raising device for those wanting to support, contribute to or better understand the complexities of a real-world sustainable solution.

Thus, starting in the academic year 2022–23, there was a shift in emphasis, with the game being used to represent a 'journey through sustainable design' (as the module handbook now put it), a simplified reimagining of the steps needed to complete an *actual* real-world solution for one or more of the problems faced by those living in a specific location: Govan, Scotland, in 2022–23.

It was expected that the process of understanding the real-world problem, designing the real-world solution and then representing the steps to the solution in a software game would iterate through several cycles in the course of the project. Nevertheless, the project's expected overall direction of travel was made clear to the students. They would progress from identifying and working out how to deal with a real-world problem (a test of the students' critical thinking and creativity), to gamifying in software the steps to their real-world solution (testing the students' ability to engineer a working software system, regardless of the real-world problem they had chosen).

For many of the young Software Engineers, this proved challenging. This was their first serious encounter with the theme of sustainability, their sustainability 'cold start'. For students used to coding there was a very strong temptation to develop code for the game almost immediately, without paying particular attention to the real-world theme. Those who adopted that approach were advised to think again: the sort or random penalty that appears in traditional board-games—like landing on a 'go to jail' square, with release dependent on 'rolling a double'—had little relevance to, and would in fact trivialise, the reality of living in Govan, where disposing of litter, dealing with digital and economic poverty, and finding shelter as an asylum seeker were among the actual and very pressing issues of concern. If nothing else, this was a useful lesson in the importance of examining the required project deliverables, so as not only to deliver a *working* solution but also to deliver an *appropriate* solution—something to remember in the world of work too.

As we shall see presently (Sect. 3.3.8), much greater attention was paid to the real-world solution in the academic year 2023–24.

3.3 Fulfilling Requirement 3: *Adopt* New Ways of Thinking

Finding ways of moving beyond the 'comfort zone' of seeing similarities with home is difficult. In the *Design Challenge*, students are, in some cases, being asked to tackle issues that they may see day to day, even in their hometown, but that they have regarded up until now as 'someone else's problem' and not matters to which they could and should legitimately devote time and energy on their academic pathway—how to stimulate urban regeneration, or tackle limited access to digital equipment and networks (digital poverty), for example. Now they are being asked specifically to see what they as young engineers can do to help. And sometimes, even though the problems being considered are similar to those nearer to home, they are on a different scale: for instance, in Govan, per head of population, there is a greater proportion, and a more diverse ethnic mix, of asylum-seekers than in Belfast. Such issues require close and sensitive attention to the circumstances and aspirations of the people involved.

University systems can, intentionally or not, focus students' minds on simply passing modules as a means of progressing to the next year of their studies, to graduation and a job. If that is a student's primary focus, the heightened level of personal engagement, insight and judgement required to deal with the problems introduced in the *Design Brief* will seem an unwelcome addition to the core business of their course (engineering a working system that can be proven to meet a set of functional requirements, for example). In the following sections we examine some of the new ways of thinking we wanted our students to adopt, and describe how those new ways of thinking began to change their way of working.

3.3.1 Considering sustainability as a 'non-functional requirement' of a system

And yet sensitivity towards, and a willingness to engage with, economic, environmental and social issues is not just a mark of a good citizen in a general sense. Discernment, initiative, and critical thinking are marks of professionalism that can and should attract credit on the students' academic modules. They are competencies that will set them apart in their future careers as well. A functioning system that is too expensive, too wasteful, too impractical or too inaccessible for the people who are expected to use it is next to useless, whether it is being developed as a project on an engineering-related university course, or worse, as an actual real-world product or service. Indeed, some researchers argue that 'non-functional requirements'—which in the broadest sense encompass the social, environmental and economic constraints within which a system operates—should be handled in the same way as functional requirements, since they describe the required behaviour of a system [40]. For organisations keen to position themselves as socially, environmentally and economically responsible, 'sustainability' may now be billed prominently as one of the non-functional requirements that they adhere to [41]. In the area of environmental sustainability, engineers are making major efforts to understand the ecosystems in which their technical solutions operate, in order to establish processes that will "maximize efficiency and reduce waste" [42].

3.3.2 Considering the bigger picture—the move towards systems thinking

Provided that some fundamental subject-specific competencies have been established beforehand (for example, Software Engineering students in their second year at Queen's should already know how to program and implement simple object-oriented architectures), a complementary, sustainability-themed module can offer the student new freedom to think imaginatively and creatively, exploiting and building on the skills that they already have. Indeed, a willingness to examine and understand technical problems 'in the round' is part of the mindset that progressive commercial companies appreciate and reward. This is illustrated by the following recent advertisement—a fairly typical one that has no specific emphasis on SDGs—for a Senior Software Engineer (the italics are ours):

> "Be part of a team who are working to *solve complex business problems* by delivering high-quality software that *provides an outstanding experience for our customers*. […] *Assess the business value of new technologies and technical solutions* using a data-driven approach and implement them to the development life cycle. […] Have worked with *Product Owners, customers, end-users, or stakeholders* in the delivery of software, solutions, or products. […] We're an *ideas company*. Always. We thrive on engineering excellence and surpass with technical mastery. […] *We work alongside the best in the business and learn from the finest minds*." [43]

Already, in this non-educational context, the implication is that software engineers (just one variety of academically trained professional) need more than narrow technical competencies if they are do their work well. While technical competencies are important (how to represent different control structures in a particular coding language; how to represent the elements of a design in a particular notation—to take other computer-related examples), sometimes those technical competencies have been regarded as an end in themselves. Academics have noted that approaches whose focus is on achieving a very specific outcome, by solving a series of smaller, tractable problems using one discipline-specific technique, generally miss the 'bigger picture': what are the consequences of achieving the intended outcome; what are its side-effects; what are its implications for the way people work; what are its effects on the wider environment? Steve Easterbrook—now Director of the School of the Environment at Toronto University *and* a computer scientist—sees in this the contrast between, on the one hand, 'computational thinking' and, on the other hand, 'systems thinking', the former tending towards narrow discipline-specific competency or 'technical solutionism' [44], the latter concerned with that bigger picture. Put simply, technical solutionism, in which an algorithmic approach is proposed for *all* problems, has the effect that any problem that is not amenable to such an approach is usually ignored. By contrast, systems thinking acknowledges the much wider interconnectedness of the elements of a fuller, more satisfactory solution, one that may have to encompass technology, human behaviour and the environment [44].

Such all-embracing solutions are clearly relevant to questions of sustainability. It is unsurprising, then, that when UNESCO, set out its eight key competencies that are needed "for thinking and acting in favour of sustainable development" [4], narrow discipline-specific competencies did not feature. Instead "the long view" is encouraged: not just providing an immediate solution to a specific problem, but finding a solution that is suited to its context and has the potential to endure. While we will not examine all eight key competencies in this article, our later remarks (Sect. 3.3.8) on some of them will help establish their relevance to the design challenges that our students undertook in both Software and Chemical Engineering, and the manner in which we encouraged our students to develop and use those competencies.

