TEACHING, ASSESSING AND OPERATIONAL SUSTAINABILITY IN UCL'S CHEMICAL ENGINEERING CAPSTONE DESIGN PROJECT

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Abstract: Sustainability is meeting the needs of the present without compromising the future, as set out in the UN sustainable development goals. This paper outlines how sustainability is embedded both technically in the various aspects of the UCL third-year chemical engineering capstone design project, and in the design, delivery, and assessment of the module. The project brief necessitates the consideration of the environmental impact of the design in a manner consistent with that set out by professional bodies such as the IChemE. In the delivery of the module, learners engage in individual and collaborative learning, undertake formative assessments, provide, and receive formative feedback and are empowered to practise sustainable self-learning. Sustainable assessment is promoted using a single rubric that allows learners and educators to gain familiarity with course expectations, ensures consistency in feedback given in summative assessments and enables learners to attain higher levels in the rubric in subsequent submissions. Sustainable delivery and self-learning allow both learners and educators to develop skillsets relevant to their career development. Learners' perspectives showed the majority of learners were aware of the importance of sustainability, felt empowered for future self-learning and felt that they applied their knowledge of sustainability, although they highlighted sections where this could be clearer. Reflecting on this, educators could signpost more clearly how sustainability informs technical decisions in these sections, while being mindful of balancing this with giving learners challenging yet achievable projects within the constraints of delivering the module and meeting all learning outcomes.

Keywords; Sustainability, Capstone design project, Assessment, Administration.
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1. INTRODUCTION

Awareness and acknowledgement of the importance of a sustainable future is evermore at the forefront of society. The United Nations (UN) recognises that a wide-ranging approach considering not only clean energy and water, but which also tackles deprivations, such as poverty, inequalities and promotion of quality education is required in order to achieve a sustainable future that deals with climate change and its impact. This is encompassed in the 17 UN Sustainable Development Goals (SDGs) (UN, 2022) and the '5P' (people, planet, prosperity, peace, and partnership) commitments through which they are achieved. The Institution of Chemical Engineers (IChemE) also identifies in their paper, Chemical Engineering Matters (IChemE, 2016) the role chemical engineering plays in addressing global challenges such as energy, water and food as well as health and wellbeing. Furthermore, in their accreditation guidelines they identify sustainability learning outcomes that must be met by learners on an accredited chemical engineering degree programme (IChemE, 2021).

This paper examines the approach adopted thus far in the third-year capstone chemical engineering design project at UCL where sustainability is integral not only in terms of the technical content, such as the chemical process being designed and tasks performed by learners but also in module design, both from a learner and educator perspective, and assessment. The module design is carefully considered to best achieve the learning outcomes whilst acknowledging and managing constraints of the learners and educators involved. The project brief ensures that sustainability is a key consideration throughout the project, in line with industry best practice (IChemE, 2022), whilst encouraging creative solutions.

In this paper, Section 2 considers the structure of the module, and how sustainability is embedded in the capstone design project brief as well as in the various stages of the project. Section 3 examines how assessments are conducted sustainably from the perspective of both learners and educators, highlighting the importance of formative assessments and how educators use a single rubric for assessments throughout the module. In Section 4, four dimensions of sustainable self-learning as set out by Ben-Eliyahu (2021), i.e., *renewing and relearning*, *independent and collaborative learning*, *active learning* and *transferability* are considered, together with examples of how the design project enables learners meet them. Section 5 examines how the core teaching team work together with other academics across the department to deliver the module sustainably, both pre- and post-pandemic. In Section 6, the learner perspective is presented through the results of an anonymous Mentimeter survey and are further reflected upon in Section 7. Finally, Section 8 brings together the overall conclusions of the paper.

2. MODULE DESIGN AND PROEJCT BRIEF

The capstone chemical engineering design project at UCL brings together knowledge acquired in modules taken by learners in the first 3 years of their undergraduate programme. Learners are seen as active learners taking ownership of their work while educators provide both technical and non-technical support throughout the project. This is achieved as learners take on the role of a contractor company completing a project to develop the design of a chemical plant according to a project brief provided by the client company, the role taken by educators.

