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SWIM OR DROWN: TOSSING 1ST YEAR STUDENTS INTO THE COMPLEXITY POOL

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ABSTRACT
The sustainability challenges we face today as a society are complex, wicked problems. As designers, we are accustomed to fuzzy problem definitions and the iterative nature of problem solving. However, in education we are just beginning to apply systems thinking to actively explore the connections between particular products or services to larger systems views and sustainability goals. Teaching designers in that complexity from their first year of education might be daunting, but we propose it's necessary to prepare these students for the future requirements of their profession. This article describes our approach to teach sustainability for first year design engineering students. It was done within the frame of the Design Methodologies course, in the Design Engineering programme at Elisava Barcelona School of Design and Engineering, during fall 2021. Based on previous years' course structure, students were expected to do two projects, an intense one done in 3 four-hour sessions and another one lasting 12 weeks. This year, both projects have had a focus on sustainability, and students were asked to collect and clean used packaging and other secondary materials for some weeks, to use them for prototyping during the course. The experience was reviewed through analysing student project outcomes and complementing the findings with a student survey to collect their impressions. The article presents these results, comparing the projects from this year to previous years and other similar approaches to draw suggestions for future teaching.

Keywords: Design education, sustainability, sustainable development goals, complexity

1 INTRODUCTION
The sustainability challenges our society faces today are complex, interconnected, difficult to define and involve multiple stakeholders. Even with the UN further specifying the elusive sustainable development objective into the 17 Sustainable Development Goals (SDGs) [1], each of the goals can still be framed as the desired result of solving different wicked problems [2]. Wicked problems, a concept originally used for problems in social policy, are described as "problems in the real world", that do not have a definite formulation, nor a right or wrong answer, and require negotiation of different value sets among diverse stakeholders [3]. The SDG framing emphasizes the need for an underlying systemic change to achieve the goals and suggests this should be achieved with a holistic perspective through multi-stakeholder partnerships [4]. Professionals of all sectors will increasingly be involved in addressing sustainability challenges; therefore, we need to teach about sustainability and the SDGs as broadly as possible. SDG 4, Equitable quality education, proposes through some of its targets to mainstream education for sustainable development and include sustainability into curricula. But when in the education is it most appropriate to include wicked sustainability problems?
Design, and design education, deals with the ambiguity of wicked problems regularly [5]–[7], with some authors highlighting that not all design problems are wicked (i.e., small scale product design, or software design) [8]. In contrast, non-design engineering students do not often learn how to address complex, multi-stakeholder, ill-structured problems, making it difficult for them later to engage in wicked sustainability challenges [9], [10]. However, design engineering and design students confront wicked design problems early on in their education. Design problems often require taking into account many factors, such as different stakeholders' values and points of view, ultimately requiring integrating technical, social and economic requirements into the proposed solution [11]. This was described as "thinking in relationships" by Moholy-Nagy and is achieved in the design process through the iterative

testing of solutions, using prototypes to obtain input from stakeholders and actors from different disciplines in order to improve the proposed solutions, often changing the initial problem formulation and expected solution space [11]. Since designers strive to "think in relationships" (evaluating how the proposed elements would relate and affect the use context) they effectively foster systems thinking, focusing on the relations between elements and how they integrate to achieve a desired outcome [12]. Systems thinking has been identified as a valuable tool to address wicked sustainability problems [13]. Therefore, it seems possible to propose wicked sustainability challenges to first year students, since they are similar to the design problem they already address. Introducing sustainability early in design education has become increasingly more common, given that design schools see a growing demand and urgency for radical change. This is done with the intention of increasing the presence of sustainability topics in the curricula, and to familiarize the students with the type of challenges they will probably face in their professional life, rather than expecting them to obtain a deep thorough understanding of the complexities such challenges bring in the lapse of an academic course.

This paper explores how this complexity could be implemented into education, specifically in the first year of the undergraduate degree in Industrial Design Engineering (IDE). Currently the IDE programme introduces SDGs and life cycle thinking to students during the first year. Then, students are taught to reflect on specific sustainable design criteria during the second year, they learn to quantify environmental impact of products and services during the third year and are expected to integrate sustainable design criteria into their own practice by the fourth year. Studies reflect that students at entry level of engineering-related degrees may have not been exposed to sustainable development issues [14], and that the use of SDGs as part of project briefings may help students' motivation [15] as well as the teachers'.