3.3.3 Tackling real-world problems: the need to think critically about sustainability

Our Software Engineering students currently enter the second year of their undergraduate degree programme having had minimal exposure to sustainability. (Undergraduate programmes at Queen's last four or five years—depending on whether they are leading to a Bachelor's or Master's degree—and generally include a year's placement in industry.) Now as 'second years' they have to develop an appreciation of what sustainable development involves, and use the 'toolkit' of analytical and coding skills that they acquired at first year to help them shape a solution to a demanding real-world sustainability challenge—EWB-UK's *Engineering for People Design Challenge*. However, for dealing with problems of sustainability, with its mixture of environmental, economic and social factors, they will need more than the computational thinking (Sect. 3.3.2) that they have been used to up until now. In a moment we shall consider some techniques that encourage critical and systems thinking, and practical problem solving. We anticipate that this 'cold start' on sustainability in the second year (see Sect. 3.2.3) will change in future years as sustainability and ways to view it become more generally accepted as an integral component of all university courses, with related learning outcomes from first year onwards.

By contrast, our Chemical Engineering students already encounter a number of sustainability themes in the first year of their degree programme: green and sustainable chemistry, environmental management, waste and resource management, and renewable energy systems. In line with a growing commitment among university teachers generally (cf. the UK University and College Union's programme of continuing professional development in climate and sustainability [45]), educators in the School of Chemistry and Chemical Engineering have set out to ensure that—beginning as early as possible—students are able to apply the principles of sustainability that they learn from lectures. This is in agreement with the guidelines set out by the IChemE: "[Graduate chemical engineering students] must appreciate the social, environmental, legal, ethical, safety, economic and commercial considerations affecting the exercise of their engineering judgement"[8].

Problem-solving classes therefore feature prominently on the Chemical Engineering course at Queen's. However, in traditional problem-solving activities, students are usually given a fixed set of problem statements to work on—individually or with a group of peers. One difficulty with such 'traditional' learning activities is that they are often based on industrial scenarios, which, for students at the start of their careers, seem remote, and consequently dull. The EWB-UK *Design Challenge* adds immediacy by providing open-ended, realistic case studies that focus on a particular community and location. For Chemical Engineering courses—and for Software Engineering courses too—this approach is game changing. Given these very accessible case studies, presented in EWB-UK's *Design Brief* from the personal perspectives of real community members, students have a new incentive—a new mission—to analyse everyday problems and design practical sustainable solutions, to apply critical thinking and to innovate. They are no longer working on a remote process: they are creating solutions that have the potential to make a positive change to the way in which members of a community live.

3.3.4 Learning to think critically: doughnut economics and the four lenses

Fortunately, with the *Engineering for People Design Challenge*, students and educators are not left to their own devices when it comes to finding ways of identifying and developing sustainable, community-focussed solutions. EWB-UK's Launch Lecture for the *Design Challenge* introduces one model that encourages a balanced view of the social and ecological factors that make for a prosperous sustainable world—Kate Raworth's "Doughnut Economics" [46]. The objective is a simple one: keep humanity below the outer ring of the doughnut (the ecological ceiling of what the planet can sustain), and above the void in the centre of the doughnut (so that people do not fall short on the essentials of life).

EWB-UK's Launch Lecture (a video to be played and paused at appropriate moments for discussion and activities in class) gives the students a first opportunity to experiment with techniques that apply the principles of 'the doughnut' locally—four questions or 'four lenses' that put into focus the criteria that would allow a city, or a community, to thrive, while respecting the wellbeing of other cities and the wider world around it:

- What would it mean for the people of the city to thrive (the Local-Social lens)?
- What would it mean for the city to thrive within its natural habitat (the Local-Ecological lens)?
- What would it mean for the city to respect the wellbeing of people worldwide (the Global-Social lens)?
- What would it mean for the city to respect the health of the whole planet (the Global-Ecological lens) [47]?

The significance of Doughnut Economics may not be fully appreciated at a 'first pass' through the Launch Lecture—this was probably the case in 2022–23. However, the influence of Doughnut Economics has been far reaching. It has been welcomed by Pope Francis as part of the "fresh thinking", from women especially, about "an economy that sustains, protects and regenerates not just regulates and arbitrates" [48]. It was adopted by Marieke van Doorninck, Amsterdam's then Deputy Mayor for Sustainability and Planning, as a model to give the city's residents a good quality of life without putting unsustainable pressure on the planet [49] (van Doornick is now director of Kennisland, an independent Netherlands-based group of academics, strategists, researchers, designers, prototypers and lobbyists, one of whose goals is to realise 'sustainable innovation together' [50]). Doughnut Economics has captured the collective imagination of organisations as diverse as the UN General Assembly and Extinction Rebellion, as pointed out by DEAL (the Doughnut Economics Action Lab, of which Kate Raworth is a team member) [51]. In Sect. 3.3.8 we explain how we made a clearer case for Doughnut Economics in 2023–24—and why introducing our students to such thinking is important.

3.3.5 Other stimuli for critical thinking and collaborative learning

Other live workshops from EWB-UK, tailored to the needs of the different institutions that are participating in the *Design Challenge*, introduce a series of exercises that encourage critical thinking: asking questions, adopting different perspectives, challenging assumptions; not being content with the first and most obvious solution; checking that the solution is universally applicable, and if not, working out how or if exceptions have to be managed; checking what skills—and what experts—would be needed to realise a solution.

These live workshops put the students at the heart of the learning process, facilitating group discussion and the opportunity for peers to learn from each other. This approach echoes the concept of *collaborative learning*, whose benefits have been recognised for some decades. Gokhale [52] cites research on the topic: "cooperative teams achieve at higher levels of thought and retain information longer than students who work quietly as individuals" [53]; "shared [i.e. collaborative] learning gives students an opportunity to engage in discussion, take responsibility for their own learning, and thus become critical thinkers" [54]. He concludes that "collaborative learning fosters the development of critical thinking through discussion, clarification of ideas, and evaluation of others' ideas. However, [both individual learning and collaborative learning] were found to be equally effective in gaining factual knowledge. Therefore, if the purpose of instruction is to enhance critical-thinking and problem-solving skills, then collaborative learning is more beneficial [than individual learning]." [55].

When it comes to the real-world, working collaboratively is so beneficial that the UK government set up a dedicated *Institute for Collaborative Working*, now in its 34th year of supporting collaborative working across a wide variety of organisations and communities [56].

3.3.6 'Imperfect ideas' as stimuli for critical thinking and collaborative working

A further exercise in collaborative design from EWB-UK (devised in collaboration with innovation consultancy Think Up) is based on the premises of 'Imperfect Design Criteria' and 'The Designer's Paradox'. The concepts are closely related. The latter (attributed to Ed McCann and Chris Wise, founders of Think Up) states that: "The client doesn't know what they want until they know what they can get; the designer doesn't know what they will design until they start designing." [57] This 'assumption of uncertainty' gives students the space they need to formulate their design creatively, thinking 'outside the box', and continuously testing their understanding of the problem by presenting their emerging solutions to, and debating them with, their peers. Gradually—through a repeated process of improvisation, comment, criticism and refinement—more appropriate, more robust solutions emerge. During such a design exercise at Queen's, we noticed how our students became less reluctant to share their 'imperfect ideas', as they realised that these 'imperfect ideas' were in fact the raw material that iterative, collaborative design needs. This is an important lesson to learn, and one which will, we hope, make it easier for the students to contribute to group work in future.

