

## **Embedding Enterprise Focused Education for Sustainable Development: Lessons from undergraduate student experiences in product design**

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### **Abstract**

As the world begins to grapple with numerous sustainability challenges such as zero waste, dematerialisation, sustainable consumption, zero emissions and a fair society, product design students must be educated on these key sustainability concepts. In industry, product designers are embedding sustainable values and processes within their everyday design practice when developing new products and services. The Nottingham Trent University (NTU) Sustainability in Enterprise (SiE) project is working to support local businesses within the Greater Nottingham area to help improve their environmental performance across four key areas: People, Products, Processes and Premises. We present a case study whereby for the first time, first-year BSc Product Design students at NTU act as design consultants during a focussed "Sustainability Week" to support local enterprises. During Sustainability Week, teams of BSc Product Design students undertook a project alongside a Nottingham, UK, based chocolate shop and bakery by reviewing their existing product line and packaging solutions. Students selected an existing packaging solution and designed new solutions associated with less and alternative materials for their products. Students learnt through discovery, experience, experimentation, research, practical doing, and other forms of experiential learning. During sustainability week, qualitative data through observation was collected to analyse the development of the sustainability week. Data from students was gathered at the end of sustainability week to gain insight into their learning experience. We collected quantitative and qualitative data to assess the students' experience and the project through a survey questionnaire. A mixed-methods approach was used to analyse the data. The development of Sustainability Week has improved student knowledge on sustainable product development. Delivered sessions promoted knowledge acquisition, skills development, and improved attitudes towards global issues, i.e., Responsible Consumption & Production (SDG12). Having attended Sustainability Week, a large proportion of the student cohort suggested that this helped improve their understanding of sustainable concepts within product design. Students submitted a physical model and two presentation boards to communicate their proposed new solutions demonstrating through their project outputs and vocational taught sessions improved knowledge on life cycle assessment, methods of communicating sustainable product solutions through design

sketching and a basic understanding of calculating a products carbon footprint. Also, students improved their basic knowledge of designing for longevity, sustainable design considerations and material selection using material databases. Based on the developed Sustainability Week, the success and positive feedback from students resulted in its integration into the BSc Product Design curriculum, with further improvements planned to enhance Sustainability Week in the future. The implementation of sustainability week in the BSc Product Design curriculum will shape new sustainability-conscious product designers and professionals who have insight into sustainable product development whilst being equipped with dedicated tools/learnings to enhance their professional expertise.

**Keywords:** University-industry collaboration, Higher education institutions, Eco-design, Undergraduate teaching, Sustainability education, Curricular innovation.

## **1. Introduction**

In recent years the demand for sustainability to be fully integrated as a core concept/topic within product design and design engineering education has continued to grow globally (Ramirez, 2006; Ramirez, 2007; Watkins & Lofthouse, 2010; Seay, 2015; Ashour, 2020). It has been recognised that sustainable product designers require additional knowledge and skills beyond traditional design education, thus highlighting that sustainable product design education should be fully integrated into the core design curriculum to have an impact (Watkins et al., 2021). Sustainable product design is an essential topic that needs to be taught across the product design and design engineering sector; however, it requires specialist knowledge and an in-depth understanding to deliver this successfully/effectively. Future designers and engineers must learn how to address sustainability's triple bottom line, i.e., addressing financial, environmental, and social goals (Oehlberg, 2010). Teaching sustainability alongside enterprise and entrepreneurship also offers a unique opportunity to provide an enhanced educational experience to students across the sector, thus enriching their educational experience.

Education for sustainable development has been addressed in scientific and grey literature in the last years. In a recent study, (Lozano et al., 2017) conducted a literature review to link pedagogical approaches adopted in Higher Education Institutions (HEI) and how they may affect sustainability competencies. For instance, systems thinking is a competence that underpins understanding the interlinkage issues that underpin sustainability problems. According to the framework by Lozano et al (2017), system thinking could be fostered by universal approaches such as case studies, mind and concept maps and project and/or problem-based learning. At the same time, these authors highlight that systems thinking can be nurtured through environmental education, e.g., eco-justice and community and place-based environmental education.

With a topic such as sustainability, it is important that students learn in an environment conducive to exploring their beliefs and values in relation to the topic. This type of learning is best conceived through experiential learning and is best facilitated by a process that allows students to draw out their beliefs and ideas to be examined, tested, and integrated with new, more refined ideas (Passarelli and Kolb, 2012).

Teaching sustainability through project-based learning and in the context of experiential learning has also been shown to provide positive experiences for product design (Green, 2011) and engineering students when considering new product development (Zancul et al., 2017). Embedding sustainability into design/engineering education has been a topic of discussion in recent years (Humphries-Smith, 2007; O'Rafferty, 2008; Watkins & Lofthouse, 2010; Watkins et al., 2021), with academics identifying that more sustainability focussed education should be embedded within the curriculum.

NTU's vision is to create the university of the future, as such one of the six key strategies is to "Embrace Sustainability" (NTU, 2022a). This is also a core research theme which aims to bring academics and industry together to explore/influence low carbon technologies, sustainable consumption, green mobility, and government policy to improve the future of our planet (NTU, 2022b).

Although sustainability is a key strategic theme at NTU, it is important to recognise that within many of NTU's themes, creating links and connecting with industry/enterprise is critical, especially within the education context. 'Therefore, moving forward in today's economic climate, students must engage with industry and enterprise as early as possible in their education in the higher education setting. By engaging with stakeholders and industrial sector experts, enterprise focussed education enables students to experience life beyond the traditional learning setting. At the same time, previous studies have shown the valuable benefits of students' insights into industrial practices (Piekarski et al., 2019). Following the UK QAA 2018 guidance, NTU has identified that all students should have an opportunity to engage with enterprise and entrepreneurship within their subject of choice (Advance HE, 2019).