Additionally, and to promote resource recovery from waste, these students were instructed to collect and clean used packaging and other secondary materials at home for some weeks, to use them for prototyping during the course. This was an additional characteristic that intended to put into practical terms some of the sustainability strategies described to them in class.

The article is structured as follows: First the context and the methodologies used are detailed. Then, project results are categorized to give an insight to the complexity and challenges the students faced, followed by the answers of the student survey. To conclude some major points are discussed.

2 CONTEXT AND METHODS USED

The course used to introduce first year students to wicked sustainability problems was Design Methodologies. This course is taken in the first semester by all first-year students of the undergraduate degree in IDE. This year consisted of 91 first-year students, aged 18-20, that were divided in 4 class groups, of 21 to 24 students with one teacher each. Design Methodologies is an introductory course to design processes and methodologies, consisting of theoretical lectures and readings about the subject matter, with two applied exercises where the students experience doing a design project for the first time. The focus of the projects is not really on obtaining specific outcomes, but rather on the students exploring their creative process to test the tools, steps, and methods they have heard and read about in the theoretical sections. The two projects developed during the course are the Dynamic Sessions (DS) and Extended Design Project (EDP), referring to their respective time dedication. Their respective academic briefs are described in the following subsections. Both projects are a practical introduction to the design process in general, and the Elisava design process in particular [16].

2.1 Dynamic Sessions academic brief

DS are three sessions of 4-hour agile group work, where students are asked to tackle a challenge. For these sessions, students from the 4 class groups are combined and mixed, to foster their ability to work with different people. Once the groups are created (approx. 8 students each) they choose to work with one of the following challenges: How would you improve Elisava students' well-being? (SDG 3: Good health & Well-being); How would you foster gender equality in Elisava? (SDG 5: Gender equality); How would you increase green and safe spaces in the city? (SDG 11: Sustainable cities and communities); How would you reduce electronic waste in the city? (SDG 12: Responsible consumption and production); How would you reduce garbage in the city's coast? (SDG 14: Life below water); and How would you nurture biodiversity in in the city? (SDG 15: Life on land). The challenges had similar formulation with the ones presented in previous years, but the topics were slightly different. This year

each challenge was explicitly linked to a SDG and described in a context that was familiar to the students so they could relate to the problematic (e.g., Elisava, local beaches).
The 3 sessions are structured following the Elisava design process (Table 1). During all three sessions students are free to exit the classroom to gather secondary materials, data, or feedback from other students, teachers or from the streets. Figure 1 shows students working on a Wallmap (left) and the general classroom situation during the DS (middle left).

Table 1. Dynamic Sessions structure and the Elisava Design process stages they relate to

Research	Definition	Conceptualization	Validation	Technical Rendering	Communication
Session 1: Research Students are provided with a Wallmap containing six predefined sections.		**Session 2: Prototyping** Each group works on one or several rapid prototypes that respond to the value proposal generated on the first session.		**Session 3: Communicating** Groups work on communicating their project, preparing a 3-minute presentation and exhibition of the material made.	

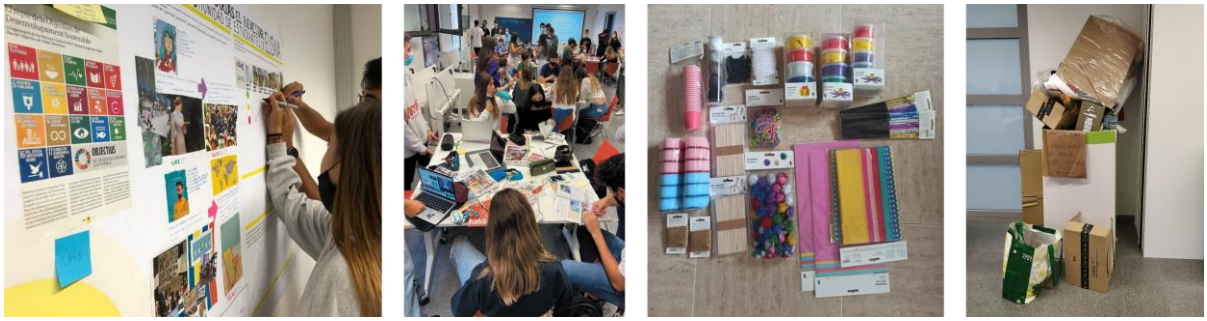

Figure 1. Images from the Dynamic Sessions. Left: Students using a Wallmap. Middle left: classroom set up. Middle right: materials for prototyping from previous years. Right: Secondary materials collected by students, stored in class for prototyping