Again, for some students, viewing a problem from all sides will seem an unnecessary distraction from learning the nuts-and-bolts techniques of their chosen discipline—for example, in Software Engineering, writing an automated unit test, or creating a new development branch in a version control package. Such specialised, domain-specific skills are certainly important in modern production environments, but, as we have already mentioned, they are not an end in themselves. In the workplace, it is sometimes tempting 'not to think too closely' about the economic goal of the product—the software system, say, that is being unit tested—or the corporate objective of the new development phase that is being scrupulously version managed. Yet in a world facing grave environmental, economic and social challenges, future young professionals need to take more than a passing interest in the goals to which their skills are being applied. As Tom Newby of the charity The Happold Foundation has said:

"It's no longer acceptable to sit at your desk and do your engineering and not think about what the consequences of that are" [58].

3.3.7 The difficulty of shifting focus to the real world

On our modules we were, then, giving our students new ways of looking at real-world social, environmental, and economic questions; we were encouraging them to work collaboratively, part which would involve having the courage to share and refine imperfect ideas.

However, for the Software Engineers, even when the connection between the game, the real-world problem and the real-world solution was better understood, there was still the problem of identifying—from the extensive information in the *Design Brief* for the *Design Challenge*—a single problem, or a tight bundle of related problems, that they could examine closely in its social, environmental and economic context, and for which they could work out a coherent, sustainable solution. A recurring difficulty among the young Software Engineers in 2022–23 was that they attempted to do too much. They saw many real-world problems in the *Design Brief*, and tried to deal with all of them. There were a number of praiseworthy and committed attempts tackle the challenges—but sometimes at too high a level and over too broad a range.

It was easy, for example, to identify lack of access to special foods, digital poverty, expensive transport and energy as all being significant problems in Govan. However, these problems and the tasks that would help resolve them sometimes remained largely as elements in the *game* that the students were asked to produce (it was assumed the steps to the solution *could* happen, but in the students' entry to the EWB-UK *Design Challenge*, it was not explained *how* they would happen in the real world). In some instances the game itself—as an awareness-raising resource—was proposed as part of the real-world solution, but again, its likely impact on the real world had not been closely enough modelled to make a convincing case for its usefulness. Similarly, teams considered ambitious new real-world facilities that, in a single location, would address multiple issues—like waste disposal, digital poverty, funding for personal transport, and provision of travel information. Again, very attractive games were produced, but with so many issues at play, it was very difficult to argue convincingly that any such facility could work sustainably in the real world.

In general our Chemical Engineering students, both in 2022–23 and in 2023–24 had a clearer idea of the importance of sustainability as an integral part of their course. As we have mentioned previously, the professionally regulated chemical engineering industry now requires its processes to be sustainable, and so universities like Queen's set out to provide their young chemical engineers with the knowledge and skills they need to meet industry's requirements. For example, in CHE1101—and this was the case even before the EWB-UK *Design Challenge* was incorporated into the syllabus—students are given a 'consultancy brief' to provide a sustainable solution based on existing processing technology available in the chemical industry: part of their work is to assess the appropriateness of their solution in its real-world context.

Just as many Software Engineers gravitated towards the software game in 2022–23, it was perhaps unsurprising that many Chemical Engineering students chose to work on challenge areas such as energy, water and sanitation, since these aligned closely with the sustainability-related content of their degree programme. For example, among those focussing on energy, some chose biomass gasification technology specifically: not only does gasification feature in CHE1101, but it will also be familiar to many students because of the important role that agriculture plays in the economy of Northern Ireland. Other interesting process-focussed innovations included conversion of food waste into biofuel, heat pumps for sustainable home heating, and use of water turbines to generate hydro energy.

But again, as was the case with the Software Engineers, many of the Chemical Engineers found it difficult to set out a convincing plan for managing, executing and maintaining their designs in the real world—a strategy that would take into account the potential socioeconomic impact on the local community. These difficulties were not unexpected. It is important to remember that as 'first years' and 'second years', students in *both* cohorts have not yet had the advantage of their placement year and the insights it offers into making businesses work in the real world—that is valuable experience that would undoubtedly colour the approach that final-year or postgraduate students would adopt to such challenges.

For some of the Chemical Engineers, the temptation to deploy a ready-made, industrial-strength solution, sourced online or identified in a research paper, was simply too great—like use of ready-made industrial equipment. Students overlooked the fact that large-scale solutions are expensive to acquire, have significant operating costs, and usually require extensive assessment of environmental impact and health and safety risks. With a ready-made solution in their sights, students overlooked the problems of initial and ongoing funding, and the acceptability of the solution in the local community.

As we have seen, attitudes among the Software Engineers were initially similar: the focus of many of the teams, throughout the academic year 2022–23, remained on the software (the game): the real-world challenge provided a context, but was probably not viewed as the real concern of software engineers. Some teams, while they managed to incorporate great authentic detail into their gamifications, were not able to make a convincing case for the social, environmental and economic viability of their solution in the real world when it came to the *Design Challenge*.

3.3.8 A further shift: concentrating on the real world—using those new ways of thinking!

However, in 2023–24 there was a further shift in the students' focus, especially noticeable among the Software Engineers. In part this was because of the greater emphasis on the sustainability theme in the launch events for our modules (see also Sect. 5.2), but—because of administrative changes—there was now also a larger number of postgraduate and final-year advisers (up from 5 to 8) on the Software Engineering teaching support team, some of whom were continuing their involvement in the module from the previous year, and like the module lecturer and module teaching associate, were growing in confidence. There may also have been a 'through-the-grapevine' effect from this being the second year that sustainability featured on the module—students had learnt from their colleagues 'in the year above' what was expected from the game.

There was also a change in 2023–24 in the way we presented Doughnut Economics to the Software Engineers. There are many resources that make Doughnut Economics accessible for the beginner—not least DEAL, which provides material that in text and image sets Doughnut Economics in context, and which we made more use of in the current academic year. As set out in the bullet points in Sect. 3.3.4, the questions for the four lenses make no suggestions as to how students might start to formulate answers. Certainly that has the advantage of giving students' imagination free rein. On the other hand, if asked live in class, such unexpected questions are likely to be met with silence—or will trigger other unspoken questions ('thrive in what way'; 'at what cost'?).

Rephrasing the questions in more concrete terms, with a few words of explanation, and an image or two to set the audience thinking, is likely to prove more productive. DEAL's *Doughnut Unrolled* [59] adopts that strategy with some success, and includes ready-made slides to use in the classroom. If the Local-Ecological question (in the form shown in the bullets above) is too open-ended, what about adding some context?—'How can this place [your city] be as generous as the wildland next door?' Examples in *Doughnut Unrolled* of what a 'wildland' is ('the healthiest natural habitat in your area') and what it does ('builds nutrient-rich soil', 'harvests the sun's energy') point students in the right direction. A few well-chosen photos provide further hints as to the sort of comparisons that are possible between the natural and the (ideal) built environment (e.g., a picture of a bee on a flower next to a picture of a man-made insect hotel, with the tagline: 'welcomes wildlife'). Such visual stimuli are likely to trigger other ideas about what is possible in the built environment ("leave roadside verges uncut"; "make green roofs"; "create hedgehog highways"; and so on). Very soon the students' own natural interest and engagement in these areas takes over and the dialogue is underway.

