

DEVELOPING STUDENT SUSTAINABILITY KNOWLEDGE, COMPETENCIES AND SKILLS THROUGH PRODUCT & SYSTEM DESIGN

Francesco Luke SIENA¹, Gamze YAKAR-PRITCHARD², Ana Rita DOMINGUES³ and Richard BULL¹

¹Nottingham Trent University, United Kingdom

²University of Nottingham, United Kingdom

³University of Leeds, United Kingdom

ABSTRACT

As the world continues to take more responsibility and confront a diverse range of sustainability challenges, including zero waste, dematerialisation, resource efficiency, zero emissions, and social equity, designers and engineers are being called to action. As such educators need to adapt and integrate sustainable values/processes into the curriculum. With the world's finite resources strained by population growth and lifestyle changes, minimising impact is crucial, therefore this has driven designers to focus on designing sustainable products and consider the entire product life cycle. This paper builds on a previous case study where first-year BSc Product Design students at Nottingham Trent University (NTU) acted as design consultants during a "Sustainability Week" (SW), engaging with local communities/businesses. Initially, the focus was on integrating sustainability teaching within the product design curriculum for specific outcomes, however our latest case study focuses on students working as design consultants for larger organisations/public sector institutions. Design decisions often exacerbate social inequalities, environmental degradation, and economic disparities; therefore, student groups were challenged to identify problems related to sustainable design problems on NTU's city campus. Students addressed issues related to the 17 United Nations Sustainable Development Goals (SDG's), defining their design challenges and proposing solutions to enhance NTU's sustainability/carbon footprint. The ongoing integration of SW has improved student knowledge in sustainable product development and systems design. Taught content focused on sustainability themes, promoting knowledge acquisition, skills development, and positive attitudes towards global issues. A pre/post-Sustainability Week survey showed significant improvements in students' sustainability knowledge, competencies, and skills.

Keywords: Carbon footprint, design for sustainable change, product design education, product & systems design, sustainability

1 INTRODUCTION

In recent years, there has been a global call to embed sustainability as a fundamental taught concept in product design/design engineering education from scholars such as Watkins & Lofthouse [1], Seay [2], and Ashour [3]. It's clear that product designers need more than just traditional design education, they require a deeper, more comprehensive skill set and must be fully conversant on sustainable design as a core concept/topic. It is important that in the education of future product designers/design engineers that sustainable product design is integrated into the core curriculum to ensure that graduates can truly make a difference [4] to equip future designers with the tools they need to create a more sustainable world. To develop a more sustainable focused society, Higher Education Institutions (HEIs) must assume responsibility and take on a leadership role in educating students on core topics/theories, to ensure we enhance students' sustainability literacy, equipping graduates with the required technical knowledge to nurture a new generation of globally conscious, sustainability-minded citizens [5-6].

To tackle the education of the complex and diverse topic of sustainability and sustainable development, in the 2021-22 academic year we developed a new initiative called Sustainability Week (SW) within the BSc Product Design course at NTU. This was designed to kick start students learning on the topic of sustainability and sustainable development. As such we developed embedded enterprise focused

education for sustainable development in collaboration with NTU's Sustainability in Enterprise (SiE) project that was part-funded by the European Regional Development Fund (ERDF) [7]. By partnering with the SiE project this gave students the opportunity to work with a real-life client in an SME setting, while also incorporating sustainability and sustainable design principles. The premise of SW was to use a design sprint approach to rapidly upskill students in sustainability core competencies. Employing an adapted design sprint approach, a series of lectures, workshops, and brief research/design activities were integrated into a structured week. Student groups redesigned an existing packaging solution while learning and applying sustainable design principles. Each day featured a set of structured activities, including research, design sketching, computer-aided design (CAD), material database exploration, product development and modeling, and culminating in the final design realisation and presentation [7]. In our most recent iteration of SW, we decided to shift the focus to students working as design consultants for larger organisations (i.e. NTU), with an emphasis on exploring product/system outcomes which can have a positive impact on sustainable outcomes for larger enterprises. By exploring NTU's campuses, students identified problems/opportunities they could address in relation to any of the 17 United Nations SDGs. This allowed students to define their design challenges and respond by proposing product/system solutions/outcomes that enhance NTU's sustainability and carbon footprint.