The 2018 European Entrepreneurial Competence Framework, which also informs the QAA guidance, encourages embedding enterprise within the curriculum. McCallum et al (2018) has also identified that entrepreneurship capability is a core competence for life. It is relevant to personal development and fulfilment whilst also contributing to progression in employment and initiating new ventures ranging from community campaigns and social enterprises to new start-up businesses. Jones (2018) also identifies an increasing demand for entrepreneurship education across all levels of education globally, thus suggesting a need for pedagogy for entrepreneurship across all teaching and learning contexts.

At NTU, the Sustainability in Enterprise (SiE) project partly funded by the European Regional Development Fund (ERDF) aims to combine sustainability and enterprise together. The SiE project supports small and medium-sized enterprises (SMEs) in Greater Nottingham to reduce their carbon emissions. The SiE project blends sustainability and enterprise/entrepreneurship to provide specialist knowledge and skills in sustainable business operations, building management, product design, and employee engagement. The SiE project also provides support in multiple ways, including offering a student sustainability consultancy from two schools at NTU: the School of Architecture, Design, and the Built Environment (ADBE) and Nottingham Business School (NBS). While NBS has a specific module related to the SiE project that students can opt into to support SMEs, ADBE is still in the early stages of integrating sustainability-related skills into its curriculum.

Sustainability-related skills are currently still added in a non-systematic way within ADBE. Thus, the SiE project provided funding from NTU and the ERDF to support ADBE's journey into integrating sustainability education more systematically into the curriculum. This paper shows how sustainability-related skills were integrated into the BSc (Hons) Product Design curriculum at Level 4 NQF (1<sup>st</sup> year undergraduate education). Students supported an SME in reducing its carbon emissions by offering alternative packaging alternatives. It enhanced students' education on sustainability and allowed first-year students to gain experience in a work-related project, offering the opportunity of a site visit and interaction with a business. The project was set up to help businesses fully understand their current carbon emissions and identify effective carbon reduction measures. Subsequently, the project also offers financial support to help businesses act on carbon after enrolling in the scheme and conducting a project (NTU, 2022c).

Within the product design sector, the SiE project also offers a product design consultancy whereby commercial product design consultants offer a wealth of design experience to help reduce the carbon impact associated with products or packaging. Services available include an independent carbon footprint of a company's existing products via a lifecycle analysis, initial research into the design challenges within a business and market context, design consultancy focused on waste reduction and a second lifecycle analysis of a redesigned product to quantify the associated carbon reduction (NTU, 2022c). The product design consultancy resources are also delivered in collaboration with students from ADBE, with concepts taught within specialist sessions.

Collaborating with the SiE project has allowed students to gain their first experience of working with a real-life client in an enterprise setting, whilst also embracing sustainability and sustainable design principles. Throughout this paper, insights are provided on the development of sustainability week, providing understanding, reflection, and student feedback from an end-of-project survey. Finally, recommendations are presented on how to adopt further sustainability-related product design education informed by enterprise for other courses and institutions across the design and built environment sector.

## **2. Methods**

Thirty-seven students split into ten groups of three to five. Each group was set the design challenge of redesigning an existing packaging solution for a female-led chocolate shop and bakery in Nottingham, UK. The outcome needed to be a packaging solution associated with the use of less materials or materials with less environmental impact. The student groups were required to explore the materials used for the existing packaging solutions and the ease of use and assembly of the packaging. It was also crucial that the capabilities of the mass manufacturability of the current and future packaging solutions were reviewed.

A key aspect of the design challenge was adjusting the packaging design and materials whilst maintaining the company's identity. Students were required to seamlessly implement the brand values of the female-led chocolate shop and bakery into any designed packaging solution, especially considering the product

range focusses on lovingly hand-painted artisan chocolates and deliciously indulgent bakery treats. The brand's personalisation needed to be conveyed through any redesigned

packaging whilst balancing the sustainability aspirations. Critically, the students were required to ensure any product solution adhered to a more sustainable solution, when compared to the original product.

A traditional design sprint methodology approach typically used in industry was adapted which to tackle the business problems allowing the students to complete the design challenge within the sustainability week time scale. In this case, the student cohort were taken through a streamlined design thinking-based process to uncover insights, prototype an idea, and test a solution. A design sprint is a flexible product design framework which is often used by design teams to improve the likelihood of producing a successful solution; this is often a product or service (Banfield et., 2015).

Design sprints are used to solve big problems and test new ideas. For this to be successful, a range of elements from the design process are utilised; scientific methods are combined with design activities in combination with philosophical viewpoints and perspectives. Knapp et al (2016) presents a structure/framework whereby a range of focussed activities are utilised to allow successful design sprints to be completed within just five days. Integrating design sprints into the classroom or a design studio is a significant challenge, especially for first-year product design students who have only just started their design education journey and therefore have only begun to embrace the design studio culture and compliance with structured design processes.

Integrating design sprints into classrooms as well as exploring new active learning tools for project- based learning has been successfully utilised in various sectors ranging from human computing, UX/UI design, engineering, and industrial design (Knapp et al., 2015; Ferreria & Canedo, 2020; Ferreria & Canedo, 2019). Many researchers have identified that design sprint activities must be run in a timely manner in order to rapidly focus product innovation to drive more valuable outcomes (Ferreria & Canedo, 2019). The sustainability week design sprint activity schedule is presented in Figure 1.



