

**STEAM Matters for Sustainability:
10 Years of *Art and Technology* Student Research on Sustainability Through
Problem-based Learning**

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ABSTRACT

Students of art-based higher educational programs use artistic practices and academic methods to explore complex societal topics and produce artistic outcomes that embody new knowledge and insights. Universities have an essential role in helping to shape sustainable futures, and art-based research frequently explores complex and abstract topics, such as sustainability. In this paper, we provide reflections on 33 of the 127 undergraduate student projects we surveyed that concern sustainability over a period of 10 years at a problem-based learning (PBL) university as part of an Art and Technology degree program. Art and Technology is a STEAM education, where STEM (science, technology, engineering, and math) subjects are taught alongside artistic methods. Specifically, we investigate how students formulate sustainability problems within an art-based research framework by identifying the (1) themes within sustainability and art that were of most concern, (2) research aims of these projects within a PBL context, and (3) artistic and academic methods employed as part of the research process. Additionally, we provide select examples of the artistic outcomes of these student projects as evidence for how artistic methods and practices – by virtue of necessarily experiential work – can concretize the often abstract notion of sustainability, making it accessible to diverse student populations and the public.

Keywords: Sustainability, Art, Art-based Education and Research, Problem-based Learning, STEM, STEAM, Interdisciplinary, Art and Technology.

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INTRODUCTION

In 1987, the Brundtland report, defined sustainability – or how to make development sustainable – as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987, p. 286). As an early actionable plan, the so-called triple bottom line considered sustainability in terms of societal, environmental, and economic impact (Slaper et al., 2011). More recently, in 2015 the United Nations (UN) sought a more comprehensive strategy through the adoption of 17 Sustainable Development Goals (SDGs) based in part on the earlier 8 Millennium Development Goals (United Nations General Assembly, 2015). Collectively, the 17 SDGs formalize 169 sustainable targets and 232 indicators which range from aiming to secure clean water and sanitation to ensuring gender equality and climate action. Across the world and notably among countries in the Global North, the SDGs have been widely adopted and used as part of various sustainability initiatives by governments, organizations, and higher educational institutions alike.

Despite a large increase in sustainability research in the last decade, there remain basic challenges in defining what exactly sustainability is as well as how best to address it and even communicate its importance. In the case of the triple bottom line, some have noted conflicts both within and between its different pillars, for example, social and economic sustainability appear sometimes at odds with economic sustainability and growth (Horvath et al., 2023), while different understandings of what constitutes the right or most ‘green’ decision in any one pillar have been observed (Eskjær and Horsbøl, 2023; Horsbøl, 2023). With respect to sustainability communication and outreach, Smith (2019) has made a compelling argument against what he calls calculative rationality – where climate change is increasingly seen as a technical issue (e.g., by presenting it merely in terms of excess carbon in the atmosphere) and proposes that discourse surrounding sustainable development should strike a proper balance between rudimentary quantifications and more personal discussions concerning human experience and closeness to nature. Even the expansive set of indicators as part of the SDGs have been criticised as being too broad or confusing insofar as performing well according to one metric may actually hinder being able to perform well according to another (Diaz-Sarachaga et al., 2018).

Due in part to these difficulties with sustainability outlined above as well as the global rush to formulate suitable solutions going forward, sustainability has become an increasingly important area of focus in many higher educational curricula today (Finnveden et al., 2019; Lozano et al., 2015). Efforts to solve problems related to sustainability have sought to do so by integrating approaches from a variety of fields in increasingly transdisciplinary ways (Vermeulen and Witjes, 2020; Vermeulen and Keitsch, 2020; Martina M. Keitsch, 2020; Padmanabhan, 2017). Art-based educations and research offer an array of interesting and useful perspectives and methods for approaching difficult

problems, and in problem-based learning (PBL), in particular, there have been efforts to clarify their role in higher educations (Heinrich and Jochum, 2018; Jespersen, 2018; Heinrich and Kjørnø, 2021). It has been further suggested that the arts can play a key role in helping to address issues of sustainability, namely, through understandings that are obtained in necessarily embodied and experiential ways (McNiff, 2009; Kagan, 2017; Heras et al., 2021; Horvath et al., 2023). However, it is not as well understood how students have defined artistic problems in real-world cases nor what constitutes such problems with respect to sustainability in a PBL sense. It remains all the more challenging to understand how artistic practices and methods can be integrated alongside academic methods in this pursuit – particularly when artistic practices sometimes appear at odds with scientific inquiry and methods.

Art and Technology Undergraduate Degree Program

The focal point of our contribution is an analysis of student projects made as part of an undergraduate degree program called *Art and Technology* that was founded in 2008 as an interdisciplinary effort originally between two faculties at Aalborg University – the Faculty of Humanities and the Faculty of IT and Design. Course instructors and student supervisors for Art and Technology currently belong to one of four different departments and schools, the Department of Communication and Psychology, Department of Architecture, Design and Media Technology, the Business School, and Department of the Built Environment, collectively representing now three separate university faculties.

In 15–20 ECTS modules, *Art and Technology* students work together in groups on semester projects in a PBL environment. During these projects, students develop artworks that are exhibited at the end of each semester in a public-facing art exhibition where members of the general public are invited to attend. Each semester asks students to create projects that fit formally within a single theme or category: (kinetic) sculpture (1st semester), public space art (2nd semester), wearable (3rd semester), interactive installation (4th semester), and theater play/performance (5th semester). The 6th semester, titled *Art as Experience*, is dedicated to the completion of the student's bachelor's theses in which the form of the artwork and object of study may be freely chosen. Importantly, *Art and Technology* seeks to integrate methods derived from quite different epistemological fields, such as the humanities, engineering, and art, with generally artistic and design-oriented methods of creation coupled with research on real-world problems being defining characteristics of the study. In this way, *Art and Technology*, is a STEAM-based educational program that integrates knowledge from STEM fields with the arts.

Contribution

In this paper, we present the results from a survey of undergraduate student semester projects on sustainability from an *Art and Technology* degree program at Aalborg

University, a university widely known for PBL. We identify how issues surrounding sustainability are addressed in an education where students work in a problem- and project-based learning environment using art-based research as their primary mode of investigation. In particular, we discuss how problems of sustainability may be formulated in this context by identifying the (1) primary themes within sustainability and art that are of most concern to students, (2) specific research aim(s) or question(s) students chose to investigate within these themes, and (3) artistic and/or academic methods employed by students to formulate a PBL problem, design or create the artwork, and analyze the artwork and/or evaluate the research questions. In our analysis, we find that five primary themes of sustainability and art emerged concerning pollution, nature, health, capitalism, and reduced inequalities, while six research aims within these topics sought to either raise awareness about sustainability-related issues, promote behavioural change in audiences, challenge assumptions and opinions or provoke, propose solutions, speculate about possible futures, or provide self-understanding. Importantly, sustainability was conceptualized by students as either a matter of (i) disconnect – between humans and nature, humans and others, or between scientific communication and individual action, (ii) imagination (or lack thereof), or (iii) conflict and/or paradox. Our findings demonstrate the importance of art-based research in exploring problems in sustainability from diverse perspectives that provide tangible means for both students and the public to better understand these issues.

ART-BASED RESEARCH

Art-based research is a growing field with one possible definition as the “*systematic use of the artistic process, the actual making of artistic expressions in all of the different forms of the arts, as a primary way of understanding and examining experience by both researchers and the people that they involve in their studies*” (McNiff, 2009, p. 29). As a formal mode of inquiry, art-based research has multiple historical predecessors that can be found in the development of art itself. For example, these predecessors appear in the different avant-garde movements that were inspired by conceptual reflections on the various means of art, its social significance and position, and epistemological potential as an embedded part of artistic practice. Regardless of its origins, there has been a growing momentum during the last three decades for the use of artistic methods of creation in many academic research fields, such as the social and natural sciences, engineering, and other humanities fields. Developments in these disciplines have led to the appropriation of some aspects of the arts – not as a subject field (this has been the case for a long time in aesthetics, art theory, and cultural studies) but as a methodological field – that promises to expand the creative and productive dimension of academic research (Eisner, 1981; Barone and Eisner, 2012). For example, the entirety of the so-called *art and science*

movement is based on the acknowledgement of the interdisciplinarity that exists between art, engineering, and the natural sciences regarding design processes, product development, and even the concept of knowledge proper. Fundamentally, universities, art academies, and conservatories today are engaged in defining artistic research as an investigatory but systematic endeavor that further includes various types of reflection (Sullivan, 2010; Smith, 2019), evaluation, and dissemination (Biggs and Karlsson, 2011) as part of the creative artistic process.