2.2 Extended Design Project academic brief

The EDP is the first project that students face in the degree spanning several weeks of dedicated work. They work in groups of 3-4 persons, for 12 weeks, to explore a semi-open brief. This year the brief was to ideate products or services that can improve or innovate on gastronomic experiences from a food design perspective. The topic of the brief is different every year, but the dedicated time and formats for the expected outputs are the same. During the first sessions, a food design researcher gave them an introduction to the topic, and students were then asked to describe some personal gastronomic experiences –either good or bad–, discuss them with the other members of their group, and relate them to one or several SDGs. From that discussion, they defined a more concrete briefing of their choice, framing their research and project development associated to at least one SDG.
The main goal is that students understand that gastronomic experiences –or any kind of experience– become so thanks to the interconnection of different scales: elements, materials, tools and products, the environment where the tools are used, associated services, production chains or people involved in any of the previous. Students shared their projects in a 5-minute final presentation.

2.3 Materials and tools for prototyping

In previous years, teachers provided materials for the students to prototype in the DS, such as pieces of cardboard, rubber, wire, plastic straws, balloons, foam, fabrics, etc. (see middle right image in Figure 1). For the EDP, no specific instructions were given on what kind of material they should be using, so students usually bought what they needed to build their prototypes. This year, after an introduction to sustainability lecture (3 weeks before their first prototyping session) students were asked to gather discarded packaging or other materials and bring them to class for prototyping. The gathered materials were kept in the classroom for most of the semester, at the students' disposal (see Figure 1, right), however no further explicit instructions were given for students to use these materials in the EDP. For tools, students use the workshop facilities and tools available at the school. Many also bring with them simple tools like cutters, scissors, glue and markers. Tool availability was the same as previous years.

2.4 Analytical approach

To analyse the experience presented in this article, information was collected on the two design projects and with a student survey. From both design projects, quantitative and qualitative data was gathered and analysed. First, observations while tutoring were made during the entire project. Each class group had an assigned tutor but some of the dynamics allowed students to get feedback from the rest of the teaching staff. Additionally, at the end of the semester students were asked to share their thoughts about the course through an anonymous 12 question survey. Results from both projects of all the class groups were gathered in a visual map where tutors categorised following an affinity diagram (also known as KJ technique [17]). Two aspects were reviewed and categorized for each of the 36 projects: the materials used in prototyping, and the final design proposal. Finally, for the EDP results, what SDG was associated to the resulting proposal was also reviewed. The categories and their occurrence are described in the following section.

3 ANALYSIS OF PROJECT RESULTS

The DS presented a total of 12 projects, 2 for each SDG related challenge. The EDP resulted in 6 projects per class group, totalling 24 unique project results. All 36 projects were used in the analysis, regardless of what project type they were developed in. Some projects fitted into more than one category, resulting in a higher count than the number of projects.

The final design proposals were categorized in 5 different groups, depending on their scale and typology. Comments on the prototype nature for each type are provided:

- **Urban (n=4):** Proposals at an urban or city level. Scale models, mostly using discarded cardboard, drawn over or covered to provide a cleaner, uniform look. Those models were used to gather feedback on the area they represented and were later modified (Figure 2, bottom middle).
- **Interior Design (n=8):** Proposals within a building context. Scaled models using discarded cardboard for the main structure and varied materials to provide texture finishes for realism, getting a rawer aesthetic when using discarded materials (Figure 2, top left).
- **Product (n=20):** Physical products. These prototypes were in 1:1 scale, to test for usability. Several materials were used depending on the project (Figure 2, top right and bottom left).
- **Information (n=11):** Communication campaigns or applications, from posters to websites. Both physical and digital prototypes were presented (Figure 2, top middle and bottom right).
- **Services (n=16):** Several projects associated a service to one or more of the previously mentioned proposal types. None of the projects was presented solely as a service.