## BSc Product Design Y1 - Sustainability Week Schedule



TIME	06/12/21 MONDAY	07/12/21 TUESDAY	08/12/21 WEDNESDAY	09/12/21 THURSDAY	10/12/21 FRIDAY
9:00 - 9:30	PROJECT LAUNCH	R1 CAD LIFE CYCLE ASSESSMENT	R2 GROUP WORK ON PROJECT	SUSTAINABLE DESIGN LECTURE	DESIGN TO LAST LECTURE
9:30 - 10:00	COMPANY SITE VISIT (1 PERSON PER GROUP)	R3 SUSTAINABILITY PROJECT DESIGN	INTRODUCTION TO MATERIAL DATABASES	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	GROUP SELF DIRECTED STUDY & PROJECT COMPLETION
10:00 - 10:30	PRODUCT & PROBLEM IDENTIFICATION RESEARCH ACTIVITIES	SUSTAINABILITY PROJECT SKETCHING	DESIGN IDEA GENERATION & GROUP TUTORIALS	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	
10:30 - 11:00		CAD LIFE CYCLE ASSESSMENT			
11:00 - 11:30	LUNCH	LUNCH	NO SESSIONS SPORTS & SOCIETY AFTERNOON	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	
11:30 - 12:00					
12:00 - 12:30	SUSTAINABILITY & CARBON EMISSIONS LECTURE	GROUP WORK ON PROJECT	NO SESSIONS SPORTS & SOCIETY AFTERNOON	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	
12:30 - 13:00					
13:00 - 13:30	GROUP RESEARCH & TUTORIAL SUPPORT	GROUP WORK ON PROJECT	NO SESSIONS SPORTS & SOCIETY AFTERNOON	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	
13:30 - 14:00					
14:00 - 14:30	DAY 1 WRAP UP & GROUP NEXT STEP PLANNING	GROUP WORK ON PROJECT	NO SESSIONS SPORTS & SOCIETY AFTERNOON	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	
14:30 - 15:00					SUSTAINABILITY PROJECT SKETCHING
15:00 - 15:30	PROJECT SUBMISSION	GROUP WORK ON PROJECT	NO SESSIONS SPORTS & SOCIETY AFTERNOON	GROUP TUTORIALS, PROJECT GUIDANCE & GROUP SELF DIRECTED STUDY	
15:30 - 16:00					CAD LIFE CYCLE ASSESSMENT

\* One member from each of the 10 groups was nominated to visit the industrial collaborator to conduct primary research.

\*\* R1/R2/R3 - Rotations of sessions on Tuesday skills day.

Figure 1. Sustainability Week Overview Schedule.

In the adapted design sprint approach, a variety of lectures, workshops, and short research and design activities were integrated into a structured week whereby the students' groups were able to redesign an existing packaging solution whilst learning and adopting sustainable design principles. Each day has a structured set of activities; throughout the week research, design sketching, computer-aided design (CAD), material database exploration, product development and modelling and final design realisation/presentation was completed (Figure 1).

Following the completion of sustainability week, an online survey with open and close-ended questions was created based on previous work on learning and teaching sustainability in higher education (Sandri, 2014). The survey was distributed using Microsoft Forms. It was also designed to collect student demographic data for suitable results analysis. Participation in the survey was entirely voluntary and was sent to the student cohort to ascertain their understanding of the topic and their experience of sustainability week. All quantitative questions utilised within the survey were measured using a 5-point Likert scale. The survey comprising of twenty-one questions aimed to establish the following:

- Student interest on the topic of sustainability prior to the commencement of sustainability week.
- Student prior experience with sustainability/sustainable design principles.
- An understanding of the importance of the topics learnt and activities that were undertaken during sustainability week.



- The students' successes and challenges during sustainability week whilst completing the design challenge.
- Student perception of their thinking on sustainable design after the completion of sustainability week.
- Overall satisfaction with sustainability week and the learning completed.
- Understanding the importance of sustainability in future professional practice and career development.

### **3. Sustainability Week**

Sustainability week aimed to improve student knowledge on sustainable product development whilst promoting knowledge acquisition, skills development, and improved attitudes towards global issues. The topic of sustainable product design/development refers to the design process that considers the source of natural resources as part of the design. Fundamentally sustainable design seeks to reduce negative impacts on the environment. As young aspiring designers, students were asked to consider their role as they move toward living in a sustainable world. Part of their journey throughout sustainability week was to consider their impact on the environment when creating products and services, including reflecting upon environmental, social, and economic impacts whether this is at the initial phase of product development or at product end life. As such, the following session types/activities were conducted throughout the week:

#### ***Product Design Studio Sessions***

Throughout the week, design studio sessions were integrated to facilitate project development and student group work. Students were briefed at the start of the day with the program of activities which included individual/group activities to help direct the student group throughout the day. Embracing the design sprint methodology, the design studio sessions were broken down into short individual activities whereby the students were empowered to complete specific rapid research activities, utilise tools such as Miro (a visual collaboration platform) to share work, conduct ideation activities based upon previously taught ideation methods from ideation workshops, complete product modelling and experimentation, produce product visualisations for the submission of client-ready presentation boards and finally produce a functional presentation worthy prototype/model.

The design studio sessions also allowed the students to work collectively and as individuals on elements of the project to meet the final deliverables. Throughout the design studio sessions, the supporting academic staff and guest speakers/experts provided group tutorials while also encouraging self-directed group study. The daily ordering of activities (Figure 1) was set out to facilitate the projects progression- Guest speakers introduced key topics throughout the week at timely checkpoints providing key reminders of the sustainability topic which needed to be fully considered. Each design studio session was also linked to the lectures provided, or skills focussed sessions delivered during the week.