Art-based research is interesting because it has at its core a basic paradox as its driving force, namely, that art making can uncover and make operational epistemological dimensions that scientific methods programmatically try to eliminate. This paradox is exemplified by the notions of subjectivity (the particular) and objectivity (the general). Artistic approaches are essentially subjective in that the artistic process is both propelled and filtered by quite personal investigations, including emotional and somatic aspects, without ordinarily any pre-established objective in the form of a research question or hypothesis (Borgdorff, 2011). Artistic forms of research have thus been criticized due to their somewhat unsettling methodological and epistemological grounding from the perspective of scientific inquiry and objectivity (McNiff, 2009). Art-based research, on the other hand, generally considers the artistic idea and artifact as most often part of more structured investigations with precise research questions and hypotheses. Moreover, one integrates artistic methods both alongside those traditionally associated with scientific inquiry and as empirical methods onto themselves. Artistic methods in this context can take many forms, ranging from idea generation and the creation of artistic artifacts as means for collecting empirical data to artistic/aesthetic presentation, investigation, and dissemination (Savin-Baden and Wimpenny, 2014). Empirical methods might include those belonging to ethnography, such as observations, surveys, or interviews that can inform the creation of artistic works. Such methods are often ‘recontextualized’ as artistic methods, however, as empirical data, they can be analyzed in terms of emotional and somatic experiences of either the creator or audience (Heinrich, 2018, 2014). Autoethnographic methods serve as good examples for how artistic and empirical methods might be integrated in service towards artistic means and outcomes in this way.

Sustainability and art-based education

Since the UN declared a Decade of Education for Sustainable Development in 2002, a growing number of higher educational institutions have begun to tackle sustainability at different levels (Wals, 2014). Sometimes, these changes are institution-wide, where a clear sustainability focus is enforced in a top-down manner on research, education, and the general administration of the university (Waas et al., 2010; Lozano et al., 2015). Regardless of institutional policy, however, in the last few years sustainability has been an area of focus that is being increasingly integrated into higher education curricula from

the bottom up. With the urgency of climate action, many researchers now feel compelled to pivot towards sustainability as climate-conscious students demand it be taught and discussed in the classroom. However, sustainability discourse in this regard has largely played out in the natural sciences and technology (Siegner and Stapert, 2020; Shrivastava et al., 2012) and less so in the arts and humanities (Bentz, 2020). Some have argued that while the arts and humanities, in general, can make significant contributions in tackling climate-change-related issues, these fields remain largely untapped or underutilized (Bentz, 2020; Heras et al., 2021; Shrivastava et al., 2012).

Both climate change communication and sustainability education have been criticized for being too abstract and complex to the point that they contribute to feelings of pessimism and anxiety about the future (Ojala, 2012), which can translate to a so-called climate-change disconnect (Mitchell and Laycock, 2019; Kiem and Austin, 2013; Bendor, 2018). In order to tackle this climate-change disconnect, some authors have called for an artistic turn in sustainability science (Kagan, 2017; Heras et al., 2021), arguing that artistic research and artful learning can contribute to transdisciplinary knowledge building which is considered a cornerstone of sustainability progress. Yet, in spite of general consensus that sustainability, as a complex issue, should be addressed as a joint effort across disciplines, e.g., by integrating STEM with the arts, humanities, and social sciences (Marcone, 2022), how to effectively carry out transdisciplinary collaborations as well as how to integrate diverse knowledge fields and, importantly, what the results of this integration could be, remain hard to discover (Sellberg et al., 2021; Pohl et al., 2020, 2021).

MATERIALS AND METHODS

We surveyed a total of 127 undergraduate student group semester projects made from 2012 to 2022 across all semesters as part of *Art and Technology*, a STEAM degree program at a PBL university – Aalborg University. All projects were supervised by four of the authors – all of whom are current teachers and supervisors for this degree program. These 127 projects were first independently screened by their respective supervisor for their relatedness to the topic of sustainability and then narrowed down accordingly, resulting in a final total of 33 projects (26 percent) that explicitly concerned one or more topics of sustainability in a concrete way. Next, each of these 33 projects was assigned a pair of coders with one being the supervisor of the given project and the other being a randomly chosen teacher from one of the remaining three supervisors for the projects. Each coder independently assessed their respective set of projects along the following seven criteria: (1) Sustainable Development Goal(s) (SDGs), (2) form and/or medium of the artwork, (3) primary theme(s) within sustainability and art (4) research aim(s) or question(s), (5) artistic and/or academic methods used to formulate the PBL problem, (6) artistic and/or academic methods used to design or create the artwork, and (7) artistic

and/or academic methods used to analyze the artwork and/or evaluate the research question(s). After this independent assessment, each pair of coders reviewed their assessments of each project together in order to reach a consensus regarding these seven criteria.

In visualizing the results of our analyses, we employ two methods. First, we use basic word clouds for illustrating the most frequently occurring words used to describe each project – according to the students – as found in the respective abstracts of each project and group these clouds by the SDGs we have identified. In creating the word clouds, the text was made lower-case, common words (e.g., ‘the’) were removed, and the remaining words were stemmed. As the thematic and methodological relationships between projects is not necessarily evident from word clouds alone, we provide additional qualitative analyses intended to synthesize our findings along two dimensions. Our second method thus takes the form of two sets of thematic clusters aimed at illustrating the primary theme(s) within sustainability and art as well as the research aim(s) of each project as identified and interpreted by the authors (i.e., supervisors of the projects). Additionally, we provide images from select projects most representative of each of the research aims identified in our analysis as real-world evidence for the artistic and public-facing outcomes of these projects.

ANALYSIS OF STUDENT PROJECTS AND ARTWORKS IN *ART AND TECHNOLOGY*

In this section, we present our analysis of the 33 student projects (shown in Tab. 1) we identified as concerning one or more topics of sustainability. We begin with word clouds illustrating the most frequently used words used by the students in the abstracts of the projects for each of the SDGs that we observed were most relevant. Next, we present our thematic analysis of these projects according to the primary theme(s) within sustainability and art identified in each. We conclude with our second thematic analysis made according to the research aim(s) identified in each project and provide images from select projects for each of these aims. It is important to note that in our analysis we do not investigate the students’ personal experiences with these projects beyond what has actually been written in each report.

Word clouds from project abstracts according to the UN’s Sustainable Development Goals (SDGs)

Figs. 1 to 4 show word clouds indicating the most frequently occurring words in the abstracts of student projects along the nine SDGs that we identified as being of primary focus in these projects. Note that not all SDGs were addressed but of those that were addressed, some were done so more frequently than others.

Ten out of the 33 projects had as their primary goal, *SDG3: Good health and well-being* (Fig. 1, top). The words which appear most frequently (and thus appear larger in the image) include *feelings, thoughts, experience, anxiety, mental, bipolar, gut*, but also *noise, pollution, and nature*. These words illustrate the projects' foci on general health as well as mental health, in particular, but also the students' perceived connection between various forms of pollution and health. In contrast, the word cloud for *SDG10: Reducing inequality within and among countries* (Fig. 1, bottom) consisted of only a single project which contained words such as *context, inclusivity, individual or includes*.

The words used with high frequency for *SDG5: Gender equality* (Fig. 2, top) include *sex, harassment, touch, unwanted, social, and sexuality*, as the two projects for this SDG engaged with topics involving sexual harassment. Six projects dealing mainly with different types of pollution and a lack of nature in cities had as their primary goal, *SDG11: Making cities and human settlements inclusive, safe, resilient and sustainable* (Fig. 2, bottom), and the most frequently used words include *nature, pollution, sound, movement, and space*.

Most of the projects corresponding to *SDG12: sustainable consumption and production* (Fig. 3, top) dealt generally with environmental waste and individual food waste more specifically, with words such as *food, waste, sustainable, self, and efficacy*. Similarly, the projects for *SDG13: Take urgent action to combat climate change and its impacts* (Fig. 3, bottom) engaged with different aspects of environmental degradation and how these might translate to future living conditions with words such as *climate change, environmental consequences, glaciers, pollution, problem, future, and pressing*.

The word cloud corresponding to *SDG14: Conserve and sustainably use the oceans, seas and marine resources* (Fig. 4, top) consists of two projects that had as some of their most frequently occurring words, *affect, encounter, sound, fiction, research, and scientific*. These projects sought to create experiences of underwater environments and speculate on climate-science futures in which water levels had risen to the point that coastal human habitats were flooded and humans needed to adapt to living under water. Another two projects concerned *SDG15: Protect, restore and promote sustainable use of terrestrial ecosystems* (Fig. 4, middle) and sought to create an emotional connection to nature through sound and show audiences the importance of biodiversity with their most frequently used words being *sound, listening, natura, time, space, and analysis*. Lastly, two projects concerned *SDG16: Promote peaceful and inclusive societies* (Fig. 4, bottom) with frequently occurring words such as *surveillance, privacy, behavior, camera, and negative*. These projects dealt with issues of surveillance through technologies, such as face recognition or faux consent for data gathering, and how these contribute to the erosion of democratic institutions. The artworks served as critical or provocative probes aimed at educating people about how large companies and governments collect private data.