Viewing the world through the four lenses side by side creates an appreciation of the happy middle ground that characterises Doughnut Economics—where, for example, efforts to make the local place thrive ecologically cannot be at the expense of resources that the planet as a whole needs to thrive ecologically. The 'safe and just space for humanity'—the body of the doughnut—is maintained by such balances, the same balances that the students have to respect in their design challenge.

Again, as an icebreaker for the topic of sustainable development, introducing and taking time to develop the theme of Doughnut Economics was useful. It put on the students' radar (in a context in which they probably were not expecting it—i.e. in a start-of-year lecture for an engineering programme—and probably all the more memorably for that!) an author and a book that, as the references in Sect. 3.3.4 indicate, has made a stir not just amongst those who might be labelled economists or environmentalists. As well-informed young adults, our students should be part of that conversation, whether they agree with the arguments of Doughnut Economics or not. And while no obligation was put on the students to use the 'four lenses' in their later project work, the guidance that environmental and economic considerations should be central to the students' real-world solution was not ignored—especially in the recently completed 2023–24 iteration of our modules (see also Sect. 5.2), where the opening lectures set the scene for the EWB-UK *Challenge* rather more emphatically than the previous year (our 'first attempt'). In the most recent iteration of our modules, as they formulated their real-world solutions, the students were much more concerned with the environmental, economic and social impact of their designs than they had been previously: using solar rather than diesel power, using plant-based rather than synthetic materials, making sure that women and girls had access to educational resources, and so on. That may not have been the direct result of applying the four lenses—but the context that the four lenses helped establish had clearly been noted.

Our priority for the last two years has been to introduce and heighten the profile of sustainable development on existing modules rather than impose a particular technique on our students and to rate them on how well they complied—good as they are, even the 'four lenses' can lead to a distracting preoccupation with how the technique is interpreted and applied, rather than appreciating the broader issue of interconnected sustainability problems that it is intended to highlight. Once the topic of sustainability is 'live', educators are in a position to gauge what has worked and what hasn't, starting from observations of reactions in a lecture theatre, and from conversations with students and colleagues. A further challenge will now be to find robust ways of confirming those initial observations: introducing more specific sustainability-related goals and assessment criteria and providing better feedback channels are all options under consideration. While we do not make recommendations for these here, we recognise the need for them as a means of monitoring academic outcomes. For the moment we are guided by EWB-UK's assessment criteria for the *Challenge* and the existing subject-related specifications and learning outcomes of our modules [60], aware that these specifications, and the modules themselves, are likely to change as competency in tackling questions of sustainable development becomes a significant outcome in itself.

And so for the Software Engineers in 2023–24, while one or two off-theme games were caught at the submission at the end of the first semester (games whose rules had little bearing on the steps to a real-world solution; games whose goals were for a setting very different from Pu Ngaol in Cambodia), now almost without exception the second semester games were on theme, whether or not they were technically accomplished!

Now, among the Software Engineers, developing the real-world solution tended to predominate, and while the games were on theme, the new difficulty was that some of the core requirements for the game (functionality that it was meant to deliver as an exercise in software engineering 'to specification') had been overlooked (e.g. accepting responsibility for—or being in charge of—all the tasks that contributed to an objective before work on those tasks could begin.) Perhaps the artificiality of such requirements now jarred with the students, whose focus—just like the focus of the module—had now shifted toward finding authentic real-world solutions. Re-examining the rules of the game will be one of the module lecturer's tasks for the next iteration of the module!

Especially in 2023–24 there were clearer examples of students exercising the key competencies that would better enable them to cope with questions of sustainability—in the real world as well as in their studies. Weekly 2 × 2-hour lab-based advisory sessions—but interactions online too—gave students the opportunity to share their evolving solutions with their lecturer, the teaching associate and the postgraduate and final-year advisers. These interactions gave the members of the teaching support team the opportunity to 'pull at any loose ends' in the students' emerging solutions, to help the students focus on a particular problem and think through its solution carefully, and to offer the students more general advice—for example on resolving problematic team dynamics. The students responded in turn, reacting to the advice, modifying their solutions, and in some cases even their attitude to the other members of their team. We give just some examples here:

Systems thinking competency: realising that educational software for a school computer network couldn't simply be assumed to be available once the hardware was in place, but that it would have to be sourced, or developed in collaboration with educational experts, and costed too.

Strategic competency: looking beyond the local—raising funds for local sustainable development, by using national and international crowdfunding platforms coupled with remote awareness raising events and activities.

Critical thinking competency: changing the contents for the game away from achieving outcomes that were more appropriate to a leisure resort to ones that would be of practical benefit to farmers and their children in a Cambodian village.

Collaboration competency: overcoming a potentially serious 'falling out' within a team (with the heightened levels of stress associated with such an event), to seeing the potential benefits of the other person's ideas, letting those ideas develop, and eventually becoming part of a highly cohesive and effective team—an important life lesson as much as an academic or sustainably-related one! (Another important software-related life lesson was learning to help, rather than compete with, fellow students—for example by facilitating pair- and mob-programming exercises that allowed more hesitant programmers to sit in with, be supported by, and learn from the stronger programmers on their team: under existing module assessment criteria this was valued, and counted as 'adherence to process'!).

Integrated problem-solving competency: providing schoolchildren with a nutritious food supplement, as well as access to a new educational computer network.

4 Concluding the *Design Challenge*: getting to the final

Already in 2022–23, despite the difficulty of shifting focus to a real-world solution, a number of Chemical Engineering teams had the courage to break through the discipline barrier and were proposing very good, innovative ideas in response to specific 'challenge areas' in EWB-UK's design brief: sustainable farming systems featuring aquaponics (in response to the *Food* challenge area); low-cost, recycled materials for home insulation (*Built Environment* and *Waste*); and small, affordable solar-powered vehicles to make travel between Glasgow city centre and Govan easier (*Transport* and *Energy*), to name just a few.

The team from *Software Engineering and Systems Development* that went through to represent Queen's at the Grand Finals in 2023, and whose work is to be found on the website for the *Engineering for People* Grand Finalists [61], took the real-world solution very seriously indeed, and, as we shall see, were ready to work in an area well outside their 'comfort zone'. For the purposes of both the Software Engineering module and the *Design Challenge*, they managed to get the balance right: enough attention to the mechanisms and theme of the game to deliver a piece of well-designed, well-implemented and well-tested software that was based on a convincing real-world scenario; enough focus on the real-world problem and its solution—a sufficient period of 'remaining in the zone' for problem solving—that they were able to make a very detailed case that their proposed real-world solution was viable.

