

**Weaving Hybrid Futures: Sustainability in Higher Education with PBL Through
Art, Science, and Robotics**
Special Issue

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EDITORIAL

Sustainability is currently one of the most important topics in higher education and curriculum development. As a connected and interdependent global community, we are facing increasingly complex and multidimensional socio-political, economic, and environmental challenges. It is clear that trans-disciplinary efforts are necessary to tackle sustainability. Integrating sustainability in educational curricula involves cultivating a way of thinking that is holistic and collaborative so that we can adequately prepare students to work across disciplines, sectors, institutions, and geographies. Problem-based

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learning, a student-centered learning approach that focuses on real-life problems and where students typically work in groups (Servant-Miklos et al., (2023)), was shown to be a good method for teaching students to engage with complex topics such as sustainability. Defining sustainability is a double act of communication across disciplines and planning for and imagining the future, which requires creativity and, at times, speculation. This act is made more difficult by the fact that there is a lack of consensus surrounding sustainability and through what means and metrics sustainability should be assessed (Horsbøl, 2023; Smith, 2019). How can we use often conflicting conceptions to imagine and design sustainable futures? How can transdisciplinarity inform education and equip future students with a sustainability mindset to face the challenges of their time? These are the core research questions that inform this special issue on Weaving Hybrid Futures: Sustainability in Higher Education with PBL Through Art, Science, and Robotics.

Background

The *ABRA project*¹ (Artificial Biology, Robotics, and Art) is a three-year Erasmus project that initiated and informs the context of this special issue. The project aims to cultivate transdisciplinary educational pathways through pilot teaching and learning programs with students and educators to help tackle the wicked problem of sustainability in higher education.

Throughout the past three years, ABRA has developed and led workshops with a dedicated group of students and educators from diverse backgrounds and disciplines from Europe, North and South America. Our aim has been to strengthen connections and build new bridges across the fields of artificial biology, robotics, and art. We focused on the topic of sustainability and capacity building for educators and students so that through new educational initiatives, we might develop tools and strategies to meaningfully address the impacts of environmental degradation and climate change through transdisciplinary inquiry. Although we come from diverse disciplines spanning biology, design, robotics, architecture, computer science, engineering, and the arts, we are connected through our mutual recognition that the world's most pressing problems are not going to be solved by experts from a single discipline alone, but will require people from many fields and sectors coming together to develop and implement new solutions and practices. This special issue, co-edited by the ABRA consortium and the *Journal of PBL in Higher Education*, is an opportunity to highlight some key outcomes from the project while also broadening the discourse to include other perspectives within higher education that have leveraged PBL to promote transdisciplinary teaching and education for sustainability.

Each of the contributions in this collection emphasizes the connections between sustainability and creativity, innovation and collaboration in research, and education within PBL. These connections are cultivated through dedicated initiatives, teaching and

training activities, theoretical understanding, and research that promote transdisciplinary thinking and practice. Educational systems will not transform overnight; centuries of mono-disciplinary degree programs and specializations have made it difficult for arts, humanities, and social science students to interact with science and engineering students. Creating learning environments where students work collaboratively across cultures and disciplines will take time and require new methods and practices. Furthermore, developing transdisciplinary curricula towards sustainability is made more difficult by the fact that defining sustainability is itself a complicated task. There is no definition of sustainability that works reliably across all fields of study. As many have observed, despite the increased focus on sustainability in the last decade, there are still basic challenges in defining what exactly sustainability is, as well as how best to address it or communicate its relevance (Horvath et al., 2023; Eskjær & Horsbøl, 2023; Horsbøl, 2023). Sustainability is a slippery and frequently paradoxical concept: social and economic sustainability can be at odds with economic sustainability and growth (Smith, 2019), and it can be difficult to reach a consensus about what decision might constitute the “correct” or most “green” in a given scenario (Horsbøl, 2023).

Definitions of sustainability should remain open and fluid, evolving at pace with new knowledge as fields of study interact and as contradictions and tensions become clear. Refining and re-defining sustainability while imagining sustainable futures will require a collective ability to imagine them creatively and through dialogue and experimentation.