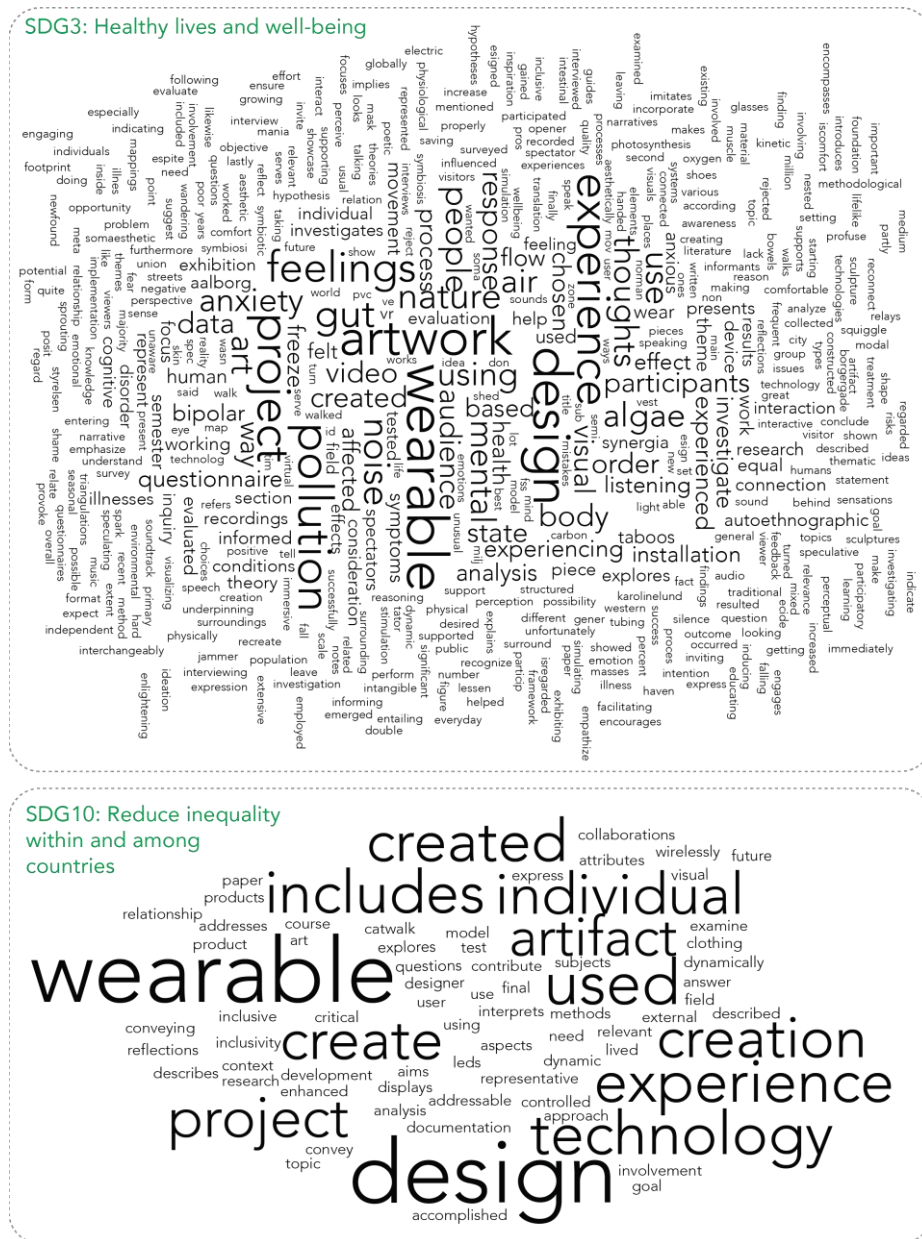


Figure 1. Word clouds created from the abstracts of Art and Technology student projects having SDG3 (top, 10 projects) and SDG10 (bottom, 1 project) as their primary goal.

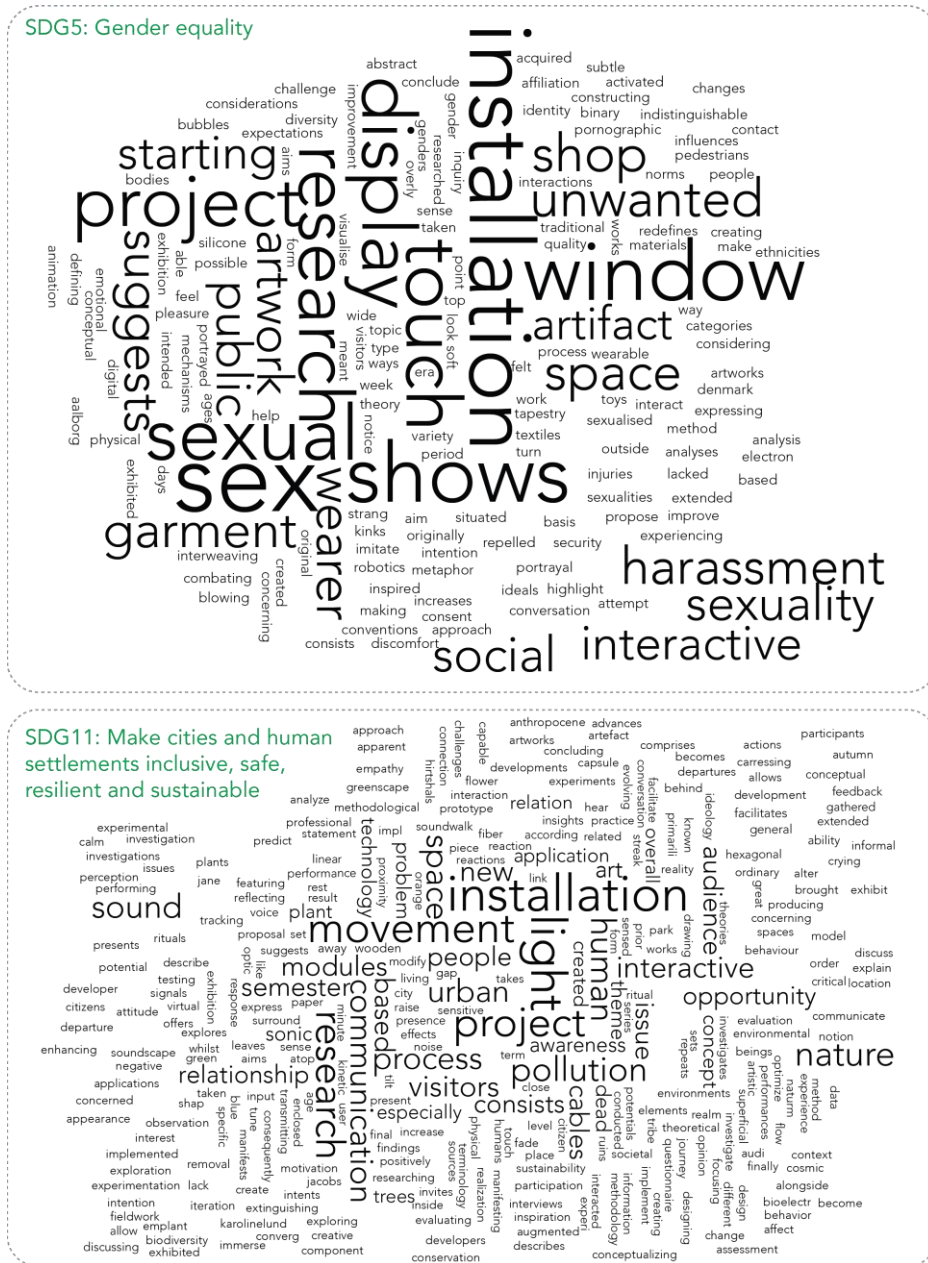


Figure 2. Word clouds created from the abstracts of Art and Technology student projects having SDG5 (top, 2 projects) and SDG11 (bottom, 6 projects) as their primary goal.