### ***Sustainability & Carbon Emissions Lecture***

This session aimed to make students reflect on their values, perceptions, and actions (critical thinking and analysis) and understand design decisions' connectivity and cause-effect relationships (system thinking). Students were given an overview of sustainability concepts related to life cycle thinking and the importance of calculating carbon equivalent emissions to quantify the impact. Food production and packaging were used as case studies to highlight how decisions on material use can affect emissions. Case studies are among the pedagogies with a high likelihood of addressing critical thinking, analysis, and systems thinking competencies (Lozano et al., 2017).

Students were also given multiple examples of how design-related decisions often have irreversible effects that can potentially increase social inequalities, environmental degradation, and economic disparities. Students were taught about greenhouse gas (GHG) emissions, their different impacts, and sources. Lastly, a preliminary overview of circular economy principles compared to a linear economy introduced the first discussion into future design approaches, using the waste hierarchy pyramid (DEFRA, 2011) and the 5R's Refuse, Reduce, Reuse, Repurpose, Recycle as the lens.

### ***Sustainability Focussed Design Sketching Session***

This session aimed to inform students on how to effectively communicate key sustainable principles regarding their designs in sketch format. This session focussed on communicating packaging products via storyboards. Storyboards are a traditional method of communicating a written story, screenplay, scene, or scenario in many different industries. However, they are a very useful tool in communicating design concepts. Storyboards can be used to stimulate creative thinking, planning projects, collecting ideas, communicating concepts, illustrating key aspects of a design, or presenting the understanding of the big picture (Birchman & Sadowski, 2006).

In this session, students were taught how to communicate and sketch packaging products through storyboarding, including movements/actions such as unfolding, assembly/disassembly, deconstruction etc. This session ultimately allowed the students to visually communicate and sketch packaging solutions with each other and potential clients frame by frame, whilst communicating the sustainability story behind their ideas.

### ***Computer Aided Design – Life Cycle Assessment Session***

In this session, students were introduced to the basics of conducting a life cycle assessment (LCA) using SolidWorks. SolidWorks is an industry-standard solid modelling computer-aided design and computer-aided engineering application published by Dassault Systèmes. SolidWorks is designed to help designers and engineers conceptualise, create, validate, communicate, manage, and transform innovative ideas into great product designs (SolidWorks, 2022). Within this session, students were taught step by step how to complete a LCA using the software, thus providing them with information on how to make the most environmentally friendly decisions throughout the design process of a product.



The SolidWorks Sustainability plugin/feature integrates LCA directly into the engineering design process, providing insight into a product's social, environmental, and economic conditions, thus allowing designers to be environmentally conscious about their designs. Within this session, students were taught how to model a piece of packaging and its multiple components, apply material settings to the components and then fully assess the sustainability of the packaging solution by completing their first LCA.

### ***Sustainable Design & Material Selection Session***

In this session, students were introduced to a wider range of sustainable design principles and topics. Critically, the student cohort were introduced to the social implications of sustainable design, such as social equity and fairness, as well as designing for the needs of people and communities affected by the production, mining, and extraction of raw materials. Students were further reminded about approaches to design using the concepts of the waste hierarchy pyramid (DEFRA, 2011) and the 5R's Refuse, Reduce, Reuse, Repurpose, Recycle, as well as being introduced to key concepts and sustainable design considerations such as The Waste Electric and Electronic Equipment (WEEE) Regulations (Health & Safety Executive, 2022), Restriction of Certain Hazardous Substances (RoHS) Directive (European Commission, 2011), design for sustainable behaviour (Selvefors et al., 2014), design for disassembly and design for modularity.

Furthermore, the student cohort were introduced to Ansys Granta EduPack (Ansys, n.d.) a piece of software that provides and enhances undergraduate materials education and includes a database of materials and process information, materials selection tools and a range of supporting resources. This software helps teach appropriate material selection based on the work completed by Ashby and Cebon (1993) which focusses on material selection in mechanical design. Material selection in relation to product design is fundamental (Ashby & Johnson, 2013), and ultimately directly impacts the perceived sustainability of a product from a material selection standpoint, design for modularity, design for disposal and energy consumption standpoint. An introduction to material selection was presented, including the methods that can be used to select suitable materials for products whilst considering sustainable design principles. Within the software, students were able to access the sustainability package and explore how to generate charts that compare materials and the properties of the different materials to justify their selection and implementation into products. Additionally, students received demonstrations and step-by-step guides on how to critically evaluate a product's environmental impact through the eco audit tool.

### ***Designed To Last Lecture***

The session focussed on "Designed To Last" was centred around recent research on product longevity and how to increase this as a part of the circular economy discussion. Product longevity function is an important element of environmental sustainability by slowing the rate of consumption. When discussing product longevity in the design context, physical durability is an important deciding factor for the actual product life. Also, the user's attachment, the ability to repair and maintain a product and the business

supporting the product will all influence the longevity of the product.

Working with product longevity and being presented with these opportunities can hopefully enable students to be more cautious in their design process. The students were firstly presented with 14 barriers that designers, companies, and users need to overcome to produce products with high longevity (Jensen et al. 2021a). These barriers form insights into obstacles for the students that might not have been considered previously. Based on a discussion of these barriers and their relevance to the student's current projects, they were then presented with real-life cases from 18 producing companies and their solution principles to the barriers (Jensen et al. 2021b). As the cases differed significantly in both marked solutions and aim, the students could select and adopt the most appropriate solution principle for their own project. Based on the presented barriers and solution principles, the students worked to incorporate considerations regarding the product longevity, ranging from limiting the number of parts needed or increasing the modularity of the product to creating a more personal experience between product and user to improve the user's experienced attachment towards the product.