At the time of writing (May 2024), the Queen's entry remains the most viewed after the 2022–23 winner [62]. Called *Neighbourhood, A self-sustaining solution for asylum seekers,* the project envisages a community of small dwellings with shared spaces for growing, working, making and selling, supported by an outreach campaign on social media. As the main component of their entry to the *Design Challenge*, the students created a poster whose text, drawings and computer renderings covered the social, environmental and economic aspects of their solution—the three pillars of sustainability—touching on use of solar energy, harvested rainwater, affordable modular construction, and food produced on-site. They also provided a portfolio of supporting documents, indicating that they had gone into the fine detail of issues concerning and affecting asylum seekers in the UK, as well as the likely cost of the proposed scheme (land, construction, facilities management, media engagement, etc.). They even created a separate and very professional portfolio of computer-generated images of the proposed dwellings: some of these images showed the dwellings and shared spaces in situ, in a strip of land between the graving docks in Govan—a persuasive visual argument that this concept would work in the place for which it was intended [63].

This was an example of young engineers engaging whole-heartedly with the *Design Challenge*, while delivering the requirements of their university module as well. They had been prepared to go beyond the confines of domain-specific (software) engineering, in order to think critically about a sustainability problem in the round, acquiring along the way new skills and resources. Let us hope that the insights they gained in this exercise and the mindsets they were able to adopt will set them apart as thinkers and innovators, and serve them well in their future careers.

5 Outcomes, and lessons learnt

5.1 Did we successfully *Acquire* New Knowledge and Resources (Requirement 1)*?*

Yes. In both the years in which we have participated in the *Challenge*, the *Design Brief* has provided new insights into the sustainability-related difficulties that are faced by actual communities. Earlier in the article we gave examples of some of the resources that are available from Engineers Without Borders, and we mentioned additional materials from the UN and other international organisations that explain the Sustainable Development Goals and show how they can be achieved in practice.

The significance of these resources (especially those from EWB-UK) will not be appreciated at a cursory first reading (viewing/visit). However, over an extended period—in a one- or two-semester project (roughly 3 or 6 months in elapsed time, not including vacations)—such materials become continual points of reference. They are sufficiently rich that by comparing and cross-checking them (a personal statement, a government statistic, an arial view of a location, an inside view of a building, a series of exchanges on Discord), a close understanding of the particular circumstances of a community and its needs being to emerge. That understanding is deepened by critical discussion of emerging solutions (among students, between educators and students, between students and Discord forum members).

5.2 Did we successfully *Adapt* Existing Modules (Requirement 2)?

The changes we have made have been generally positive, though some fine-tuning is still needed.

The structure of the year-long Software Engineering module, with its distinction between the real-world sustainability challenge and the software-based gamification of the steps to the real-world solution, presents the students with particular challenges. In the latest academic year, 2023–24, in order to help establish the correct balance, Software Engineering students were discouraged from attempting to develop their software game to completion in the first semester. While, as we have mentioned, this delay introduces a *new* danger that students might overlook the need to develop the game according to the software specification set out in the module handbook (a test of students' software engineering skills specifically), we have nevertheless successfully held back the rush to completing the interpretation in software before the real-world challenge has been adequately assessed. To achieve this further shift of focus from the 'technical solutionism' of the previous year, the owner of the Software Engineering module substantially reworked the module handbook, giving much more prominence in the opening sections to the real-world sustainability challenge. Now, greater emphasis is placed on the fact that that a real-world sustainability problem and key steps to its solution must be identified first, before an attempt is made to create a complete software system (gamification of the steps to the real-world solution).

The opening workshop from EWB-UK was much more of an 'event' at the beginning of the 2023–24 academic year, for both the Chemical and the Software Engineers. In 2022–23, the launch event (for the Software Engineers at least) was fully online via Microsoft Teams: students joined the session with EWB-UK's facilitator remotely as individuals, with their mics and cameras muted. That brought with it the difficulty of keeping a large group of students engaged and 'on the same page' when they split into virtual meeting rooms for group work. By contrast, in 2023–24, the combined Chemical and Software Engineering students assembled on-site, filling a 390-seat lecture theatre that was equipped with the latest conferencing technology (a striking example also of coordination between the two modules owners: securing such a large lecture venue for the combined cohort requires some forward planning). Again, calling in remotely via Teams, but now assisted by a team of educators and student assistants onsite, and with the benefit of a two-way audio and video link with the auditorium, EWB-UK's facilitator was able to lead the students (who were seated together in their newly formed project groups) in a number of exercises designed to encourage critical thinking about real-world sustainability problems. The scale of the event, and the extra organisational effort that allowed it to run so smoothly, helped reinforce the impression that 'something different' was happening in Software and Chemical Engineering this year.

With this opening workshop, the tone for the year 2023–24 had been set. During the first weeks of the autumn semester, the students identified the sustainability problem they intended to tackle, and most were able to propose key steps (including acquisition of resources and funding) that would help build a socially and environmentally sensitive, and economically viable path to a possible solution.

In presenting EWB-UK's prerecorded introductory lecture, which is intended to be paused for discussion and exercise, we have introduced, in some detail (for the Software Engineers), content from the Doughnut Economics Action Lab's presentation on the Doughnut Unrolled (mentioned in Sect. 3.3.8 above). Even if this means that some pre-recorded content from the opening lecture has to be viewed in the students' own time, the 'doughnut' perspective helps set problematic questions of sustainability in a variety of easily understood contexts. We will see if this approach is appropriate for the Chemical Engineers as well.

5.3 Did the students (and their educators) *Adopt* New Ways of Thinking (Requirement 3)?

Though we cannot yet *quantify* the extent to which our students have mastered the UNESCO key competencies, there are indications that they are already applying them in the decisions and choices they are making as they develop their designs. The examples given in Sect. 3.3.8—covering system thinking, critical thinking, strategic thinking, collaborative working and integrated problem solving—are typical, and emerge not only in the solutions the students propose, but in the discussions that they have with their educators during workshops and weekly advisory sessions. Moreover, their educators are now regularly asking the questions, and suggesting plans of action, that require the students to exercise those competencies (How will you raise funds for your solution? How will you ensure that it will be accessible to those who need it? How will you source the electricity to run it? Who will develop and maintain the software that will be needed? How will that be installed? And so on…). Increased teaching support for CSC2058 has made such detailed interaction easier with the Software Engineers—we will see if similar arrangements can be made for the Chemical Engineers as well.

On both the Chemical and Software Engineering modules, finding an engineered solution to a sustainability problem is now one of the students' prime motivations. Gradually students are becoming aware that these are not simply modules that teach subject-specific competencies, but that they require systems-based solutions that stand up to scrutiny, and that have real potential to improve people's everyday lives. That last point is something the students are passionate about—as their comments in advisory sessions, in workshops, and through the University's feedback channels and discussion forums are making clear.

The process of changing ways of thinking is ongoing. In 2023–24, for the Chemical Engineers, we attempted to narrow the gap between the strongest and weakest performing groups, by encouraging non-engaging students to become more actively involved in workshop discussions, both within their teams and with their teachers. For this, the brainstorming exercises proposed by EWB-UK in collaboration with Think Up (Sect. 3.3.6), have proved to be effective icebreakers. In introducing such collaborative sessions, we make sure to remind the students of the benefits of group-based learning, and the importance that future employers place on a candidate's track-record of collaborating as a member of a team. We have made a point discussing and raising awareness of the role of the Chemical Engineer as a practical problem solver in the real world—ready to look beyond set-piece textbook solutions.