2 METHODS

During the 2022-2023 academic year, data was gathered through a quantitative questionnaire survey. Before the primary data collection process, ethical clearance was secured from NTU's Research Ethics Committee (REC) (Schools of Art, Architecture, Design and Humanities REC) by following the official process. Data was collected, analysed, and reported accordingly. This survey aimed to collect information on three key variables: (i) capacity building, which includes knowledge, competencies, and skills; (ii) the affective domain, encompassing perceptions, attitudes, and behaviours; and (iii) career readiness for sustainability. The survey variables were derived from a framework by Yakar-Pritchard et al. [8], which aims to evaluate the impact of student knowledge exchange on sustainability. The items used to measure students' sustainability knowledge were determined based on the project's focus and content. Sustainability competencies were assessed using items adapted from the framework developed by Wiek et al. [9], while items measuring students' skill development were adapted from the framework developed by Yakar-Pritchard et al. [8]. Students' perceptions of sustainability were measured using items adapted from Ngo and Chase [10], their attitudes from Ceulemans and Severijns [11], and their behaviours from Heeren et al [12]. The career readiness scale was adapted from Read et al. [13]. The Microsoft Forms survey developed used seventeen closed-ended questions which were measured on a 5-point Likert scale. The scales ranged from 1 to 5 and focused on variables such as: sustainability knowledge (not at all knowledgeable to very knowledgeable), sustainability competencies (very poor to excellent), skills development (very poor to excellent), sustainability perceptions (very low to very high), sustainability attitudes (strongly disagree to strongly agree), sustainability behaviours (never to always), and career readiness (strongly disagree to strongly agree). Students were required to complete self-assessments before and after SW to ensure that data obtained could establish a baseline and subsequently identify the skills, knowledge and behaviours that had been improved upon as result of the SW focused initiative. Student participation in SW was n=62, however only n=47 students completed both the pre- and post-intervention questionnaire survey, representing a sample size of 75.8% of the student cohort. Data analysis was conducted using IBM SPSS Statistics 28.0.1.1. Descriptive statistics were used to determine the mean, standard deviation, percentage, and frequency of the dataset variables.

3 RESULTS

This section evaluates SW's impact on students across three dimensions: capacity building, the affective domain, and career readiness. It assesses their sustainability knowledge, competencies, and skills, highlighting the effectiveness of educational strategies. It also examines students' perceptions, attitudes, and behaviours toward sustainability, and their readiness to apply this knowledge professionally.

3.1 Capacity building: students' knowledge, competencies, and skills in sustainability

After conducting independent samples t-tests, Table 1 shows that there was a significant difference between the pre- and post-intervention scores of the students who had participated in the SW project for all the themes regarding their sustainability knowledge ($p < 0.05$). Considering the total score, the

students reported that they had a higher level of knowledge about sustainability after the intervention (M=3.57, SD=0.49) compared to the pre-intervention period (M=2.97, SD=0.54).

Table 1. Comparison of the pre- and post-intervention mean scores of the students who participated in the SW project for their sustainability knowledge

Sustainability knowledge	Pre-intervention (N=48)		Post-intervention (N=47)		t-test for equality of means		
	Mean	SD	Mean	SD	t	df	p
Climate change	3.43	0.74	3.87	0.57	3.190	93	0.002**
Ecosystems and biodiversity	3.18	0.89	3.68	0.72	2.956	93	0.004**
Waste and recycling	3.35	0.72	3.93	0.63	4.133	93	<0.001***
Greenhouse gas emissions	3.39	0.76	3.82	0.60	3.070	93	0.003**
Water resources	2.79	0.79	3.25	0.84	2.748	93	0.007**
Affordable and clean energy	3.33	1.03	3.76	0.78	2.286	93	0.024*
Life cycle assessment	3.04	0.96	3.74	0.79	3.871	93	<0.001***
Carbon management	2.52	0.94	3.44	0.90	4.878	93	<0.001***
Sustainable materials	3.33	0.80	3.93	0.67	3.949	93	<0.001***
Responsible production and consumption	2.85	0.87	3.48	0.80	3.682	93	<0.001***
Social equity and justice	2.33	0.93	3.10	0.96	3.984	93	<0.001***
Stakeholder participation	2.10	1.05	2.82	1.00	3.425	93	<0.001***
Overall score	2.97	0.54	3.57	0.49	5.594	93	<0.001***

*p<0.05, **p<0.01, ***p<0.001; N - total number of participants; SD - standard deviation; df- degrees of freedom

Table 2 shows the pre- and post-intervention t-test results of the students who participated in the SW project for skill improvement/development. These results show that there was no significant difference between the students' pre- and post-intervention overall scores for skill development (p>0.05).