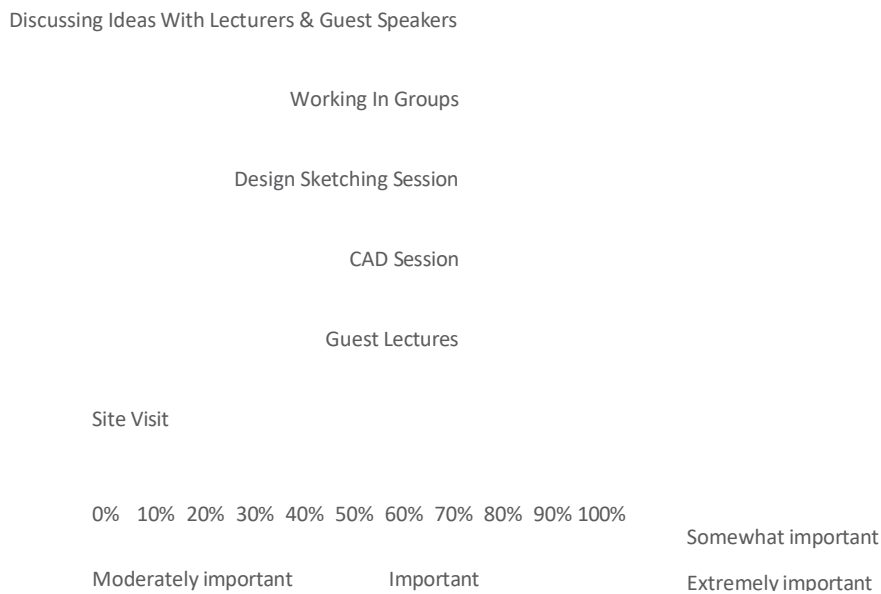
#### **4. Results and Discussion**

Thirty-seven students took part in sustainability week, of which twenty-two students voluntarily completed the anonymous end-of-week survey representing a 59% response rate. The male to female response rate was 91% male to 9% female; however, it is worth noting that the student demographic for the 2021/22 academic year for BSc Product Design first year cohort is predominantly male, representing 84% of the student cohort. The average age of respondents was 20.3 years old, with the student cohort age range consisting of students aged 18 – 30.

Results show that the higher the student age, the more interested they are in learning about sustainability/sustainable design. Students more interested in learning about sustainability/sustainable design typically haven't studied or had previous experience with sustainability/sustainable design before sustainability week. The overall satisfaction with sustainability week was positive; 15 out of 22 students who completed the feedback survey were satisfied or extremely satisfied with sustainability week in understanding sustainable development principles. 19 out of 22 students agreed or strongly agreed that participating in the sustainability week helped them understand sustainability concepts associated with product design.

Student feedback also showed that the different sessions were important or extremely important (Figure 2). While discussing ideas with lecturers and guest speakers was the session considered most important, students felt the design sketching session was only moderately or somewhat important. The perception of the design sketching session may have been deemed less important by the students as they receive weekly design sketching classes throughout the entire first-year curriculum. Conversely, this might also be explained by the fact that product design students often prefer to "learn by doing" (Lawson, 2006, p.7).

Therefore, in this situation, had the design sketching classes allowed the students to focus on the communication of their specific designs through the storyboarding sustainability focussed activity, rather than just teaching the fundamental skills, this session may have been better received by the students. It is also recognised that product design students prefer to "learn by doing" and through experiential learning experiences, whether this is by experiencing handling materials (Parisi et al., 2017) or through hands-on project-based learning in a design studio setting (Gomes et al., 2018).



**Figure 2.** Level of important of the different Sustainability Week sessions.

Sustainability week was the first experience for most students to integrate sustainability-related concepts into the design phase of a project. At the end of the experience, 11 out of 22 students stated they were very or extremely confident in applying sustainability principles/ideas/theory in their professional careers. From the survey results, additional key findings concerning the student experience and future sustainable practices were as follows:

- 15 out of 22 students identified it was either very relevant or extremely relevant for them to work on a project brief based on a product from a company/enterprise.
- 19 out of 22 students identified that sustainability week was very relevant or extremely relevant to their future professional practice.
- 18 out of 22 students agreed or strongly agreed that they believe sustainability is relevant to them personally.
- 19 out of 22 students agreed or strongly agreed that sustainability week should continue to be part of the product design degree program.
- 18 out of 22 students agreed or strongly agreed with the statement that "they would engage in

more initiatives like sustainability week in the future".

Students reflected upon the activities conducted throughout sustainability week, identifying the sessions they felt helped them learn the most about sustainability and the related principles and ideas; key quotes from the survey results included:

*"Session with [Guest Speaker 2] about product lifecycle, as this made me more aware that the products we design could have a secondary use to prolong the life of the product". (P1)*

*"Thinking about the whole supply chain as a whole rather than just the finished product and that some sustainable materials are in fact not as sustainable as they claim to be". (P3)*

*"The presentations from the guest lecturers were insightful, and the sustainability week project was beneficial as it improved knowledge on sustainable materials through research". (P4)*

*"The CAD session was very interesting; learnt about the sustainability features in SolidWorks as well as interesting information presented..." (P6)*

*"The CES [materials database] session because it's such an important and useful piece of equipment. Also, the storyboards because they are also applicable to other projects we do. The talks given by guests were interesting to give an insight into what they do". (P12)*