We have mentioned the clearer explanation of Doughnut Economics and the four lenses for the Software Engineers. In addition, visiting speakers from the local software industry have presented convincingly in guest talks on the theme of sustainable software engineering. They have pointed out the threat to the planet from the massive growth of cloud-based systems. While students were made aware of the mitigations that are currently in place or are currently being promoted as best practice, they will have been left in little doubt that the longer-term wellbeing of the planet is very much under threat, if current patterns of software-related growth and energy consumption continue. The urgent and questioning tone of such lectures encourages the students to think critically about these matters also, aware of the role that they will have to play as future industry professionals and academics.

5.4 Effective *Adaptation*

We return briefly to the matter of adapting existing modules to incorporate the theme of sustainability. One small change to the deliverables on the Software Engineering module proved particularly effective. Rather than ask only those who are going forward to the formal EWB-UK competition to produce a poster, we asked all the teams on the module to produce a poster. (The module specification does not stipulate how project work is to be delivered, so we had the freedom to do this.) The result was startling. There was such a remarkable range of well-presented, convincing sustainable solutions that, with the School's and students' support, there was enough material for a substantial awareness-raising poster display in the foyer (lobby) of Queen's Computer Science Building (Figs. 1, 2), and a satellite display (in slightly more compact format) at the end-of-term showcase for Electronics and Electrical Engineering students in a neighbouring building on campus (Fig. 3). The interest shown by students (many of whom were seeing their posters on paper for the first time) and by members of staff (who were seeing first-hand the good work on sustainability that was happening within their school) was encouraging.

In addition, the Computer Science poster display coincided with a new Arts and Sustainability Festival at Queen's (Reach'24, [64]). Liaising directly with the festival organisers ensured that the students' sustainability posters were given prominent mention during the main festival seminar—making a largely arts-oriented audience aware of a Queen's STEM department's efforts in raising awareness of sustainability. There are now plans to incorporate the Queen's/EWB-UK poster event into next year's festival programme.

6 Looking ahead

As educators, we are pleased by the emerging outcomes of 2023–24, but there is more to do.

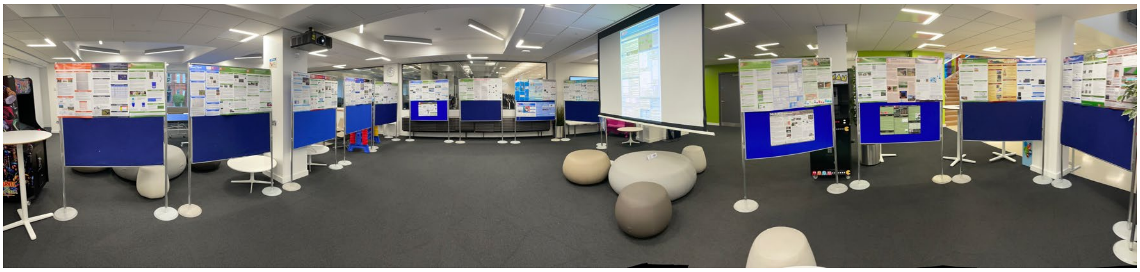

Fig. 1 The 2023–24 Software Engineering students' sustainable design posters in Queen's Computer Science Building

Fig. 2 The posters in the Computer Science Building were a source of interest for the student authors, and for those wanting to find out more

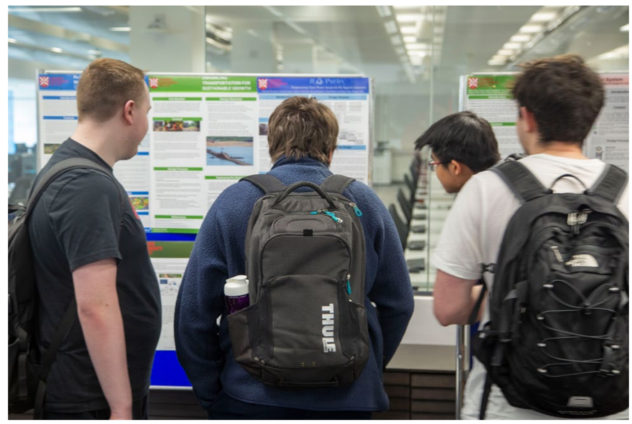

Fig. 3 Queen's staff also had an opportunity to view the student Software Engineers' posters (in compact form) at the Electronics and Electrical Engineering end-of-year showcase event

For those on computing-related pathways (which includes Software Engineering), plans are now also taking shape for a two-part sustainability hackathon, focussed specifically on local sustainability issues, open to all our software engineering and computing students, and taking place soon after the start of the autumn and spring semesters. The build-up to these events and the events themselves will lessen the 'cold sustainability start' faced by second-year Software Engineering students in week one: the hacks will let them see they are not alone—indeed, supported by a team of staff, student mentors and technology experts, they will see that they are part of something much bigger in the School and around the world.

We also need to ensure adequate feedback mechanisms, so that we can verify the extent to which our students have embraced the UNESCO competencies and can apply them elsewhere. Where one module has adopted a strategy that has worked, we will see if can be introduced on the other module as well.

We are still adding detail to our sustainability roadmap. The sustainability hacks are just one example. We hope that some of the waymarks that have helped us so far will reassure and encourage other educators: using an established challenge to start the process off; being ready to encourage and constructively critique students' first steps into sustainable, systems-based design, whatever direction they take; having, and giving them, the confidence to share their ideas with a wider audience; being prepared to adjust the balance of course content as students' understanding and commitment to sustainable development grows (and being ready to give occasional reminders of subject-specific orthodoxies, just to keep everything grounded).

Importantly, sustainability has been given a significant and very visible position in our modules, on our pathways and beyond, a subject for conversation where that conversation would not have taken place before. We hope that others will join with us in finding practical ways of tackling some of the obstacles—whether administrative, content-related or procedural—that prevent sustainable development from gaining prominence in the university curriculum. We look forward to reporting further progress in future articles.

Acknowledgements Our thanks to Engineers Without Borders UK (EWB-UK) for presenting and coordinating both the 2022-23 Design Challenge, which was set in Govan, Scotland, and (in association with Engineers Without Borders Australia) the 2023-24 Design Challenge, which is set in Pu Ngaol, Cambodia. Our thanks to the Faculty of Engineering and Physical Sciences at Queen's University Belfast for financially supporting the participation of the School of Chemistry and Chemical Engineering and the School of Electronics, Electrical Engineering and Computer Science in the Design Challenges in 2022-23 and again in 2023-24.

Author contributions Each author contributed content that is specific to the module that they taught (M.M.G., Introduction to Chemical Products and Processes (CHE1101); I.O'N., Software Engineering and Systems Development (CSC2058)). Both authors contributed content that is more generally applicable. I.O'N. edited the final draft, incorporating M.M.G.'s comments and corrections.