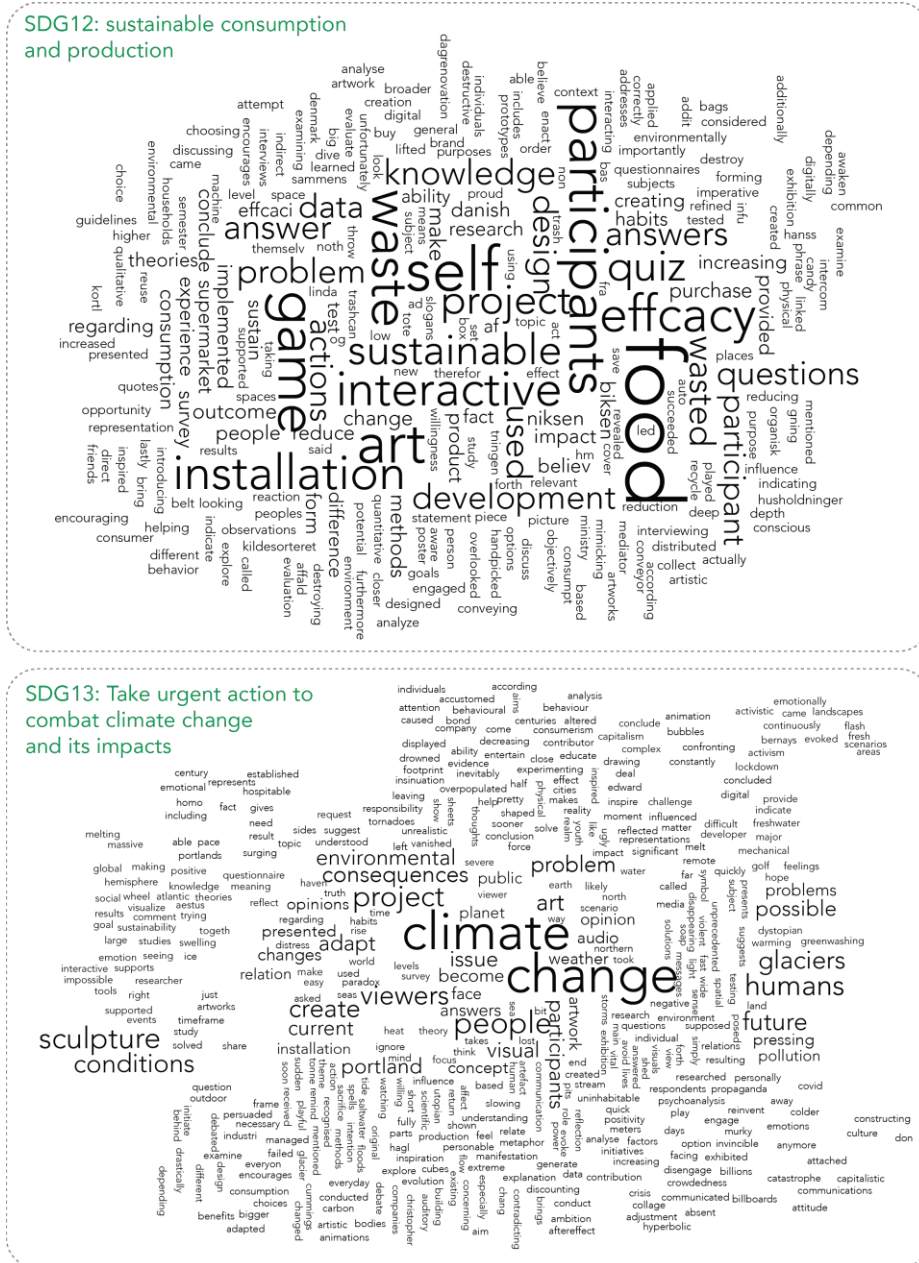


Figure 3. Word clouds created from the abstracts of Art and Technology student projects having SDG12 (top, 3 projects) and SDG13 (bottom, 5 projects) as their primary goal.

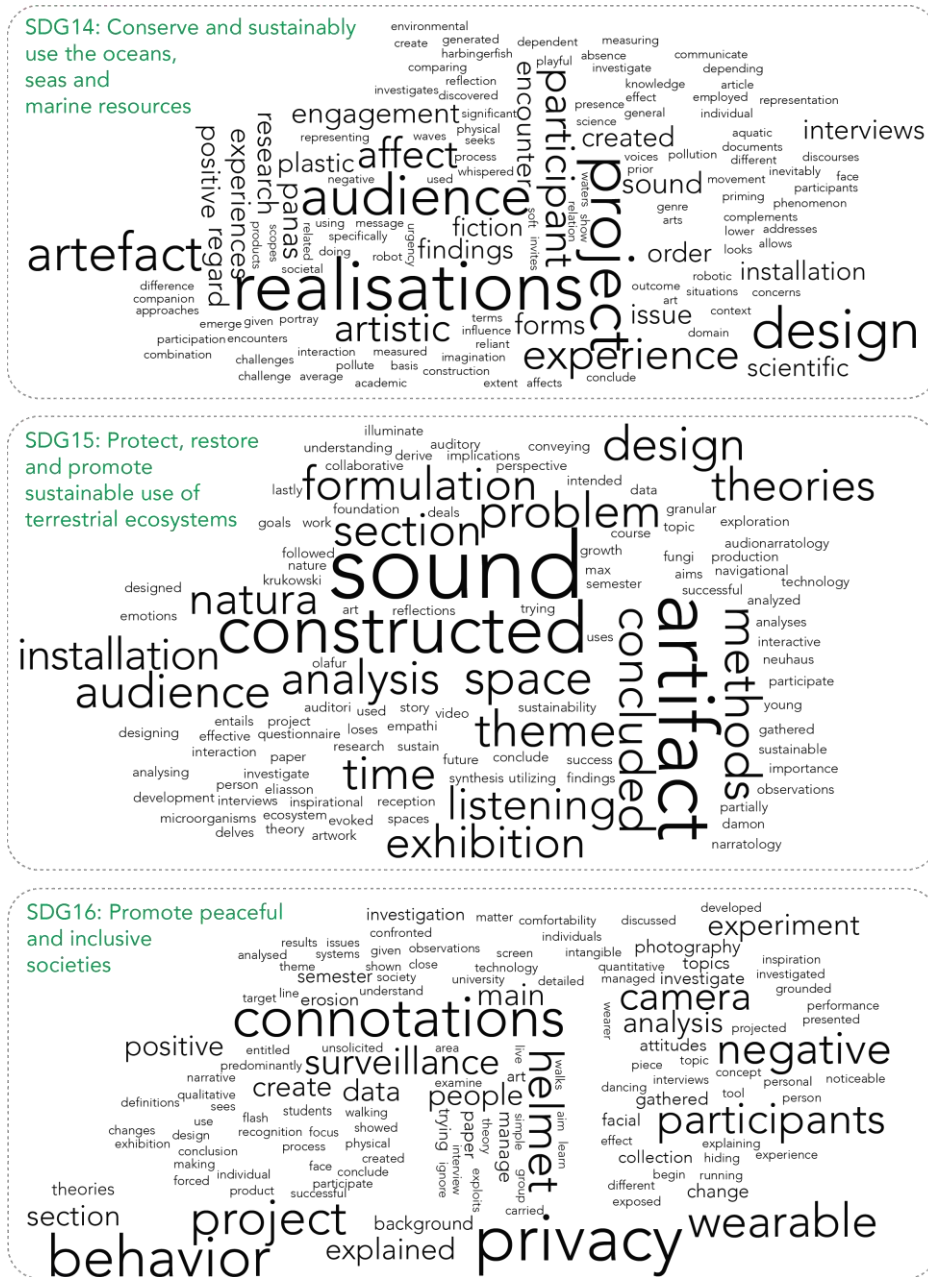


Figure 4. Word clouds created from the abstracts of Art and Technology student projects having SDG14 (top, 2 projects), SDG15 (middle, 2 projects), and SDG16 (bottom, 2 projects) as their primary goal.

Thematic clusters of primary theme(s) within sustainability and art

Fig. 5 shows our analysis of the projects clustered according to the primary themes within sustainability and art that we identified. Five main clusters emerged with one or more sub-themes in each:

1. **Pollution** with sub-themes of **light, sound, air, and plastic**
2. **Nature** with sub-themes of **creating a connection to nature** and **destruction of nature**
3. **Health** with a sub-theme of **mental health**
4. **Capitalism**
5. **Reduced inequalities** with sub-themes of **gender politics, democracy, and surveillance**

In Fig. 5, projects that sit at the intersections between different themes and sub-themes deal with all those that they intersect.

Overall, six projects dealt with pollution in some way, ten projects dealt with nature, six projects dealt with mental health, five projects dealt with capitalism, and another six projects dealt with the topic of inequality. Regarding the cluster for *Pollution*, students dealt with the subject in various forms and media with one project about light pollution, three projects about sound pollution, four projects about air pollution and air quality, and one project about plastic pollution. Of the projects having to do with *Nature*, six focused on creating empathy towards nature or bringing it closer to human experience, and three dealt with the destruction of nature, illustrating possible environmental catastrophes or how possible futures would play out if the erosion of ecosystems and natural habitats continues at its current pace. Out of the six projects that dealt with *Health*, four concerned mental health in different forms from anxiety and seasonal affective disorder to bipolar disorder. From the six projects concerning *Reduced inequalities*, two dealt with gender politics, one explored democracy and including citizens in decision-making processes for city planning, and two dealt with surveillance, privacy, and consent when sharing personal data.