*"The CAD session gave a practical way to learn about sustainability and how to achieve it in modelling". (P14)*

Students were asked if they found any of the sustainability concepts or theories challenging to understand during sustainability week. A variety of topics were taught in a short space of time during the sprint-inspired project, thus reinforcing some topics that may be needed in future projects. Responses to this question provided little insight as most students found aspects of the design task challenging and not necessarily the sustainability concepts/tools taught:

*"Trying to come up with a design that used a single material and not using any glue or other fixings, developing the net became the biggest challenge, and researching existing products that do similar things and taking them apart really cleared up the methods they use". (P3)*

*"The most challenging theory was trying to make a universal packaging [product] that could be increased and decreased in size whilst also saving packaging". (P12)*

*"Having to compare materials and always trying to find the best for the situation". (P18)*

Students were also asked if there were any 'light bulb moments' that helped them learn about sustainability during the week. Interestingly a variety of topics were raised based on the guest lectures delivered and the self-directed research conducted in groups:

*"Yes, when further research was done into what is sustainable, because it was confusing at first, once the processes of how long something takes to decay was researched, and what conditions it needed, it was easier to find materials that met the needs of the company as well as being sustainable". (P5)*

*"During the [guest] lectures and a presentation where some examples have been shown and how the product can be used for different things". (P7)*

*"Price of material production changed our outlook on what our design was made of". (P17)*

Over the course of sustainability week, students identified that finding the balance between design creativity and realism in combination with suitable sustainable design considerations was a big challenge. The survey asked students to reflect on any aspect of the project brief they found challenging:

*"The biggest challenge was finding the balance between design and sustainability, as the client relies heavily on presentation. We found an abundance of choice when it came to choosing sustainable materials though". (P4)*

*"Finding a material that's suited what the company wanted as well as being sustainable". (P5)*

*"Producing a packaging product that is creative and different but also viable as a real-world option". (P10)*

*"Trying to make our design more sustainable than the original. It took a while for us to make something worth producing, by making it reusable". (P15)*

The integration of sustainability week into the BSc (Hons) Product Design first-year curriculum has been successful and has addressed some challenges that Watkins et al (2021) identified. Although it was not possible to overcome all of the challenges Watkins et al (2021) identified, the integration of sustainability week has addressed factors such as integrating sustainable product design into the core curriculum as a standard and not as an elective subject. Sustainability week has also ensured the topic was covered thoroughly and not in the discipline's broad, holistic nature. This is often the challenge in a culture of reducing contact hours and growing pressure from other aspects of the curriculum. Sustainability week also allowed focused teaching on specific aspects of the discipline by experts rather than taking a holistic approach by providing a general appreciation for sustainable product design within the broader discipline of design. Sustainability week also allowed students to obtain, comprehend and apply resources to project work which supported industrial partners/collaborators on a focused sustainable product design project/challenge.

Furthermore, the success of sustainability week and the SiE project has now led to the further development of more rapid sprint informed design projects within the Product Design Department at NTU with further sustainability driven and enterprise informed projects being embedded into the second-year curriculum as of the 2022/23 academic year. The drive to embrace sustainability and a net zero carbon strategy is an

ethos NTU has embraced at an institutional level and continues to develop. It is an important driver behind how students think and their decision-making. This is demonstrated in the survey results feedback. A selection quotes from the survey demonstrate how students perceived sustainability concerning the sectors professional practice and their own professional practice:

*"It will most likely play a key part in any design sector that I'll choose to go into and will influence the outcome of many future projects to come in terms of materials, manufacturing, and societal impact."*  
(P6)

*"Minimising throwaway items such as packaging, labels, stickers and trying to use reusable methods of packaging or schemes to reduce throwaway and offer bring back pay back schemes."* (P18)

*"In a design setting, I expect that sustainability reports will have to be produced for every product you design."* (P19)

*"Designing in a smarter manner to extend a product lifespan. Also, the removal of planned obsolescence."*  
(P21)

Moving forward other methods of integrating and assessing education for sustainable development within the curriculum are to be explored. It is strongly recommended that institutions globally do so too. In addition, based on the survey results collected, these demonstrate that there is a demand from students to learn more about sustainable product design and sustainability in enterprise. The students identified that they learnt many new skills throughout sustainability week as demonstrated by the survey feedback:

*[Improved skills include:] "Material science, working with a client, being more conscious of sustainability."* (P1)

*[Improved skills include:] "How to use material databases, how to explore multifunctionality, how to use CAD [Computer Aided Design] to better understand the impact of production."* (P13)

*[Improved skills include:] "How to look at sustainable materials i.e., effect and function."* (P18)

*[Improved skills include:] "How to be more sustainable in CAD [Computer Aided Design], how to work faster as a team and effectively manage time."* (P22)

This recommendation does present its challenges; Watkins et al., (2021) also identifies many of the same challenges faced throughout the sustainability week project. There is a growing demand from industry for graduates to have not only an appreciation of the topic, but to have a detailed understanding and awareness of sustainability in addition to possessing sustainability focussed skills. Academics and academic institutions globally would benefit from continually investing in sustainability driven education. To enhance sustainability projects moving forward, it is necessary to invest further in developing or redeveloping classes whilst also further supporting research into sustainable product design/development to ensure the latest knowledge generated is disseminated at the undergraduate level.