The design project has 5 stages running across two academic terms – Appraise, Select, Unit Design I (UDI), Unit Design II (UDII) and Present. Specific safety studies are embedded throughout the different stages of the project. Appraise and Select are the group stages taking place in term 1 with a focus on conceptual and preliminary design. In term 2, as part of the UDI and UDII stages, learners develop a detailed process design of a specific unit as individual deliverables. In the Present stage, learners present a summary of their individual designs from the UDI and UDII stages to assessors. Throughout the design project, there are weekly 'Client' meetings with a supervisor which have a strong focus on learner support, coaching and guidance. During the group stage, the supervisor provides technical content and project management support whereas during the individual stages, the focus is on aiding learners with the project management of their individual tasks and monitoring their progress. There are expert technical sessions throughout the year providing additional support as appropriate. The design project in general is formulated to be challenging but rewarding as it allows the learners to develop skillsets that they can apply to overcome future challenges.

Sustainability is incorporated in the chemical engineering capstone design project through the development of a project brief that encourages learners to consider raw materials, products, waste, energy consumption, plant location, energy resources and green-house gas emissions. Incorporation of sustainability in this manner aligns with the latest trends in industry and best practices put forward by professional bodies, such as the IChemE Sustainability Hub (IChemE 2022). During conceptual design in the Appraise stage, learners investigate various design options and then recommend a process route, products, raw materials and energy resources. In terms of sustainability tasks, learners consider the impact of their recommendations on various stakeholders through a power/interest matrix and examine the influence of external factors by performing a PESTLE (political, economic, social, technological, legal and environmental) analysis. In the preliminary design stage in Select, learners perform a gate-to-gate Life Cycle Analysis (LCA) and reduce energy consumption of their design through an energy integration study where they consider how energy generated at various points within the process can be used to provide energy elsewhere in the process. Throughout the module and the various deliverables, learners gain a wide range of skills that prepare them for their future roles.

3. ASSESSMENT

In this section a variety of steps adopted thus far to promote sustainable assessment from both a learner and educator perspective, incorporating principles as outlined by Boud (2000) such as formative feedback and the ability to extend learning to future situations, are outlined. For learners, there are various opportunities for formative feedback. In the initial group stage of the project, learners perform practice tasks that align with the intended learning outcomes and assessment criteria. Learners receive formative feedback from educators which include verbal formative feedback in tutorial sessions and written formative feedback in the form of 'Frequently Asked Questions' via forum posts in the virtual learning environment (VLE). There are also opportunities for peer-to-peer formative feedback. For example, learners critique posters that they have sourced to help inform themselves of how to develop a technical poster - a form of assessment that they complete in the Appraise stage. This is then discussed with an educator in a tutorial session. Furthermore, by working in teams in the initial stages of the project, learners have the opportunity to provide peer feedback on team submissions. At the end of the second group stage of the capstone design project learners complete a peer assessment reflecting on the contributions of themselves and their peers in the Select stage of the project. As discussed in Biggs and Tang (2011) formative feedback enables learners to move into the formative assessor role themselves, enabling them to critically reflect on the quality of their own work as they move into the individual stage of the project. Furthermore, these activities provide them with the confidence to self-assess in other modules and beyond the context of higher education.

The same assessment rubric, which covers varying levels of complexity depending on the type of work that learners are performing, describes how different levels of achievement will be measured for all group and individual assessments. This rubric, which includes guidance and explanatory notes, is made available to learners at the beginning of the module and can be referred to, throughout the duration of the course via the virtual learning environment (VLE). It is also referenced in formative feedback and key words from the rubric are used in qualitative feedback provided to learners in summative assessments. By using the same assessment rubric throughout

the duration of the course both learners and educators gain familiarity with expectations and learners can attain higher levels in the assessment rubric in later submissions following feedback in earlier assessments. Furthermore, ensuring assessment consistency is key in this complex coursework-based module where assessment is performed typically by a core teaching team of 4 or 5 and can extend to more assessors depending on the specific task and type of assessment. This is achieved through application of the rubric in initial alignment marking. Assessors then discuss and share formative feedback on expectations amongst themselves, aligning expectations before moving on to assess deliverables from the entire cohort. Based on experiences of assessment within the design project module, assessors can then extend and apply these learnings to future assessment situations.