The article *STEAM Matters for Sustainability: 10 Years of Art and Technology Student Research on Sustainability Using Problem-based Learning* [1] surveys ten years of student projects from a transdisciplinary undergraduate education program in Art and Technology. The authors focus on student projects that specifically address sustainability within an art-based research framework, identifying important themes within sustainability, research directions within a PBL context, and the artistic and academic methods the students employed. In their analysis, the authors identify five primary themes of sustainability that the artworks deal with: (1) pollution, (2) nature, (3) health, (4) capitalism, and (5) reduced inequalities. Within these topics, six research aims sought to either: (a) raise awareness about sustainability-related issues, (b) promote behavioral change in audiences, (c) challenge assumptions and opinions or provoke, (d) propose solutions, (e) speculate about possible futures, or (f) provide self-understanding. Importantly, sustainability was conceptualized by students as either a matter of (i) disconnect: between people and nature, between people and others and between people and abstract scientific communication, (ii) imagination, or the ability to imagine futures (or lack thereof), or (iii) conflict and/or paradox. The article highlights how artistic methods and practices can help make concrete the often abstract notion of sustainability, and illustrates how art methods can help make topics in sustainability accessible to diverse student populations and the general public.

The article *Becoming a Creative Genius: How a Creative Learning Environment Can Facilitate Transdisciplinary Engagement and Creative Mindset in a Life-Long Learning Perspective* [2] evaluates another transdisciplinary program at Aalborg University, entitled Creative Genius, an elective course focusing on creativity and interdisciplinary PBL with more than 200 students from fifty-six disciplines completing the program between 2013-2018. Based on interviews with graduates from the program, the article explores whether a PBL environment that focuses on creativity facilitates transdisciplinary engagement and creative competencies, and considers to what extent this manifests into transdisciplinary career paths and creative mindsets in a life-long learning perspective. Further, the findings indicate that a pedagogical approach which focuses on the embodiment of creative competencies helps prepare students to transition to professional settings, and equips them to engage in transdisciplinary and complex problem-solving in industry and society. The paper proposes a “double helix” model for creative transdisciplinary thinking, illustrating the intertwining of vertical and horizontal knowledge and emphasizing the significance of horizontal thinking, open-mindedness, and co-creation in problem-solving. Further, the authors suggest the need for PBL environments to cultivate creative self-efficacy and foster connections between various forms of knowledge for effective, transdisciplinary PBL.

Mattila et al.’s *The Interplay of Engineering Skills, Aesthetic Creativity and Ethical Judgment in the Creation of Sustainable Urban Transformations: Aristotelean Perspectives on PBL* [3] examines a PBL project module on “Sustainable Urban Transformation” within the Urban Design Master program at Aalborg University combining urban design and hydrology engineering. During the module, lectures and study circles that touch on various dimensions of sustainability, especially *vis-a-vis* climate change are introduced and students are given the freedom to choose how to balance between design and engineering approaches when giving a physical form for sustainability in their urban design interventions. The authors discuss the development of student skills scaffolded on the Aristotelian concepts of *techne* (understood as engineering), *poiesis* (interpreted as aesthetic form-giving), and *phronesis* (conceived as the making of ethical judgments) and argue that the last two concepts are especially important for issues and topics within design education. Analysing a sample of student projects, the authors examine how sustainability is made concrete, and how the students negotiate and find a balance between engineering skills, aesthetic creativity, and ethical judgment in their urban design work. These designs, however, should always be conceptualized as flexible over time, rather than fixed. Therefore, educators should encourage students to understand designs as *poietic* narratives.