There is also a need to promote the demand for sustainability skills in graduates in industry and ensure students are aware of this demand. Professional institutions and course accreditors are also demanding this as part of their code of practice. If sustainability is taught in the correct setting, and supported by sustainability focussed projects, students have proven they are prepared to embrace this much quicker and subsequently they recognise the importance of this much quicker. The drive by ADBE and the SiE project team has also helped promote and involve academic staff and students in sustainability initiatives and strategic sustainability plans. Sustainability week is a clear example of this, and similar initiatives should be promoted institutionally and sector wide; this is another recommendation highlighted by Watkins (2010) in earlier work conducted on the integration of sustainable product design knowledge and practices in HE.

Despite the challenges identified, integrating the design sprint into the first year is a valuable first step in students' education for sustainability. It represents the first overview of concepts that will be used and experienced in more detail throughout the course. Previous research has discussed the benefits of integrating first-year sustainability-focused content (see, e.g. Coops et al., 2015). Particularly, to create a sense of community between students and staff and expose students to an interdisciplinary teaching team from the beginning of their course.

From the feedback collected, it is evident that students have found the experience of engaging with sustainability week challenging and rewarding whilst also enriching their educational experience. The mixture of activities and session types embedded through a sprint approach has allowed a variety of key concepts and skills to be taught in a short space of time. Although the key concepts have been taught and communicated to a good standard, it is evident that some of the more complex skills, such as LCA, material selection need further integrating into future projects throughout the academic year to reinforce and reapply the taught skills, whilst also interrogating the topic to a deeper level. Students appear to have embraced sustainable design principles within the packaging sector, therefore, it will be interesting to see in future projects whether they can apply the skills and teaching knowledge to a different product sector.

The present study did not assess specifically whether the approach undertaken were effective in behavioural change, but this will be addressed in the following academic year when the same cohort of students, now in year two, will go through another sprint sustainability project. Nevertheless, even though only a minority of students stated being interested or extremely interested in learning about sustainability/sustainable design, the majority confirmed their thinking had changed due to the sustainability week. This cohort of students will go through the next stages of a more in-depth understanding of sustainability concepts and their application to product design, including circular economy principles such as designing to regenerate in year two which forms the next stages of developments of embedding enterprise focussed sustainable design principles into the curriculum.

### ***Embracing Sustainable Principles – Student Outcomes***

Throughout the week, students were encouraged to embrace a number of different sustainable design principles and consider various factors that would influence the success or failure of their designed product. Many students considered how to make the current packaging solution more sustainable, especially when considering the existing materials and manufacturing methods, whilst exploring other options. Students also explored other options regarding materials which could open up new packaging solutions and how the product net could be manufactured and subsequently tessellated to minimise waste during production.

While exploring materials and manufacturing, the students also had to consider the elegance of the brand and the product range, as the texture of the material significantly impacts the perception of the product's elegance to both the client and the customer. Furthermore, suitability and adherence to sustainability values and principles were consistently considered by examining the packaging life cycle and sustainable packaging considerations. The key design considerations the students reflected upon and implemented into their designed product focussed on the following questions posed:

- Is the solution beneficial, safe & healthy for individuals and communities throughout its lifecycle?
- Does the product solution meet the desired market criteria when factoring in the performance vs cost considerations?
- Are materials sourced, manufactured, transported, and recycled effectively when considering renewable energy sources?
- Are product solutions optimised when considering the use of renewable or recycled source materials?
- Can the designed solution be manufactured using clean production technologies and best practices?
- Can the designed product be recovered and utilised in biological and/or industrial closed-loop cycles?
- Does the product solution minimise the mixture of different materials?
- Could compostable and biodegradable alternatives be utilised?
- Has the designed product minimised over-packaging, which can reduce the impact on the supply chain?
- Are there any secondary uses or reuses for the designed solution?

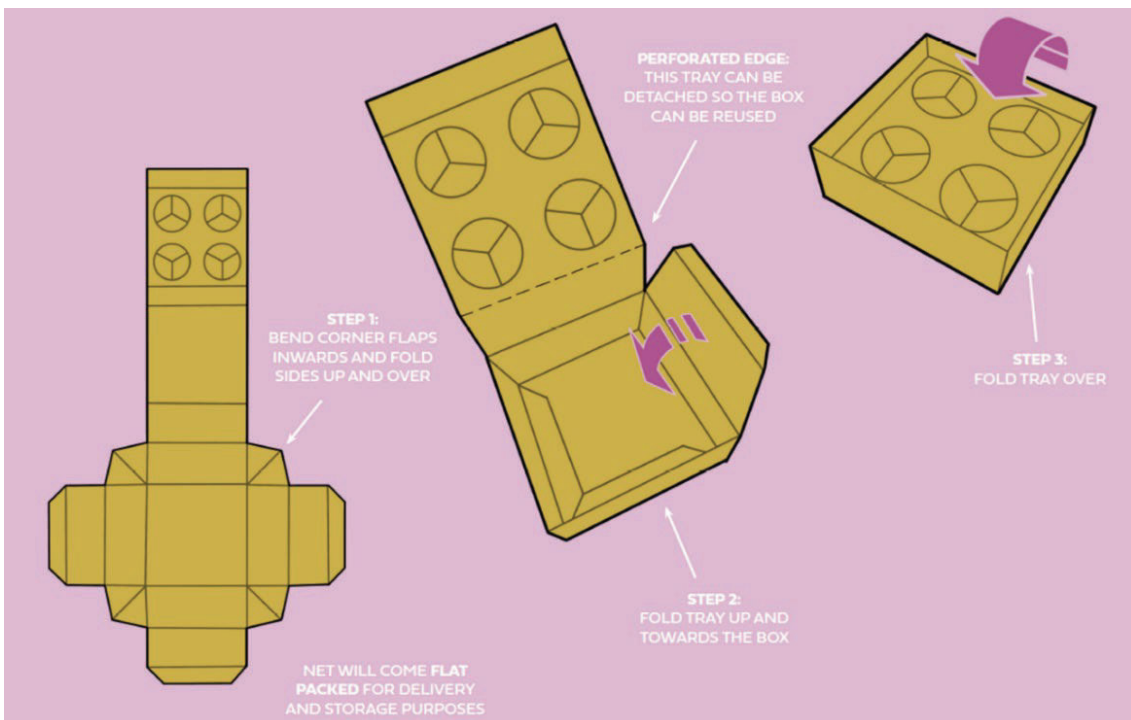
The posed questions consider many of the total life cycle considerations when designing products where both closed loop and open loop life cycle systems are considered (Jawahir et al., 2006). In addition, students are often influenced by the design thinking approaches linked to the circular economy and design guides developed by IDEO and the Ellen MacArthur Foundation (The Circular Design Guide, 2018). Furthermore, the questions posed were also influenced by the 5R's Refuse, Reduce, Reuse, Repurpose, Recycle and DEFRA's (2011) waste hierarchy pyramid. Based on these taught principles, the