4. SUSTAINABLE SELF-LEARNING

Learners should be change-ready and engage in sustainable self-learning through *sustained enquiry-based learning* (Khan & O'Rourke, 2005) in order to meet the intended learning outcomes (ILOs) of the module. The four aspects to sustainable self-learning proposed by Ben-Eliyahu (2021) are met on the capstone design project as follows:

4.1 Renewing and relearning: learning and relearning are viewed as renewable resources and part of lifelong education. In previous modules, learners gain experience in the design of reactor and separation units, use of process modelling and computational tools and in conducting LCAs. The design project provides a platform for adapting and applying this previous knowledge to more complex and open-ended problems with limited or contradictory information. Learners can reflect, assess their own knowledgebase and determine what is missing in order to make and justify their decisions, making them responsible for their learning and relearning.

4.2 Independent and collaborative learning: the design project is split into group and individual tasks. Learners need to recognise that learning occurs in an *autodidactic* (learning by oneself) fashion and/or as part of a community of both learners and educators and understand when and how to switch between both while seeking help as needed (Karabenick & Gonida, 2018). In the group stages, learners work together and support each other in both the technical and soft skills including project management before going on to work individually on the detailed process design. During both stages, educators provide expert helpdesk sessions, and enable a community of sustainable learning.

4.3 Active learning: is being intentional about learning and measuring one's progress, and according to García-Jiménez et al (2015), feedback and *feedforward* loops are crucial. Learners in a feedback loop assess their own progress, identify existing gaps and determine modifications to be made for effective learning. A feedforward loop involves forward thinking by the learner. Based on previous skills and problem-solving strategies gained from previous activities, learners anticipate, evaluate and calibrate their future learning in a proactive manner. In either case, learners begin by self-evaluating and/or seeking and receiving guidance during coaching sessions and on VLE forums from educators and peers on the project brief or specific problems they are facing, much as they would in a typical client-contractor setting in industry.

4.4 Transferability: is the application of familiar strategies or processes in a different context or setting (Tractenberg, et al., 2017). The design project builds on *Scenarios* (smaller week-long mini design projects completed in the first two years of the degree programme), which furnish learners with helpful skillsets that are directly transferrable to the design project which runs for an entire academic year. Project planning through the development of a spider diagram which is conducted and repeated at the start of different stages of the design project is an example of how learners transfer skills across different stages of the module. These skills are transferable beyond the design project and can be repurposed for use and reuse in the future workplace.

5. SUSTAINABLE DELIVERY

The capstone chemical engineering design project is delivered by a core team of typically 4 or 5 teaching academics who have experience and expertise in education, industry, computational tools, safety and research. They lead on the planning, delivery, assessment, and communication with the learners and are the main point of contact and interaction with the learners. The core teaching team are supported by academics across the department who provide additional discipline specific support in areas such as in reactor or separation design or further computational tools, as and when needed, as well as advisory roles in planning, delivery, and assessment.

To enhance the continuous professional development of the core design teaching team, different team members lead on different aspects of the project. Furthermore, the core design team members will swap with or train-up other team members in different topic advisory roles so that every member of the team becomes more familiar with different components of the course and can lead in different areas. The assignment of the various roles among the core design team is typically pairwise to ensure that there is a backup should a member becomes unavailable. This ensures sustainability in the delivery of the module – a strategy that facilitates continuity and maintains efficiency of the module delivery in the face of uncertainty such as during the COVID pandemic.

Before the COVID pandemic, teaching of the module was entirely on campus and in 2020/21 following the outbreak of the pandemic, teaching and project meetings were held entirely online. In the 2021/2022 academic year, hybrid delivery was adopted which combined the social aspect of on-campus teaching that the learners missed in the previous year with some of the identified advantages of virtual delivery. This way, the project meetings were face-to-face, with virtual participation supported where needed, while technical helpdesk sessions were online which allowed all participants to listen and join in with discussions while allowing flexibility in delivery.