The materials used in prototypes were categorised as follows:

- **Purchased materials (n=12):** to cover specific aesthetic of material needs. E.g.: balsa wood, silicone, methacrylate.
- **Discarded materials (n=6):** gathered from the students' homes or at the school and used as bits and pieces. E.g.: Cardboard; bottle caps as basins, eggcups as toilets, or espresso-to-go cups as bins to build a restroom model (Figure 2, top left).
- **Reused objects (n=13):** gathered from the students' homes or at the school and used as essential parts of the prototypes. E.g.: flowerpot, water bottle.
- **Food waste (n=2):** turned into material. E.g.: mix of clay and fruits to model a cup.
- **Digital models (n=9):** using online apps for graphic prototyping, or 3D representation software. E.g.: website for low waste recipes, interior design model.
- **Printed elements (n=23):** as the prototype itself, or for graphic customisation. E.g.: posters.
- **Rapid digital prototyping (n=4):** E.g.: 3D printing, laser cutting.

In the prototypes made during the DS, very few materials were acquired especially, most were reused from what the students gathered. This could be due to the lack of time for prototyping, or due to direct instructions of prototyping with what was available. Prototypes done for the EDP were more varied and included more purchased and printed materials, and digital models.

Regarding the 24 EDP results, all but 2 final proposals had a clear connection to one or more SDGs. The most frequent SDGs being #12: Responsible consumption and production (n=12), followed by #11: Sustainable cities and communities (n=5), #2: Zero hunger (n=4), #3: Good health and well-being (n=3), then #4: Quality education and #10: Reduced inequalities (with n=2 each) and finally with #11: Life below water and #15: Life on land, both considered in the same project (that proposed a bio-plastic from

coffee waste to make disposable cup lids). Fifteen projects related to just one SDG, 6 could be linked to