Table 2. Comparison of the pre- and post-intervention mean scores of the students who participated in the SW project for their skill development

Skills development	Pre-intervention (N=48)		Post-intervention (N=47)		t-test for equality of means		
	Mean	SD	Mean	SD	t	df	p
Project management	3.39	0.70	3.68	0.75	1.900	93	0.61
Consulting	3.06	0.75	3.34	0.59	1.983	93	0.50
Research skills	3.47	0.77	3.74	0.64	1.822	93	0.72
Problem-solving	4.02	0.69	4.06	0.67	0.305	93	0.761
Leadership	3.35	0.86	3.63	0.70	1.756	93	0.082
Communication skills	3.45	0.87	3.63	0.76	1.068	93	0.289
Presentation skills	3.22	0.85	3.44	0.77	1.298	93	0.198
Teamwork	3.97	0.63	4.00	0.62	0.161	93	0.872
Innovation/ Creativity	3.85	0.79	3.97	0.73	0.790	93	0.432
Critical thinking	3.75	0.66	3.91	0.61	1.246	93	0.216
Embracing diversity and interdisciplinarity	3.85	0.77	3.82	0.70	-0.161	93	0.872
Overall score	3.58	0.44	3.75	0.40	1.928	93	0.057

N - total number of participants; SD - standard deviation; df- degrees of freedom

The independent samples t-test results reveal significant improvements in students' sustainability competencies following their participation in the SW project. Table 3 indicates that there was a significant difference between the pre-intervention (M=3.16, SD=0.69) and post-intervention (M=3.55, SD=0.61) Specifically, the systems thinking competency showed a notable increase, with a p-value of 0.005, indicating a statistically significant enhancement. Similarly, the anticipatory competency was significantly higher, validated by a p-value of 0.002. Additionally, the overall sustainability competencies improved significantly, as evidenced by a p-value of 0.010. These findings suggest that the SW project effectively enhanced students' abilities in these critical areas of sustainability.

Table 3. Comparison of the pre- and post-intervention mean scores of the students who participated in the SW project for their sustainability competencies

Sustainability Competencies	Pre-intervention (N=48)		Post-intervention (N=47)		t-test for equality of means		
	Mean	SD	Mean	SD	t	df	p
Systems thinking	3.16	0.69	3.55	0.61	2.862	93	0.005**
Anticipatory or Future thinking	3.33	0.63	3.76	0.69	3.172	93	0.002**
Normative or Values-thinking	3.33	0.69	3.57	0.65	1.745	93	0.084
Strategic thinking	3.77	0.72	3.82	0.66	0.412	93	0.681
Interpersonal or collaboration	3.58	0.67	3.80	0.61	1.696	93	0.093
Overall score	3.43	0.52	3.70	0.47	2.630	93	0.010*

*p<0.05, **p<0.01; N - total number of participants; SD - standard deviation; df- degrees of freedom

3.2 Affective domain: students' perceptions, attitudes, and behaviours toward sustainability

Table 4 shows the pre- and post-intervention t-test results of the students who participated in the SW project regarding their perceptions, attitudes and behaviours towards sustainability. These results suggest that there was no significant difference between the students' pre- and post-intervention scores for their perceptions, attitudes, and behaviours towards sustainability, as evidenced by p>0.05.

Table 4. Comparison of pre- and post-intervention mean scores of students who participated in SW project for their perceptions, attitudes and behaviours towards sustainability

Variables	Pre-intervention (N=48)		Post-intervention (N=47)		t-test for equality of means		
	Mean	SD	Mean	SD	t	df	p
Sustainability perceptions	3.87	0.46	3.84	0.46	-0.326	93	0.745
Sustainability attitudes	3.43	0.49	3.49	0.60	0.530	93	0.597
Sustainability behaviours	3.42	0.56	3.48	0.62	0.510	93	0.611

N - total number of participants; SD - standard deviation; df- degrees of freedom

3.3 Career readiness: students' workplace preparedness

Table 5 shows that students' career readiness scores significantly decreased after participating in the SW project (pre-intervention: M=3.69, SD=0.40; post-intervention: M=3.34, SD=0.56; p<0.001). However, this difference was in the negative direction. This indicates that students felt more prepared for sustainability careers before the project than after but could highlight the acknowledgement of the amount of content required to be learned within the topic.

Table 5. Comparison of the pre- and post-intervention mean scores of the students who participated in the SW project for their career readiness

Variable	Pre-intervention (N=48)		Post-intervention (N=47)		t-test for equality of means		
	Mean	SD	Mean	SD	t	df	p
Career readiness	3.69	0.40	3.34	0.56	-3.454	93	<0.001***

***p<0.001; N - total number of participants; SD - standard deviation; df- degrees of freedom

4 DISCUSSIONS

As presented in the results, it is evident that significant educational gains within sustainability knowledge were observed in areas such as climate change, ecosystems and biodiversity, waste and recycling, greenhouse gas emissions, water resources, affordable and clean energy, life cycle assessment, carbon management, sustainable materials, responsible production/consumption, social equity/justice, and stakeholder participation. This demonstrates the effectiveness of the SW project in enhancing students' knowledge, competencies, and skills in sustainability. Specifically, the overall sustainability knowledge score increased from a mean of 2.97 (SD=0.54) to 3.57 (SD=0.49).