6. LEARNER PERSPECTIVE

To obtain the learners' perspective of sustainability in the capstone design project, an anonymous survey using Mentimeter ™ was conducted during the last Client-contractor meeting. To ensure that the necessary ethical consideration steps were taken, UCL's Research Ethics Office were consulted before it was conducted. Learners were notified of the survey in advance, informed of its purpose (i.e., the development of the module and for this conference paper) and informed that it was entirely voluntary and anonymous. The four survey questions varied in type, including binary, scoring and open-ended ones, to robustly capture the learners' views. The survey with each

team was conducted in a virtual meeting via a well-known environment and managed by their project supervisor to ensure that learners were comfortable when submitting their comments and that a high response rate (n=73 out of 103 learners) was achieved so that responses were as representative of the cohort as possible. Initially considering the module overall, it can be seen from Figure 1 that the learners feel that they applied their knowledge of sustainability well in the

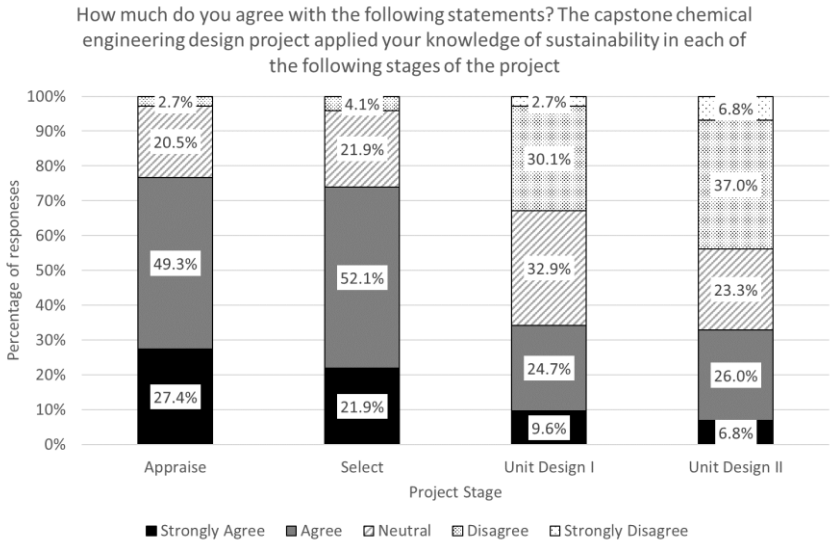

Figure 1: Application of sustainability knowledge during the stages of the project (n=73).

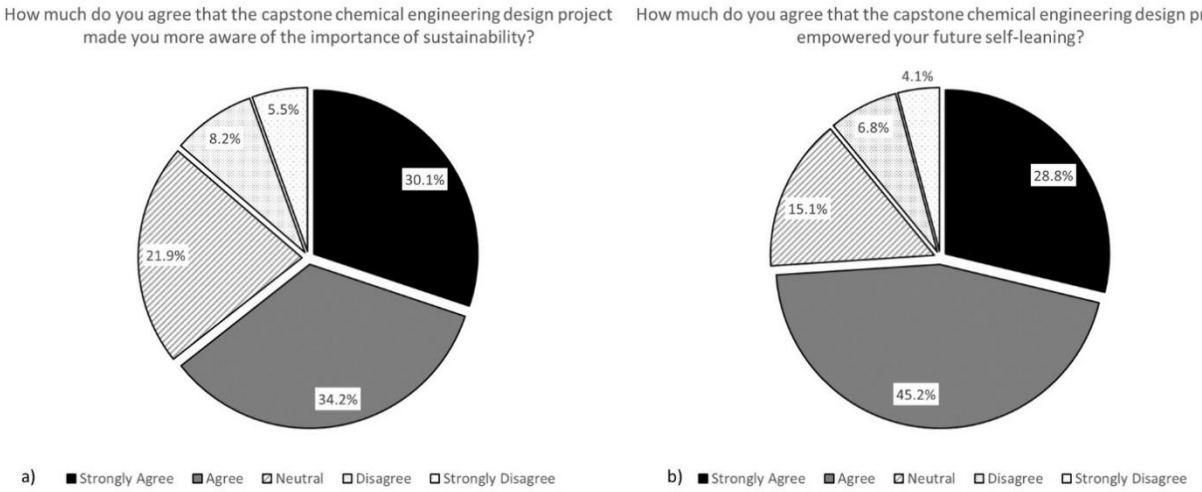

Figure 2: a) Has the module improved learners' awareness of the importance of sustainability (n=73), and b) has the module empowered future self-learning (n=73).