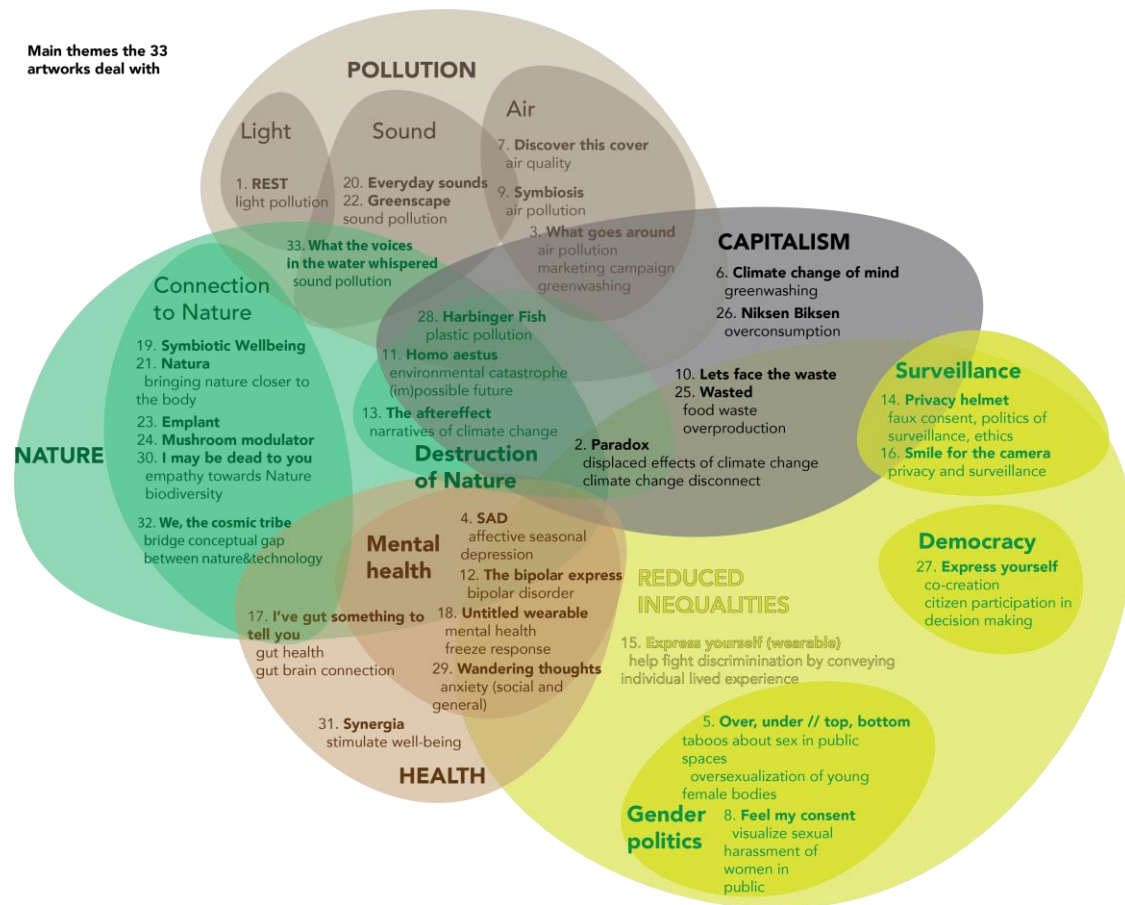


Figure 5. Thematic clusters of Art and Technology student projects categorized according to the primary theme(s) within sustainability and art observed in our analysis.

Thematic clusters of research aims

Fig. 6 shows our analysis of the projects clustered according to the research aims that we identified and are colored according to their primary themes within sustainability and art indicated in Fig. 5. Six main clusters emerged:

1. **Raise awareness** about sustainability related issues
2. **Promote behavioral change** in audiences
3. **Challenge assumptions and opinions or provoke**
4. **Propose solutions** to sustainability-related issues
5. **Speculate** about possible futures
6. **Self-understanding** in which students use the process of creating the artwork to better understand themselves

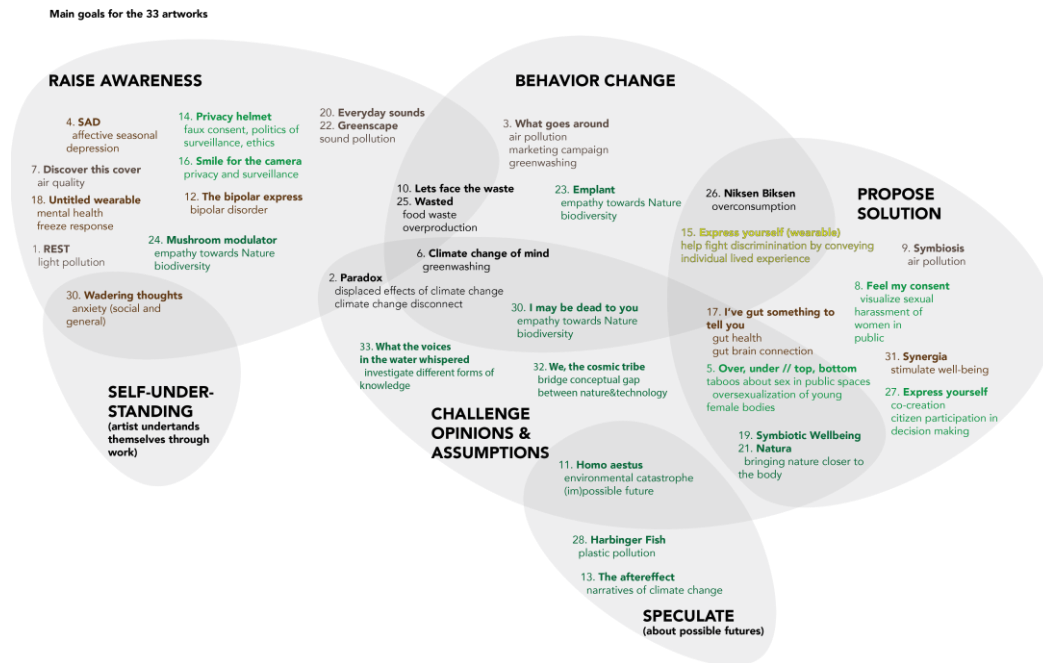


Figure 6. Thematic clusters of Art and Technology student projects categorized according to the research aims observed in our analysis.

Similarly to before, some projects lie within two or three different clusters. For example, many of the projects sought to both challenge preconceptions about a subject and further offer a resolution. Accounting for all projects in this way, eleven sought to educate or raise awareness about different sustainability related issues with one of these having the goal of both raising awareness about mental health and producing self-understanding. Additionally, ten projects offered solutions to sustainability related issues and three projects sought to either speculate or explore fiction as their research aim, for example, by exposing audiences to the realities of the effects of rising sea levels. Eight projects sought to instill behavioral change in their audiences, and another ten aimed to challenge inherent opinions and assumptions. It is interesting to note that the number of projects that aimed to raise awareness in audiences is the same as the number of projects which proposed actual solutions to sustainability related problems. While artists are not traditionally well accustomed to encountering problems that require “solutions” as is frequently the case in STEM disciplines, the equal distribution between projects that give solutions and projects that raise awareness could be due to the interdisciplinary nature of the *Art and Technology* program and is enlightening in terms of the possible outcomes of STEAM collaborations. Below, we describe in more detail one or more given artworks most representative of each of the six clusters identified in Fig. 6 above.



Figure 7. The Bipolar Express, a wearable artifact that aims to create awareness in wearers and observers of bipolar disorder. Project and photographs provided courtesy of Tasja L. Dahlstrøm, Emilie Klemmensen, Sirichok Ruamwong, and Nicoline Mou (2021).

Raise awareness. *The Bipolar Express* (Fig. 6) is a wearable artwork that aimed to educate and raise awareness of the symptoms and experiences of bipolar disorder through an interactive experience. The artwork was developed using autoethnography and consisted of three individual pieces, that together interchangeably represent the three conditions: mania, depression, and mixed conditions. The pieces incorporate different technologies, such as convertible glasses, speech jammer, and electric muscle stimulation as a means for achieving the artwork's desired effect.



Figure 8. Discover this cover, an artwork that aims to raise awareness about air pollution. Project and photographs provided courtesy of Alena Komperova, Anna Major, Irene Liut, Kamilla Mez, and Roxana Roşu (2017).

Another project that had as its research aim to raise awareness about issues surrounding sustainability is *Discover this cover* (Fig. 8). The artwork took the shape of a wearable artifact that aimed to create awareness around fine particle air pollution by extending the audience's perception during an interactive experience. The physical form of the art piece is a vest that takes inspiration from life-saving vests and combines this with inflatable

soft-robotic elements on the inside that create pressure on the wearer's chest in accordance with rising levels of fine particle air pollution.



Figure 9. Wandering thoughts, an autoethnographically-informed audio-visual experience that aims to provide one with greater personal insight into the lived experience of an individual with anxiety. Project and photographs provided courtesy of Anonymous Student Name (2020).

Self-understanding. *Wandering thoughts* (Fig. 9) is an audio-visual experience that aimed to give an account of how it feels to live with general and social anxiety. The project was developed using autoethnography and sought to educate and create awareness about mental health issues as well as provide a greater self-understanding of the creator herself. The student reported that her use of autoethnography to develop the experience also helped her become more aware of the situations in which her anxiety would arise and helped her to better understand her condition and ultimately manage it better.