Funding No external funding. Faculty funding only, covering costs of participating in the*Design Challengefrom Engineers Without Borders UK in 2022–23 and 2023–24.*

Data availability This article reports the authors' experience of teaching on recent and current university courses. The work of the student team that represented Queen's at the Grand Finals of the Design Challenge in June 2023 is published with the students' agreement at https://crowdsolve.net/challenge/EfP-23/p/103, part of the Engineers Without Borders UK website for the Engineering for People Design Challenge 2022/23—UK & Ireland (https://crowdsolve.net/challenge/EfP-23); a portfolio, published by the students themselves, is available at https://neighbourhoodproject.my.canva.site/. No other data or references that identify specific student participants or their work are made available or cited in this article. No sensitive data are made available or cited in this article.

Code availability Not applicable.

Declarations

Competing interests The authors declare no competing interests.

References

1. QAA. Education for sustainable development. 2021. https://www.qaa.ac.uk/the-quality-code/education-for-sustainable-development. Accessed 14 Feb 2024.
2. Queen's University Belfast. Strategy 2030. 2021. https://www.qub.ac.uk/about/strategy/. Accessed 14 Feb 2024.
3. UNESCO. Education for sustainable development goals: learning objectives; 2017. p. 49.
4. UNESCO. Issues and trends in education for sustainable development. 2018. https://unesdoc.unesco.org/ark:/48223/pf0000261954. Accessed 2 May 2024.
5. QAA. Subject benchmark statement—computing. 2022, https://www.qaa.ac.uk/docs/qaa/sbs/sbs-computing-22.pdf?sfvrsn=ebb3dc81_4. Accessed 2 May 2024.
6. Abernethy K, Treu K. Integrating sustainability across the computer science curriculum. J Comput Sci Coll. 2014;30(2):220–8. https://doi.org/10.5555/2667432.2667464.

7. Penzenstadler, B, Betz, S, Venters, CC, Chitchyan, R, Porras, J, Seyff, N, Duboc, L, Becker, C. Everything is INTERRELATED: teaching software engineering for sustainability. In: Proceedings of the IEEE/ACM 40th International Conference on Software Engineering: Software Engineering Education and Training (ICSESEET); 2018. p. 153–62. https://doi.org/10.1145/3183377.3183382.
8. IChemE. Accreditation of chemical engineering programmes: A guide for education providers and assessors. 2023. p. 6–8; https://www.icheme.org/media/19722/university-accreditation-guide.pdf. Accessed 14 Feb 2024.
9. Engineers Without Borders UK. Engineering for people design challenge. 2024. https://www.ewb-uk.org/upskill/design-challenges/engineering-for-people-design-challenge//. Accessed 14 Feb 2024.
10. Engineers Without Borders UK. About us. 2024. https://www.ewb-uk.org/movement/about-us/. Accessed 14 Feb 2024.
11. Pargman D, Eriksson E. Exploring inner transition: expanding computing for sustainability. In: Limits. 2023. https://doi.org/10.21428/bf6fb269.22dea4ad. https://computingwithinlimits.org/2023/. Accessed 2 May 2024.
12. Peters A-K, Capilla R, Coroamă VC, Heldal R, Lago P, Leifler O, Moreira A. Sustainability in computing education: a systematic literature review. ACM Trans Comput Educ. 2024;24(1):1–53. https://doi.org/10.1145/3639060.
13. Eriksson E, Pargman D. On the inherent contradictions of teaching sustainability at a technical university. In: Hazas M, Nathan L, editors. Digital technology and sustainability. London: Routledge; 2017. p. 154–65.
14. Argento D, Einarson D, Mårtensson L, Persson C, Wendin K, Westergren A. Integrating sustainability in higher education: a Swedish case. Int J Sustain High Educ. 2020. https://doi.org/10.1108/IJSHE-10-2019-0292/full/html.
15. Murray P, Coyle EJ, Marshall S, Strachan SM, Sonnenberg-Klein J. Using vertically integrated projects to embed research-based education for sustainable development in undergraduate curricula. Int J Sustain High Educ. 2019;20(8):1313–28. https://doi.org/10.1108/IJSHE-10-2018-0198.
16. Palacin-Silva MV, Seffah A, Porras J. Infusing sustainability into software engineering education: lessons learned from capstone projects. J Clean Prod. 2024;2018(172):4338–47. https://doi.org/10.1109/CSEET.2017.15.Accessed02May.
17. Pargman, D, Hedin, B, Eriksson, E. Patterns of engagement: Using a board game as a tool to address sustainability in engineering educations. In: Proceedings of the 8th International Conference on Engineering Education for Sustainable Development; 2016. p. 302–10. https://www.researchgate.net/publication/322626504. Accessed 2 May 2024.
18. Eriksson, E, Hedin, B, Pargman, D, Hasselqvist, H, Börjesson Rivera, M. Systems thinking games in computing education—a case study. In: Proceedings of the International Workshop on Computing Sustainability Education (CompSusEd'19); 2019. p. 170–6. https://doi.org/10.1145/3401335.3401670.
19. Creswell, JW, Creswell, JD. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th international student ed.). Los Angele: SAGE; 2018.
20. Lidgren A, Rodhe H, Huisingh D. A systemic approach to incorporate sustainability into university courses and curricula. J Clean Prod. 2006;14:797–809.
21. Brundtland, G. Report of the World Commission on Environment and Development: our common future. United Nations General Assembly document A/42/427. 1987. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf. Accessed 8 May 2024.
22. Hill GM, Howe J. Sustainability of the chemical manufacturing industry—towards a new paradigm? Educ Chem Eng. 2010;5:e100–7.
23. García-Serna J, Perez-Barrigon L, Cocero MJ. New trends for design towards sustainability in chemical engineering: green engineering. Chem Eng J. 2007;133:7–30.
24. Aurandt JL, Butler EC. Sustainability education: approaches for incorporating sustainability into the undergraduate curriculum. J Prof Issues Eng Educ Pract. 2011;137(2):102–6.
25. Harris AT, Briscoe-Andrews S. Development of a problem-based learning elective in "green engineering." Educ Chem Eng. 2008;3:e15–21.
26. Favre E, Falk V, Roizard C, Schaer E. Trends in chemical engineering education: process, product and sustainable chemical engineering challenges. Educ Chem Eng. 2008;3:e22–7.
27. Montañés MT, Palomares AE, Sánchez-Tovar R. Integrating sustainable development in chemical engineering education: the application of an environmental management system. Chem Educ Res Pract. 2012;13:128–34.
28. Green Software Foundation. Opensource/Impact framework. 2023. https://greensoftwarefoundation.atlassian.net/wiki/spaces/~612dd45e45cd76006a84071a/pages/17072136/Opensource+Impact+Framework. Accessed 8 May 2024.
29. Glassey J, Haile S. Sustainability in chemical engineering curriculum. Int J Sustain High Educ. 2012;13(4):354–64.
30. Othman MR, Hady L, Repke JU, Wozny G. Introducing sustainability assessment and selection (SAS) into chemical engineering education. Educ Chem Eng. 2012;7:e118–24.
31. Engineers Without Borders. Twelfth year of the design challenge. 2022. https://www.ewb-uk.org/?s=twelfth+year. Accessed 2 May 2024.
32. Gallagher SE, Savage T. Challenge-based learning in higher education: an exploratory literature review. Teach High Educ Crit Perspect. 2023;28(6):1135–57. https://doi.org/10.1080/13562517.2020.1863354.
33. Malmqvist, J, Kohn Rådberg, K, Lundqvist U. Comparative analysis of challenge-based learning experiences. In: Proceedings of the 11th International CDIO Conference, Chengdu University of Information Technology, Chengdu, Sichuan, P.R. China; June 8–11, 2015. https://publications.lib.chalmers.se/records/fulltext/218615/local_218615.pdf. Accessed 3 May 2024.
34. Robertson, E, Strachan, S. Embedding education for sustainable development in the engineering curriculum through challenge-based education. In: Proceedings of the 8th International Symposium for Engineering Education, The University of Strathclyde; September 1–2nd 2022. Paper: 0295; https://doi.org/10.17868/strath.00082005. Accessed 2 May 2024.
35. Siller, TJ, Cook, A, Johnson, GR. Creating international experiences for first-year engineers through the EWB Australia Challenge Project. In: Proceedings of the American Society for Engineering Education 123rd Annual Conference and Exposition, New Orleans, LA, USA; 2016. Paper ID #15031; https://peer.asee.org/creating-international-experiences-for-first-year-engineers-through-the-ewb-australia-challenge-project.pdf. Accessed 2 May 2024.
36. General Assembly, United Nations. Transforming our world: the 2030 Agenda for Sustainable Development. 2015. https://sdgs.un.org/2030agenda. Accessed 14 Feb 2024.