Appraise and Select stages with 76.7% and 74.0% selecting either *agree* or *strongly agree* respectively. This percentages drop to 34.3% and 32.8% when considering Unit Design I and II respectively, when learners are individually conducting the detailed unit design. Figure 2a shows that 64.3% of learners think that having completed the capstone design project they are more aware of the importance sustainability whilst Figure 2b shows an overwhelming majority of 74.0% of learners agreed that the capstone design project had empowered their future self-learning. The

learners' perspective on whether enough importance had been placed upon sustainability relative to all other aspects of the design project was captured by asking whether they *thought that sustainability was weighted (with marks) significantly enough.* A notable majority of 82.2% (n=73) thought it was and multiple learners commented that sustainability aspects should stay as they are since *it has a good balance*. It is particularly encouraging that the learners have not only developed and applied their knowledge of sustainability but have also improved their understanding of its importance, approve of the module design, and feel empowered in their own self learning.

7. REFLECTIONS

This section builds on the quantitative results presented in section 6, and considers additional learner comments from the survey, which were in response to the final open-ended question asking *if there were any other comments and if there was any aspect / activity that should be either stopped, started or remain the same*. The learner consensus was that the module design and this year's project brief worked very well and that the format and sustainable analyses conducted should *remain the same*. It was pleasing to read one learner comment that they *...appreciated the fact that sustainability could be built upon from the previous task so we could further develop our understanding and ideas*. The LCA was identified by a significant number of learners as *useful*, *informative*, and *highly beneficial*. One learner commented the *LCA is a very good aspect in the project and should remain the same if not be more high[ly] weighted*. The in-person walkthroughs of specific aspects of LCA were considered particularly useful in supporting learners conduct their own. Further learner comments that align with the responses shown in Figure 1, noted that *sustainability could be encouraged more in Unit Design I* and that *some more elements of sustainability [could be incorporated] in Unit Design II*. While there is greater emphasis placed on sustainability during the group stages (Appraise and Select), sustainability is still a key aspect of the detailed design. As a result of this learner feedback, clearer signposting of how sustainability is tied to the technical decisions made during detailed design stages is needed. Other interesting suggestions from learners for new areas for module development included *the circular economy within engineering applications and industrial settings* and *sustainability vs profit*.

This feedback will be considered as part of ongoing module evaluation. The comments allow reflection on one of the main challenges educators encounter on the design project: with limited time and other learning outcomes to meet, how do we ensure the project is challenging yet achievable and with enough technical detail to ensure that learners can conduct similar analyses in the future? The design project cannot and should not require or fully enable learners to conduct a detailed industry-level design but, should prepare them for this by requiring the demonstration of their knowledge and developing self-learning to improve further.

8. CONCLUSION

The UN sustainable development goals serve as motivation for incorporating sustainability within all spheres of human endeavour. The importance of the technical concept of sustainability on the capstone design project, the practicality it brings to the design, delivery and assessment of the module and how it engages learners in sustainable self-learning have been set out in this paper. The module design and project brief ensure that learners have opportunities to be intentional about sustainability in their design, such as conducting an LCA. Learners work in teams to support one

another's learning in the initial stages of the project life cycle before performing the detailed design individually. They are encouraged to assume formative assessor roles, by providing and receiving formative feedback from educators and peers alike on formative tasks. Educators ensure sustainable assessment by using a single rubric and performing initial alignment marking with opportunities for formative feedback, which ensures consistency in applying the rubric amongst multiple assessors across the cohort. Furthermore, as part of sustainable delivery strategies, the core teaching team take turns to lead on different aspects of the project and are supported in specialist knowledge areas by the wider academic team in the department. Critical to learners meeting the learning outcomes of the module is the need for sustainable self-learning enabling them to apply the skills learnt in future roles. Quantitative results from the student survey showed that an overwhelming majority felt that their experience on the capstone design project empowered their future self-learning. Overall, it can be concluded that incorporation of sustainability into the module, not only in terms of technical content but also in terms of module design has been successful. Moving forward, educators could consider clearer signposting to learners of sustainability within individual process unit design stages and incorporating other interests from learners such as introducing the circular economy model. A careful balance must however be struck between giving learners challenging yet achievable projects within the constraints of delivering the module and meeting overarching learning outcomes.

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