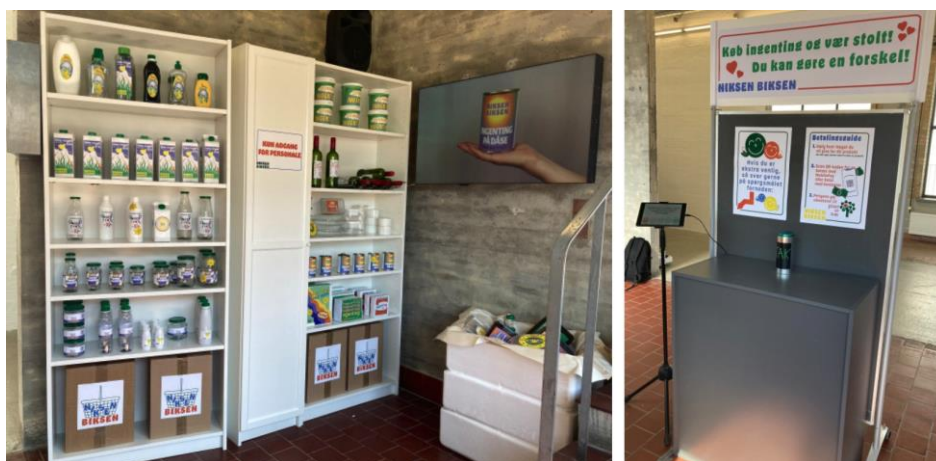


Figure 10. Niksen Biksen, an interactive art installation in the form of a faux grocery store in which a person purchases 'nothing' as a means for becoming more aware of over-consumption while donating to charity in the process. Project and photographs provided courtesy of Johanna Møberg

Lauritzen, Olivia Fenger Hove, Anne Katrine Muhligh Ejstrud, Tasja Langhoff Dahlstrøm, and Benjamin Sarthak Elton Baagøe-Thomsen (2022).

Behaviour change. *Niksen Biksen* (Fig. 10) is an interactive installation staged as a grocery store where audience members could buy ‘nothing’. The students collected the trash they produced during the semester and repurposed some of it into empty objects one could buy from this faux supermarket. Upon leaving the experience, the audience member could take home store items of trash by paying a certain price. The money was then donated to a charity that planted trees. The aim of the artwork was to invite the audience to reflect on their own over-consumption all while having a real-world impact on sustainability.



Figure 11. *What the water whispered through the waves*, an artwork that sought to provide listeners with a real-time experience of underwater sounds as a means for investigating sound pollution. Project and photographs provided courtesy of Christine Hvidt Grønberg (2019).

Challenging opinions and assumptions. The artwork *What the water whispered through the waves* (Fig. 11) investigated the difference between scientific and artistic forms of knowledge generation and dissemination. Scientific knowledge was presented in the form of an academic research paper about underwater sound pollution and the artistic knowledge was conveyed through a sound installation created by the student displaying real-time underwater sounds from different sites in the local city’s surrounding waterway. The research design thus consisted of two parts: reading excerpts of the scientific article and listening to underwater sound in the context of an art installation. The project asked whether the order of the presented forms of knowledge influenced the overall experience of the installation.



Figure 12. Symbiosis, a wearable bio-reactor filled with algae that proposes a solution to the problem of air pollution through a symbiotic relationship between artifact and wearer. Project and photographs provided courtesy of Emma Purkær, Frederik Melving Vigil Hansen, Mia-Maja Madsen, and Sólja Holm Mortensen (2019).

Propose solutions to problems. *Symbiosis* (Fig. 12) is a wearable artwork that aimed to enlighten the audience about air pollution by providing a potential solution to the problem. The piece consisted of a wearable bioreactor in the form of a coat with PVC as the base material and a container and tubing system that circulated an algae culture. The algae created a symbiotic relationship with the wearer converting the heat and carbon dioxide provided by the wearer through photosynthesis into oxygen that, through a face mask connected to the tank, was recycled back to the wearer.



Figure 13. Harbingerfish, an artwork that uses speculation in the form of design fiction to challenge the audiences' perception of the environmental concern of microplastics in the ocean. Project and photographs provided courtesy of Anna Dagmar Bille Milthers and Sidsel Abrahamsen (2019).

Speculate about possible futures. *Harbingerfish* (Fig. 13) is a bio-engineering design fiction that addresses the issue of micro-plastic pollution in oceans. The artwork proposes a speculative future in which jellyfish, that were genetically engineered to destroy plastic in the ocean, evolved into a new species with an exterior of plastic due to bacteria that bind with micro-plastics. The interactive sculpture consisted of a scientific poster, as well as an aquatic soft robot that would react to the audience getting closer to the aquarium in

which it was placed. The purpose of Harbingerfish was to engage with audiences in discussions around current problems and potential solutions to micro-plastic pollution.

DISCUSSION

The interplay between how students in an *Art and Technology* degree program in which art-based research is the primary means of investigation formulate sustainability-related problems is interesting from the perspective of PBL. Such students are introduced to methods and theories that come from artistic, designerly, and scientific methodologies, traditions, and ways of thinking and knowing. How students thus formulate problems in these ways and understand that these problems should be addressed in the first place are not necessarily well aligned with established disciplinary traditions. An analysis of problem formulations in student projects, as we have begun to provide here, can illuminate the various possible ways in which the arts might be integrated in STEM educations and how this integration could further contribute to sustainability-related research. With the projects presented here, students formulated sustainability-related problems within a PBL structure that ensured they were not only personally relevant to them, for example, through research aims of self-understanding but also representative of real-world problems facing society at large. Sustainability thus became not merely an abstract and distant topic but something that could be personally experienced by the students and their public alike. It could be said that allowing students to formulate problems themselves can help alleviate the climate-change disconnect that has sometimes been reported in classrooms (Ojala, 2012). Over the last decade, over a quarter of all projects we supervised dealt concretely with sustainability, even when the topic was not enforced from above, by teachers or curricula, demonstrating that students consider this topic important and appear motivated to contribute towards a more sustainable future.

Jespersen (2018) has previously analyzed problems students formulated in an *Art and Technology* program through a framework developed by philosopher, Mogens Pahuus, in which problem orientations can be either theoretical or applied. Applied problems can be societal-humane or practical-productive (Pahuus, 2004). Societal-humane problems concern fairness, justice, or well-being, while practical productive problems deal with situations that can be improved in terms of functionality or efficiency. Solving practical-productive problems would result in expanding or improving tools and methods which translate, for example, into new technologies (Jespersen, 2018). Jespersen states that while all these types of problems are addressed in a hybrid study program such as *Art and Technology*, the majority of the problems in her analysis are applied problems from the societal-humane category rather than theoretical problems. Only ten of the projects we analyzed had as their research aim to propose actual solutions to sustainability related problems, which could be considered practical-productive problems within Pahuus's

framework (see Fig. 5). However, some projects engaged critically with definitions of the term sustainability itself, which suggests they could be placed under Pahuus' theoretical problem orientation - meaning the artworks contribute to theoretical discussions surrounding and defining sustainability.

In order to develop the projects we surveyed, students created artworks and exhibited them in public-facing exhibitions at the end of each semester. Through this process, students re-defined their own understanding of sustainability and provided audiences with the opportunity to engage critically with the subject themselves. Many of the artworks sought to create awareness, raise awareness, or provoke audiences to think differently. A key component of this process lies in inviting audiences to inhabit sustainability problems by living them out (Olsen, 2023). Instead of mere climate-science communication or visualization, students worked with concepts such as *empathy* or *speculation*. Many projects sought to make audiences somatically *experience* different sustainability-related issues: i.e. full-body suits provided audiences with a sense of how it might feel to have bipolar disorder. Audiences could be involved at various somatic levels of engagement, including visceral, emotional, physical, and cognitive-conceptual (somatic engagement refers here to the embodied and lived quality of aesthetic and artistic experience and not solely to the philosophical discipline (Shusterman, 1999)). Moreover, it could be argued that the students' own personal involvement along all somatic levels in creating the artworks allowed for a greater understanding of how best to similarly engage their audiences.

If we consider our findings in a broader context, we can identify three types of sustainability-related problem orientations that guided our student projects. First, a number of the projects considered people's behaviour as being somehow at odds with or disconnected from issues surrounding sustainability. Second, another set of projects explored links between sustainability and imagination, speculation, and futuring. Finally, the remaining projects identified various conflicting views about what sustainability is, how it should be defined, or paradoxes surrounding the topic. We describe each of these in further detail below.

Sustainability as an issue of disconnect

Climate-change disconnect has been a well-documented phenomenon (Mitchell and Laycock, 2019; Kiem and Austin, 2013; Ojala, 2012; Wu and Lee, 2015), and many of the sustainability problems formulated in the student projects can be viewed through this lens in one of three ways: (1) a disconnect between people and nature, (2) a disconnect between people and other people, and (3) a disconnect between people and abstract scientific communication and the displaced effects that climate change has over space and time.