student groups were challenged to approach their packaging redesign with these in mind.

Each student group picked an existing packaging solution and thoroughly examined every aspect. Figure 3 presents an example of an existing packaging solution for the company's chocolate bonbons. Figure 4 presents a student-designed output demonstrating how an existing product has been redesigned to be manufactured out of a single type of material whilst still being easily manufactured and assembled yet conversely also reducing the number of components needed and variety of materials used.



Figure 3. Existing Chocolate Bonbon Packaging



**Figure 4. Redesigned Chocolate Bonbon Packaging**

*(Credit: Student Group 4 - J. Cecil, I. Gilbert, J. Gore, J. Inglis & B. Randall)*

A key aspect moving forward that needs to be further integrated into any further sustainability week, is the introduction of more activities focused on calculating a product's carbon footprint. Many simple calculators and templates exist online and within software packages taught within higher education. Introducing this concept earlier within the product design / sustainable education curriculum would allow students to make more valuable and quantifiable comparisons of their design decisions, providing further value to the project partners.

When considering the topic of "designed to last" (Jensen et al. 2021a; Jensen et al. 2021b), to further improve the integration of this consideration regarding product longevity into the student projects, a second "sustainability week" is recommended within the curriculum; as previously discussed, the same cohort of students will experience this in the second year of their studies. In sessions delivered, students should be provided with the opportunity to integrate product longevity considerations in an earlier phase of their project, such as the idea generation process. Further insight on the topic could lead to further co-development of products alongside product longevity considerations, which could help create a more integrated result and improve the total sustainable footprint of products. Furthermore, sessions on the considerations between different sustainable choices in the design process would help improve the students understanding of environmental sustainability and help make them consciously select their solutions.

## **5. Conclusions**

In conclusion, sustainability week has provided an initial platform for enterprise-driven sustainability focused projects to be embedded into the ADBE curriculum at NTU. Using the design sprint methodology allowed the students to focus on sustainability for a week whilst being guided through specific activities and taught sessions. It has allowed the students to become self-supportive and present sustainable solutions to real-life clients. This project has further unlocked the potential for adopting sustainability and enterprise focussed teaching across different settings and has demonstrated how an institutionally driven ethos/approach can benefit academics, students, and industry partners alike to work collaboratively regardless of the setting.

The development and integration of sustainability week is just the start of the wider adoption and focus on sustainable development teaching. As a direct result of the success of sustainability week, further sustainability weeks are planned with consideration on how this model could be adopted across a wider range of year groups and courses across the product design department and also the school. Developing on from the success of sustainability week, the student group were then able to work on numerous projects for the rest of the academic year with a great deal of success. Design competition projects later in the academic year focussed on upcycling and developing products based around the process of sustainable aluminium extrusion design, this allowed

further sustainable design principles to be taught and embedded into the student's design practice. This has now allowed academics to develop longer sustainability focussed projects for the same year group to experience in their second year within the 2022/23 academic year; this would have not been possible had the student group not had this initial intense introduction on the topic.

Future development and collaborations with the SiE project are also opening up other opportunities, with wider integration of circular economy principles being integrated into the student's daily design habits and model making experience. Schemes are currently in development whereby the actual product making experience in the university's workshops are influenced by these principles from the ground up, whether this be designing and model making at year one or whether this be final year degree show exhibition development.

Finally, one of the most exciting aspects for future development is the possible 'vertical integration' of sustainability weeks, months, or projects across the different levels of degree programs which will lead up to degree shows to showcase the most sustainably conscious products and designers. Sector wide design competitions are demanding students to be sustainably conscious and the success or failure of projects can be defined by the correct application and adoption of these principles. By developing a deeper understanding of sustainable design principles, circular economy understanding etc., this will allow students to also gain a deeper understanding of sustainable or circular design business models which is needed to allow students to know how to make a business case for sustainable products.

Cross course collaboration could help further influence and leverage staff knowledge bases ensuring students hear from experts across numerous subject fields. An initial trial of cross course collaboration is planned with the Engineers Without Borders (EWB) project for 2<sup>nd</sup> year product design and civil engineering students. The EWB project provides the opportunity for students to build up on their acquired knowledge from sustainability week and apply this to a design challenge that will broaden their awareness of the social, environmental, and economic implications of engineering and design solutions. By sharing the resources required to deliver this complex subject fully and comprehensively this will not only benefit the student cohort, but this will also enable all product design educators to upgrade their knowledge and skills to be able to teach and assess this subject by increasing literacy and expertise in this area both from a design, business, and entrepreneurship perspective.

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