Upon reviewing the pre- and post-intervention mean scores of the students for their skill development, there were slight improvements in individual skills such as project management, consulting, research skills, leadership, communication, presentation, innovation, creativity, and critical thinking. Due to the rapid nature of the project, it is not a surprise that these skills did not significantly improve, however this did provide a platform to kick start student learning in a variety of sustainable product design concepts such as design for behavioural change, circularity, dematerialisation, product efficiency, regenerative approaches and systems thinking which were to be explored in subsequent projects within the curriculum. Another factor that could have influenced this was engaging in the “sprint” like nature of the project. The design sprint approach may not have provided the students enough time to fully develop some skills in enough depth due to the rapid nature of the project-based learning approach adopted. This approach did provide students an opportunity to engage with new concepts and development opportunities that can be leveraged in future projects.

SW has significantly enhanced students' sustainability competencies. Notably, 'Systems Thinking' and 'Anticipatory' competencies, along with the overall sustainability score, all showed significant improvements post-intervention, with p-values of 0.005, 0.002, and 0.010. This demonstrates that SW project had a positive impact on enhancing students' competencies in sustainability. The development of these competencies is reflective of the approaches adopted, where students were challenged to identify possible impacts using systems thinking and consider alternative scenarios. Student feedback indicated that while they gained substantial knowledge through SW, it also made them aware of the vastness of the topic, highlighting that there is more to learn and understand. An interesting finding from the results identified that the students career readiness/workplace preparedness had decreased, as this was determined to be higher before they participated in the SW project compared to their relevant perceived career readiness after the project. After ad-hoc conversations with students, they identified that SW made them truly aware of how big of a topic sustainability is, but also what expectations industry have with regards to the topic. As such, they feel less prepared mainly because they now have a realistic understanding of the size/scope of the topic and that they know there is more work to do, more theory to understand and more concepts to apply to their project work to make sure they are career ready.

5 CONCLUSIONS

This study demonstrates it is possible to educate students on core sustainability principles in a rapid manner using a design sprint approach whilst also transitioning from traditional product outcomes to a more comprehensive approach that incorporates systems thinking and sustainability. The inclusion of SW within the BSc Product Design curriculum at NTU continues to provide students with the opportunity to act as design consultants, tackling real-world challenges faced by larger organisations, including NTU itself and as such has allowed the students to further develop their learning. The practical experience gained by participating in SW is crucial, as it enables students to identify and address sustainability issues aligned with the 17 United Nations SDGs. The innovative approach undertaken within this case study extends beyond the classroom, encouraging students to explore their campus environment to identify and solve problems using their knowledge of designing for sustainable change. Additionally, the use of pre- and post-intervention surveys to assess the impact of SW on students' knowledge, competencies, and skills in sustainability offers a robust method for evaluating student learning outcomes. The significant improvement in students' sustainability knowledge, as evidenced by survey data and independent samples t-tests, highlights the effectiveness of SW. Although some of the data captured highlights that certain aspects of sustainability as a topic need much more time and depth to be fully comprehended, this can be built upon in longer-term project/work-based learning projects rather than short-term project-based activities such as SW. However, participating in short-term projects structured by SW can serve as a catalyst for positive learning experiences, encouraging students to explore and develop their knowledge and competencies.

Finally, initiatives such as SW have further impacted the wider education of sustainability within the School of Architecture, Design and the Built Environment (ADBE) at NTU, not just within the product design department, but in other departments such as architecture, civil engineering etc. Specifically, within the product design department at NTU this has resulted in other year groups/courses integrating sustainability focused teaching into the development of their modules. Not only have specific modules that focus on sustainability been developed, but specific learning outcomes directed to sustainability education. ADBE is now committed to ensuring all courses embed sustainability-related course learning outcomes related to SDGs and sustainable development, linking this to additional initiatives within NTU

i.e., Sustainability in Practice Certificate (SiP) which explores the SDGs and sustainability issues from a personal, disciplinary and supradisciplinary perspective. This links directly to the foundational research conducted by Puntha et al [14], within the areas of sustainability literacy and employability. This study has some limitations. The results derived from the survey are based on students' self-assessments, which could introduce subjective bias and inflated results. Future research could employ multi-source feedback assessment approaches to evaluate students' development of sustainability knowledge, competencies, and skills, providing a more holistic perspective within project-based learning processes. Additionally, follow-up studies would be beneficial to analyse the long-term impact of participation in current or similar projects on graduates' career development.

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