Disconnect between humans and nature. Several projects identified a disconnect that people have towards nature and argued that this is one of the reasons people fail to act more sustainably. Students tried to mitigate this disconnect by creating experiences that instill empathy towards the environment. Examples in this category include artworks such as *Mushroom modulator*, *Emplant*, and *I may be dead to you*. This human-nature disconnect has also notably been discussed in ecological perspectives and later eco-feminist theories (d'Eaubonne, 1974; Bardzell, 2010). These theories argue that the current means of production that mistreat the planet lack care towards the environment and nature which is conceptualized as “chaotic, irrational and in need of control” (Miles, 2018, para. 2). This need to control nature had its origins in the first industrial revolution and has since alienated people from natural environments (Zuboff, 2019). Through their artworks, students tried to bring to the forefront ideas such as *caring for nature* as a sustainability imperative.

Lack of human-to-human connection. Students also identified a body-mind disconnect and a lack of human-to-human connection in understanding or empathizing with one another in the context of some sustainability topics. They proposed alleviating this disconnect by creating artworks that educate and show (often through experiences where the audience is made to feel *empathy*) how it feels to inhabit another person’s body and experience their lived condition. Many of the projects that concerned mental health, for example, lie within this category but so do some of those that dealt with sexual harassment, violence, or discrimination. Examples include *Bipolar express*, *SAD*, *Wandering Thoughts*, *Express Yourself*, and *I’ve got something to tell you*. These artworks touch on political dimensions and bring forward conversations about inclusivity in general, including discrimination and/or violence based on health conditions, race, or gender. These projects touch on a crucial topic, namely, the importance of politics but also on democracy and equality in human rights in achieving ambitious climate goals (Hamilton, 2011), which could be placed alongside recent work on design justice (Costanza-Chock, 2020; Dombrowski et al., 2016).

Disconnect between climate change action and climate science communication. Several other projects identified a disconnect between climate-science communication and decision making by both individuals and society. Smith (2019, p. 1) states that the field of sustainability is “quickly moving down the track of abstraction, quantification, and neoliberalisation”. He argues that while current conceptualizations of sustainable development seem neutral, they come from specific assumptions about the world and the role of humans in it. In the most prevalent discourses today, ‘solving’ issues of sustainability is considered through the lens of mathematical quantification or calculability (Smith, 2019). Narratives of quantification (e.g., carbon footprint, energy use, and carbon offset) frame the issue in too abstract terms that make it difficult to determine what is a ‘good’ carbon footprint threshold, and what does one’s carbon footprint mean exactly for

the individual? Students identified this as a problem of disconnect and proposed that, through their artworks, they could contribute to resolving this disconnect. For example, the project *Let's face the waste* asks, why does society (in the Global North) continue to over-produce in order to later create waste from this over-production? The artwork shows the audience member how their individual choices result in food waste and presents this to them not as information in the form of the number of kilograms/person/year/country but directly, as actual food being wasted as a consequence of their actions (Sinclear et al., 2022).

Sustainability and the role of imagination

Sustainable development has something to do with planning for the future. This requires though that possible futures are first imagined before they can be planned for, and collective imagining can play a critical role in shaping productive narratives. Many authors have argued for using fiction and speculation as tools for planning for sustainability and the future (Sustar et al., 2020; Dourish and Bell, 2014; Bates et al., 2012; Burton et al., 2023; Wakkary et al., 2013; Dunne and Raby, 2013; Russell and Yarosh, 2018; Wang et al., 2021). Appropriately, some of the students have indeed used speculation and fictioning about possible or probable futures as a means to address and think about sustainability through their artworks. Examples of such projects include *Harbingerfish*, *Homo aestus*, and *The aftereffect*. By crafting future fictional worlds based on climate change-informed predictions and data, these projects presented audiences with concrete and immediately accessible manifestations of the effects of climate change, thus making climate-change prediction informed futures feel less abstract.

Sustainability conflicts and paradoxes

Finally, some of the artworks we surveyed identified conflicting views and paradoxical definitions about sustainability, including *Niksen Biksen*, *What goes around*, *Paradox*, or *Climate change of mind*. For example, when creating the artwork, *Niksen Biksen*, students described their problem field simply: sustainability is not good for business. The triple bottom line is not a useful framework in this case, as economic sustainability can be at odds with environmental or societal sustainability. The project report for *Niksen Biksen* starts with a critique of *SDG12: Ensure sustainable consumption and production patterns*. While reading through the goal, students noticed that only one of its 11 targets mentions the need to reduce consumption, which they found insufficient. Other projects described similar problems as informing their artworks. While some authors have been critical of the SDGs (Smith, 2019), these views are not the same as those dominating public discourse on sustainability, and many higher-educational institutions have taken up the SDGs as guiding principles. By engaging with what sustainability means as a concept to both individuals and society, a case could be made that artworks such as those created by the students actually engage with theoretical problems that can contribute to building new theories and understanding on the subject.

#	Title	SDG	Research Aim	Artwork Form	Problem	Design	Evaluation
1	REST	11, 12	Reflection on audience (and societies) actions as light polluters	Interactive Sculpture		Design Thinking, Double Diamond, Mind Mapping, Sketching, Brainstorming	Questionnaire, Observation
2	Paradox	12, 13	Reflection on how consumption patterns impact on climate change	Interactive Sculpture		Design Thinking, Double Diamond	Questionnaire, Interview
3	What goes around	12, 13	Exposure (and reflection) of greenwashing in marketing campaigns	Interactive Sculpture	Site Analysis	Design Thinking, Double Diamond	Questionnaire, Interview
4	SAD	3	Awareness about seasonal affective disorder	Interactive Sculpture	Auto-ethnography	Design Thinking, Sketching, Brainstorming, Mood-boards	Questionnaire, Observation
5	Over, under // top, bottom	5, 10	Re-conceptualize sexuality and the over-sexualization of young female bodies in public spaces	Interactive Sculpture	Site Analysis	Design Thinking, Interview	Interview, Observation, Focus Group
6	Climate change of mind	13	“Awareness and opinion change about how companies manipulate their ‘numbers’ to look sustainable (greenwashing)”	Digital Experience		Mind Mapping, Brainstorming, Moodboard, Storyboard, Design Fiction	Questionnaire
7	Discover this cover	3, 15	Create awareness of, embody the air quality and make it possible of being experienced by the audience member	Wearable		Sketching, Brainstorming	Questionnaire, Observation
8	Feel my consent	5, 10	Create awareness about sexual harassment of women in public	Wearable	Auto-ethnography	Interview, Sketching, Moodboard	Questionnaire, Interview, Touchmap (Dunbar et al. 2015)
9	Symbiosis – A Wearable Bioreactor	3, 15	Create awareness of air pollution by creating a solution (bio-reactor)	Wearable		Sketching, Brainstorming	Questionnaire
10	Let’s Face the Waste	12	Create awareness about food waste and learning of food literacy	Interactive Sculpture	Auto-ethnography	Sketching, Brainstorming, Serious Game Design, Provocative Design	Interview, Observation, Serious Game Design
11	Homo Aestus	13, 14	Create awareness about the impact of climate change and the potential needed human adaption	Wearable		Mind Mapping, Sketching, Brainstorming, Design Fiction	Questionnaire, Interview, Observation
12	The Bipolar Express	3	Educate the audience about symptoms of Bipolar Disorder	Wearable	Auto-ethnography, Concept Map	Sketching, Autoethnography, Inclusive Design	Questionnaire, Interview, Thematic Coding, Word Cloud Analysis, Self-Assessment Manikin
13	The Aftereffect	13	Create awareness of the impact of climate change	Interactive Sculpture	Mind Mapping, Brainstorming	Sketching, Serious Game Design	Observation, Serious Game Design
14	Privacy Helmet	16	Create awareness and change attitude about surveillance through technology	Wearable		Mind Mapping, Sketching, Brainstorming	Interview, Grounded Theory

15	Express Yourself	10, 17	Create awareness of marginalized and other peoples lived experience towards a more inclusive society	Wearable	Brainstorming	Inclusive Design, Human Centered Design, Co-Design	Questionnaire, Interview
16	Smile for the Camera	16	Create awareness and change perception of surveillance in society	Wearable	Brainstorming	Sketching	Observation, Word Cloud Analysis, Narrative Inquiry
17	I've Gut Something to Tell You	3	Create a sense of union between body and mind (breaking taboos on what is acceptable from human bodies, especially in public settings)	Wearable	Auto-ethnography	Narrative Inquiry, Speculative Design	Interview, Thematic Coding, Narrative Experience Writing
18	Untitled Wearable	3	Create awareness of the effects of the freeze response as a mental problem	Wearable	Auto-ethnography	Design Thinking, Double Diamond, Sketching	Questionnaire, Interview, Feeling Wheel (Willcox, 1982)
19	Symbiotic Wellbeing	3	Create an understanding for the importance of the connection between humans and nature	Wearable		Design Thinking, Double Diamond, Sketching	Questionnaire, Focus Group
20	Everyday Sounds	3, 11	Create awareness for noise pollution in urban environments	Interactive Sculpture	Site Analysis	Sketching	Questionnaire, Feeling Wheel (Willcox, 1982), Video Observation Analysis
21	Natura	15	Create emotional connection between audience and nature	Sound Installation		Brainstorming	Questionnaire
22	Greenscape	11	Create awareness of noise pollution in urban- and green environments	Sound Installation		Sound Walking, Deep Listening	Interview, Observation, Visitor Heatmap Analysis
23	Emplant – Sounds of a Plant in Distress	11, 15	Create empathy for plants to cultivate pro-environmental behaviour	Sound Installation	Personas	Brainstorming, Sketching, Observation, Human Centered Design	Questionnaire, Interpersonal Reactivity Scale (Tam, 2013), Environmental Attitude Scale (Kortenkamp and Moore, 2001)
24	Mushroom Modulator	15	Create awareness towards the necessary presence of microorganisms and mushrooms in an ecosystem	Sound Installation	Site Analysis	Sketching	Interview, Video Observation Analysis
25	Wasted	12	Create reflection on plastic consumption and food waste	Digital Experience	Questionnaire	Sketching, Iterated Design Process (Dahlstedt, 2012)	Questionnaire
26	Niksen Biksen	12	Create awareness of over-consumption	Interactive Sculpture		Speculative Design	Sustainable Development, Self-Efficacy Questionnaire
27	Express Yourself: a research on communication between citizen and city planner	11, 17	Facilitate collaboration between citizens and city planners	AR App		Human Centered Design	Interview