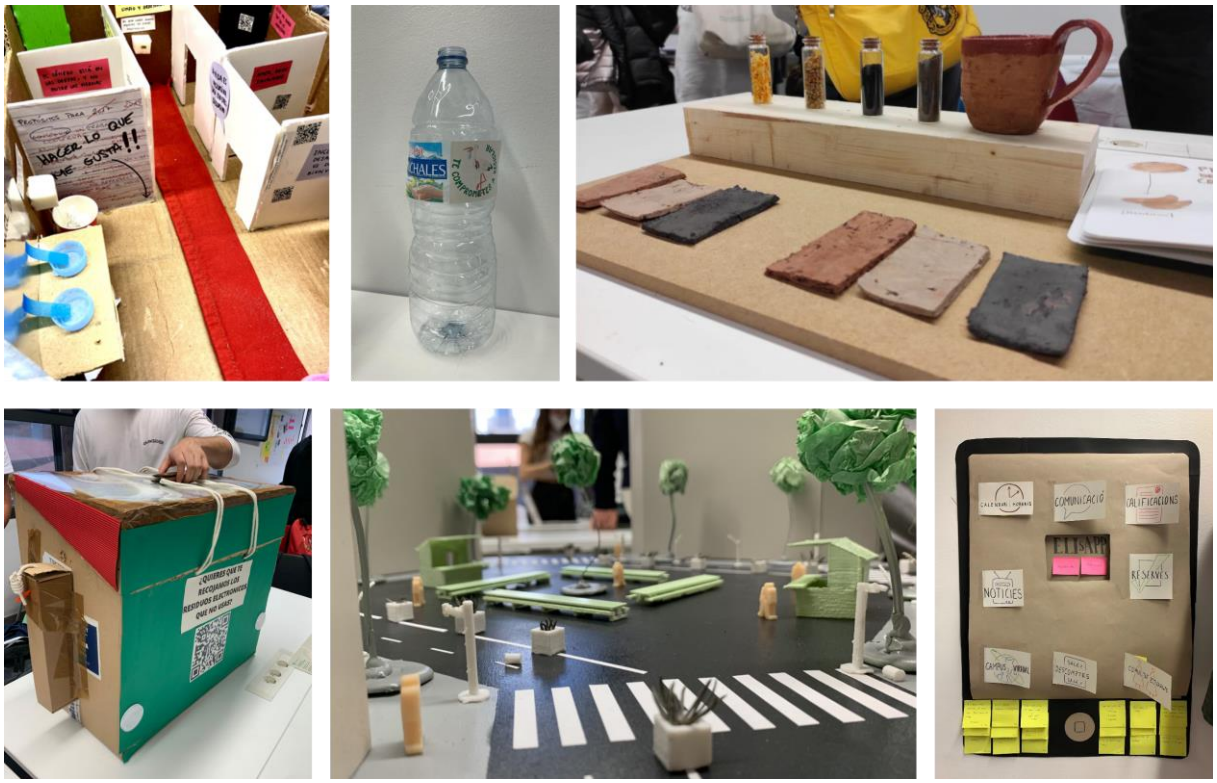

Figure 2. Examples of final project prototypes. Top left: Scale model for a gender inclusive toilet. Top middle: Information campaign against plastic littering. Top right: Ceramic made with organic waste. Bottom left: Backpack for residential electronic waste collection service. Bottom middle: Food sharing experience in urban areas to promote local commerce and avoid food waste. Bottom right: An app to promote student well-being

two SDGs and one connected 3 SDGs with a solar oven (i.e., SDGs 2, 12 and 13).

4 STUDENTS FEEDBACK

After the course a survey was circulated to students to collect their perceptions about the challenges and complexity they had faced. It was an optional activity, in which unfortunately we got low participation, with only 26 of 91 students responding. The survey started with a general evaluation of the course, with students justifying their answers by mentioning the methodologies used in the projects, the topics covered in the sessions, and the feeling of learning by doing from the beginning. Students scored their knowledge about SDGs as almost non-existent before the course (77% of the respondents) and reported that after the course this knowledge had changed (80.8%). Including SDGs in both exercises were perceived as very interesting and appreciated to be included as a statement (88.5%) however in the EDP it was a key element they chose to apply (61.6%) and in the DS, it felt more forced (30.8%). SDGs were considered in all project phases (61.6%) and helped them to think about the sustainability of the final design proposal (61.6%) but at the same time, added a bit of complexity (38.5%). On the other hand, secondary/reclaimed materials in order to prototype were scored as a good idea (92.3%), inspiring (76.9%), adequate (50%), not hard nor easy (42.3%) and almost all respondent groups used only secondary materials (61.5%).

We think one of the reasons for low participation is that it was an action separate from the course learning activities, a few weeks after the final evaluation. It could be more appropriate to integrate the survey in the final reflection of the course. In this way, sustainability becomes equally important as creating their own personal design process.

5 DISCUSSIONS

The typology and complexity of the resulting proposals seem to stem from the complexity of the challenges proposed. Of the products proposed, few were presented as only a product (i.e., only 9/24 EDP and none in the DS) all other products were proposed as being part of a Product Service System (PSS) or broader interior design or urban interventions. If we relate this to the Design for Sustainability

(DfS) evolutionary framework [18], we can draw clear relations between the categories observed in this study to the levels of the framework, with the three first levels of said framework clearly present in this article's categorization (i.e., Product, PSS and Spatio-Social Levels). The last level of the DfS framework, the Socio-Technical Systems levels, requires a deeper understanding of the underlying socio-technical systems that are present in society before one could attempt to change or re-design them. This seems too much to ask from first year students with no previous introduction to systems theory or socio-technical systems. However, they intuitively envision several types of PSS and interventions in the Spatio-Social dynamics observed.

Using secondary materials in design education is not new, and here it proved to be unproblematic for first year students as well. To further promote this practice in more courses at Elisava, staff is aiming to facilitate material reuse through an internal material deposit, connected to external resources.

Compared to the most relatable EDP brief from previous years, where students were asked to observe somebody cooking and choose to design something based on those observations, it is clear that this year's results have been of a higher complexity, without missing academic content from the course. Students explore the same design processes but propose with a wider range of possible solution spaces. In previous years most project results were products, with a few PSS ideas, but now that trend is clearly reversed, with higher levels of complexity, in the spatio-social levels also appearing. To summarize, if tossed into the sustainability complexity pool, first year IDE students' swim.

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