37. United Nations Development Programme (UNDP). Sustainable development goals booklet. 2015. https://www.undp.org/publications/sustainable-development-goals-booklet. Accessed 14 Feb 2024.
38. International Telecommunication Union (ITU). Digital technologies to achieve the UN SDGs. 2021. https://www.itu.int/en/mediacentre/backgrounders/Pages/icts-to-achieve-the-united-nations-sustainable-development-goals.aspx. Accessed 14 Feb 2024.
39. QAA. Education for sustainable development. 2021. p. 34. https://www.qaa.ac.uk/the-quality-code/education-for-sustainable-development. Accessed 14 Feb 2024.
40. Eckhardt J, Vogelsang A, Fernández DM. Are "non-functional" requirements really non-functional?: an investigation of non-functional requirements in practice. In: ICSE '16: Proceedings of the IEEE/ACM 38th International Conference on Software Engineering (ICSE), Austin, TX, USA; 2016. p. 832–42. https://doi.org/10.1145/2884781.2884788.
41. AWS. Sustainability as a non-functional requirement. 2024. https://docs.aws.amazon.com/wellarchitected/latest/sustainability-pillar/sustainability-as-a-non-functional-requirement.html. Accessed 14 Feb 2024.
42. AWS. Sustainability pillar—AWS Well-Architected Framework. 2023. https://docs.aws.amazon.com/wellarchitected/latest/sustainability-pillar/sustainability-pillar.html. Accessed 14 Feb 2024.
43. Liberty IT. Advertisement for Senior Software Engineer Belfast. 2023. https://careerslit-libertymutual.icims.com/jobs/59147/senior-software-engineer---java/job. Accessed 4 July 2023.
44. Easterbrook, S. From computational thinking to systems thinking: a conceptual toolkit for sustainability computing. In: ICT4S 2014: Proceedings of the 2nd International Conference on ICT for Sustainability, Stockholm, Sweden; 2014. p. 235–44. https://doi.org/10.2991/ict4s-14.2014.28.
45. University and College Union. UCU climate and sustainability CPD offering. 2023. https://www.ucu.org.uk/article/12096/UCU-climate-and-sustainability-CPD-offering. Accessed 14 Feb 2024.
46. Raworth K. Doughnut economics: seven ways to think like a 21st-century economist. New York: Random House Business; 2017.
47. Raworth K. So you want to downscale the Doughnut? Here's how. 2020. https://www.kateraworth.com/2020/07/16/so-you-want-to-create-a-city-doughnut/. Accessed 14 Feb 2024.
48. Pope Francis. Let us dream: the path to a better future. New York: Simon and Schuster; 2020. p. 63–4.
49. Time. Amsterdam is embracing a radical new economic theory to help save the environment: Could it also replace capitalism? 2021. https://time.com/5930093/amsterdam-doughnut-economics/. Accessed 14 Feb 2024.
50. Kennisland. About KL: Kennisland researches and designs social progress. 2024. https://www.kl.nl/en/about-kl/#waarom. Accessed 14 Feb 2024.
51. Doughnut Economics Action Lab (DEAL). About doughnut economics. 2024. https://doughnuteconomics.org/about-doughnut-economics. Accessed 14 Feb 2024.
52. Gokhale AA. Collaborative learning enhances critical thinking. J Technol Educ. 1995;7(1):22–30. p. 22.
53. Johnson RT, Johnson DW. Action research: cooperative learning in the science classroom. Sci Child. 1986;24:31–2.
54. Totten S, Sills T, Digby A, Russ P. Cooperative learning: a guide to research. New York: Garland; 1991.
55. Gokhale AA. Collaborative learning enhances critical thinking. J Technol Educ. 1995;7(1):22–30. p. 30.
56. Institute for Collaborative Working (ICW). Advancing collaboration to make good things happen. 2024. https://www.instituteforcollaborativeworking.com/. Accessed 14 Feb 2024.
57. Think Up. Conceptual design for structural engineers (online)—notes and resources. https://thinkup.org/conceptual-design-for-structural-engineers-online-notes-and-resources//. Accessed 14 Feb 2024.
58. Newby T. Quoted in: Engineers Without Borders UK: Designathon; 2020. https://www.ewb-uk.org/wp-content/uploads/2020/01/Designathon-Chapter-presentation.pdf. Accessed 14 Feb 2024.
59. Doughnut Economics Action Lab (DEAL). 'Doughnut unrolled'—now in five languages. 2023. https://doughnuteconomics.org/news/48. Accessed 14 Feb 2024.
60. Queen's University Belfast. Course catalogue. 2024. https://qsiscat.qub.ac.uk/. Accessed 4 May 2024.
61. Campbell L, Dominicus AW, Cazar J, Andrews M, Loenan A. Neighbourhood: a self-sustaining solution for asylum seekers. At: Engineers Without Borders UK/Crowdsolve. https://crowdsolve.net/challenge/EfP-23/p/103. Accessed 14 Feb 2024.
62. Engineers Without Borders UK/Crowdsolve. Projects. 2023. https://crowdsolve.net/challenge/EfP-23/p. Accessed 14 Feb 2024.
63. Andrews M, Campbell L, Hayashi, M, Loenan A, Cazar Rubio JI, Dominicus AW, Wilson P. Neighbourhood: a self-sustaining solution for asylum seekers. https://neighbourhoodproject.my.canva.site/. Accessed 14 Feb 2024.
64. Queen's University Belfast. REACH '24. https://www.qub.ac.uk/events/whats-on/listing/festivalofartsandsustainabilityatqueens.html. Accessed 2 May 2024.