28	Harbinger-fish	14	Create reflection on plastic pollution	Interactive Sculpture		Sketching, Design Fiction, Human Centered design	Questionnaire, Interview, Positive and Negative Affect Schedule
29	Wandering Thoughts	3	Create awareness about mental health (anxiety) and self-understanding	Sound Installation	Auto-ethnography	Observation, Autoethnography	Questionnaire
30	I may be dead to you	11,15	Create awareness of biodiversity and alter people's attitude towards the appearance of dead trees	Sound Installation		Design Thinking	Questionnaire, Interview
31	Synergia	3	Create creative flow through a VR experience	VR Experience		Sketching, Human Centered Design	Interview, Flow State Scale Questionnaire
32	We the cosmic tribe	11, 15	Bridging the conceptual and perceived gap between nature and technological artefacts	Interactive Performance		Autoethnography	Questionnaire
33	What the voices in the water whispered	14	Investigating the difference between scientific and artistic/aesthetic knowledge apprehension	Sound Installation		Deep Listening	Interview

Table 1. Overview of all analyzed student research projects, including project title, sustainability theme(s) as indicated by the Sustainable Development Goals (SDGs), research aim(s), form of the artwork, and methods (as described by students in their written projects) used in problem formulation, design, and evaluation. It should be stated that all projects used background research in formulating a problem and prototyping techniques in the design process.

CONCLUSION

In this paper, we provided findings concerning a survey of 33 undergraduate student projects on the topic of sustainability made as part of an *Art and Technology* degree program at a PBL university. Across the student projects, we identify five primary themes of sustainability and art concerning pollution, nature, health, capitalism, and reduced inequalities, while six research aims within these topics sought to either raise awareness about sustainability-related issues, promote behavioural change in audiences, challenge assumptions and opinions or provoke, propose solutions, speculate about possible futures, or provide self- understanding.

In looking more deeply at the projects, sustainability was conceptualized in three distinct ways. First, issues of sustainability were understood as a matter of disconnect (between people and nature or the environment, from person to person, and between climate science communication and action), while the artworks sought primarily to instill empathy in the audiences as a means for possible resolution. Second, sustainability was understood as a matter of planning for the future and imagining how this future should look, while the artworks sought to help audiences imagine various visions of climate futures, often through methods such as climate science data-based fictioning and speculation. The third and final way of conceptualizing sustainability, explored the possible conflicts and paradoxes

within sustainability itself by either exposing the general lack of consensus regarding its definition or bring attention to the increasing amount of superficial efforts or greenwashing taking place, while the artworks sought to help mediate discussions between audiences with possibly conflicting views on the topic.

These findings could prove useful to other STEAM-oriented higher educational programs looking to introduce sustainability in their curricula. Given that art-based research has been increasingly recommended as a useful method for transdisciplinary research in general, for example, as a method to foster participation, imagination, and engagement with complex, or so-called wicked problems, educators from other STEM fields could find this work useful in introducing their students to artful learning (Kagan, 2017) about sustainability, that engages head, hands, and heart (Sipos et al., 2008).

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2. *Paradox* – Marcus Skovhus Pedersen, Mathias Augustine, and Matilde Jensen (2021).
3. *What goes around* – Alberte Spork, Line Krogh Sommer, Olivia Fenger Hove, and Tasja Langhoff Dahlstrøm (2020).
4. *SAD* – Amalie L. Fosvang, Ida W. L. Larsen, Maja T. Nielsen, Mathilde M. Jensen, and Sophia A. W. Rokkedahl (2020).
5. *Over, under // top, bottom* – Alberte Spork, Cecilie Madsen, Klara Rokkedal, Lillie Karlsen, and Nicoline Mou (2021).
6. *Climate Change of mind* – Caroline Wedel Thrane, Shobana Sutharsan, and Lizette Mary Guldfeldt (2020).
7. *Discover this cover* – Alena Komperova, Anna Major, Irene Liut, Kamilla Mez, and Roxana Roşu (2017).
8. *Feel my consent* – Kamilla Ruberg Jensen, Maria Camila Arciniegas Sanchez, Rikke Bogetoft Jensen, and Trine Størner Westphalen (2018).
9. *Symbiosis – A wearable Bioreactor* – Emma Purkær, Frederik Melving Vigil Hansen, Mia-Maja Madsen, and Sólja Holm Mortensen (2019).
10. *Let's Face the Waste* – Dorian Sinclear, Johanne Lindblad Fogsgaard, Linda Flensborg, and Frederik Ertmann Huerta (2020).
11. *Homo Aestus* – Anne Ejstrud, Cecilie Madsen, Lillie Karlsen, Mette Offersen, and Olivia Hove (2022).

12. *The Bipolar Express* – Tasja L. Dahlstrøm, Emilie Klemmensen, Sirichok Ruamwong, and Nicoline Mou (2021).
13. *The Aftereffect* – Lucas Arngrimson, Anne-Kathrine Søndergaard Møllerand, and Maria Sneding Rohde (2020).
14. *Privacy Helmet* – Anton Thorbøll, Benjamin Baxter, Bojana Kruscic, Maria Østergaard Hansen, and Mie Thirup Petersen (2019).
15. *Express Yourself* – Matilde W. S. Jensen, Mathias Augustine, and Jacob Lund Sørensen (2022).
16. *Smile for the Camera* – Lisa Maria Milling, Matthias Klages and Milo Lykke Frederiksen (2022).
17. *I've Got Something to Tell You* – Johanna Møberg Lauritzen, Mathilde Merete Jensen, Line Krogh Sommer, Louise Biller, and Alberte Spork (2022).
18. *Untitled Wearable* – Ina Jessen (2022).
19. *Symbiotic Wellbeing* – Donna Isabella Simonsen, Luna Annabell Linn´e Jensen, and Marie Fritjof Knudsen (2022).
20. *Everyday Sounds* – Lenette K. Langsø and Victor E. Mikkelsen (2020).
21. *Natura* – Emma Purkær, Frederik Melving Vigil Hansen, Katja Chua Starup, and Maria Gøth-Johansen (2020).
22. *Greenscape* – Dominik Tendl, Trine Westphalen, Maros Pekarik, and Liucija Paniuskyte (2018).
23. *Emplant – Sounds of a Plant in Distress* – Oana C. Burca, Isabella S. Hau-rholm, and Andreas R. Gøthler (2019).
24. *Mushroom Modulator* – Anders Christian Gade Skaarup, Christian Steen Møller, and Paula Uspenski (2019).
25. *Wasted* – Brigita Juzenaite, Heine Winthereig, Malou Kristine Hedemann Gundersen, Nicolai Harning, and Steffen Thomsen (2020).
26. *Niksen Biksen* – Johanna Møberg Lauritzen, Olivia Fenger Hove, Anne Ka- trine Muhlig Ejstrud, Tasja Langhoff Dahlstrøm, and Benjamin Sarthak El- ton Baagøe-Thomsen (2022).
27. *Express Yourself – A research on communication between citizen and city planner* – Anne-Kathrine Søndergaard Møller, Astrid Kjeldal Graungaard, and Maria Sneding Rohde (2021).
28. *Harbingerfish* – Anna Dagmar Bille Milthers and Sidsel Abrahamsen (2019).
29. *Wandering Thoughts* – Anonymous Student Name (2020).
30. *I may be dead to you* – Daniela Bretes Maciel Elneff (2019).
31. *Synergia* – Oana Camelia Burca and Maros Pekarik (2020).
32. *We the cosmic tribe* – Mamma Dahl Nedergård, Karina Ace Lindegaard Jensen, Stefan Engelbrecht Nielsen, and Louise Ørsted Jensen (2018).
33. *What the voices in the water whispered* – Christine Hvidt Grønborg (2019).

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