We are interested in the ways that PBL can help centre questions of equity, justice, and power in sustainability and design curricula. Identifying the unspoken values and assumptions of conventional sustainability research and education programs can be

challenging. We recognize that educators play a key role in transforming educational and design practices that render marginalized communities invisible to prepare students for more just and transparent action. By giving access to and gathering perspectives from diverse stakeholders, PBL can help frame investigations on issues that are important to marginalized communities. McDonald et al.'s *Elicitation and Empathy with AI-enhanced Adaptive Assistive Technologies (AATs): Towards Sustainable Inclusive Design Method Education* [4] articulates this role by considering how to approach incorporating non-normative methods in design thinking to better meet the needs of people with disabilities. Recognizing the ethical challenges and sensitivity of working with people with disabilities in design education and wishing to avoid unnecessary burdens on users, the authors pilot-tested a participatory elicitation toolkit for generating empathy and self-reflection in technology for design students when developing new adaptive tools for users living with disabilities. The tool attempts to incorporate intersectional thinking in privacy elicitation while enabling sustainable and inclusive design practice in higher education.

Fricker et al.'s *Interconnected Agencies for Sustainable Futures: A Discourse on the Notion of Adaptation and Space* [5] invites a broader discussion on possible trajectories for sustainable futures by intersecting different practices and discourses on the concepts of *adaptation* on the one hand, and *space* on the other. The authors note that increasingly, tools and methods of science and technology are adopted and introduced into creative work within art, design, and architecture, although there is little traffic in the other direction. The article considers why this might be and presents four different disciplinary perspectives, which contribute to current discussions on sustainable futures. Further, the article describes the concept of *adaptation* as the process by which systems or individuals adjust to changing circumstances in order to optimize their performance and propose that *adaptation*, viewed through this perspective, can be a useful lens when designing PBL activities for students.

Embedding Digital Data Storytelling in Introductory Data Science Course: An Inter-Institutional Transdisciplinary Pilot Study, [6] presents a semester-long pilot study where a framework dubbed *Digital Storytelling* was presented in an introductory data science course at a four-year Minority Serving Institution, in collaboration with students studying non-STEM disciplines at a partner community college. The authors found that *Digital Storytelling* helped raise student awareness of sustainability issues and increased confidence in cross-disciplinary communication competency while deepening their understanding of data science concepts. The article reflects on the role of transdisciplinary communication as an important competency for increasing diversity in the data science workforce.

The contributions in this special issue highlight how creativity, like sustainability, is not domain-specific; it cuts across all research areas and sectors. The need for human

imagination and creative thinking in problem-solving has never been more apparent or more necessary than right now. Those educated with transdisciplinary skills are prepared for a dynamic future that will require flexible thinking, fluency of ideas, active and life-long learning, and collaborative skills.

Institutions of higher education increasingly prioritize curricula that train and prepare the next generation of students to work across disciplines in order to be able to tackle sustainability. However, our understanding of sustainability is evolving along with what it means for our respective fields. Refining and redefining conceptions of sustainability starts with conversations across disciplines and with re-thinking our current disciplinary system. This transformation requires more than technical solutions and environmentally sensitized practices; rather, it calls for innovative and just methods for collective and creative collaboration between scientists, engineers, designers and artists, policymakers, and educators to ensure that sustainability is addressed from multiple angles and across disciplines.

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The issue articles:

1. Horvath et al. (2023). *STEAM Matters for Sustainability: 10 Years of Art and Technology Student Research on Sustainability Using Problem-based Learning.*
2. Hansen et al. (2023). *Becoming a Creative Genius: How a Creative Learning Environment Can Facilitate Transdisciplinary Engagement and Creative Mindset in a Life-Long Learning Perspective.*
3. Mattila et al. (2023). *The Interplay of Engineering Skills, Aesthetic Creativity and Ethical Judgment in the Creation of Sustainable Urban Transformations: Aristotelean Perspectives on PBL.*
4. McDonald et al. (2023). *Elicitation and Empathy with AI-enhanced Adaptive Assistive Technologies (AATs): Towards Sustainable Inclusive Design Method Education.*
5. Fricker et al. (2023). *Interconnected Agencies for Sustainable Futures: A Discourse on the Notion of Adaptation and Space.*
6. Chen et al. (2023). *Embedding Digital Data Storytelling in Introductory Data Science Course: An Inter-Institutional Transdisciplinary Pilot Study.*

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**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.

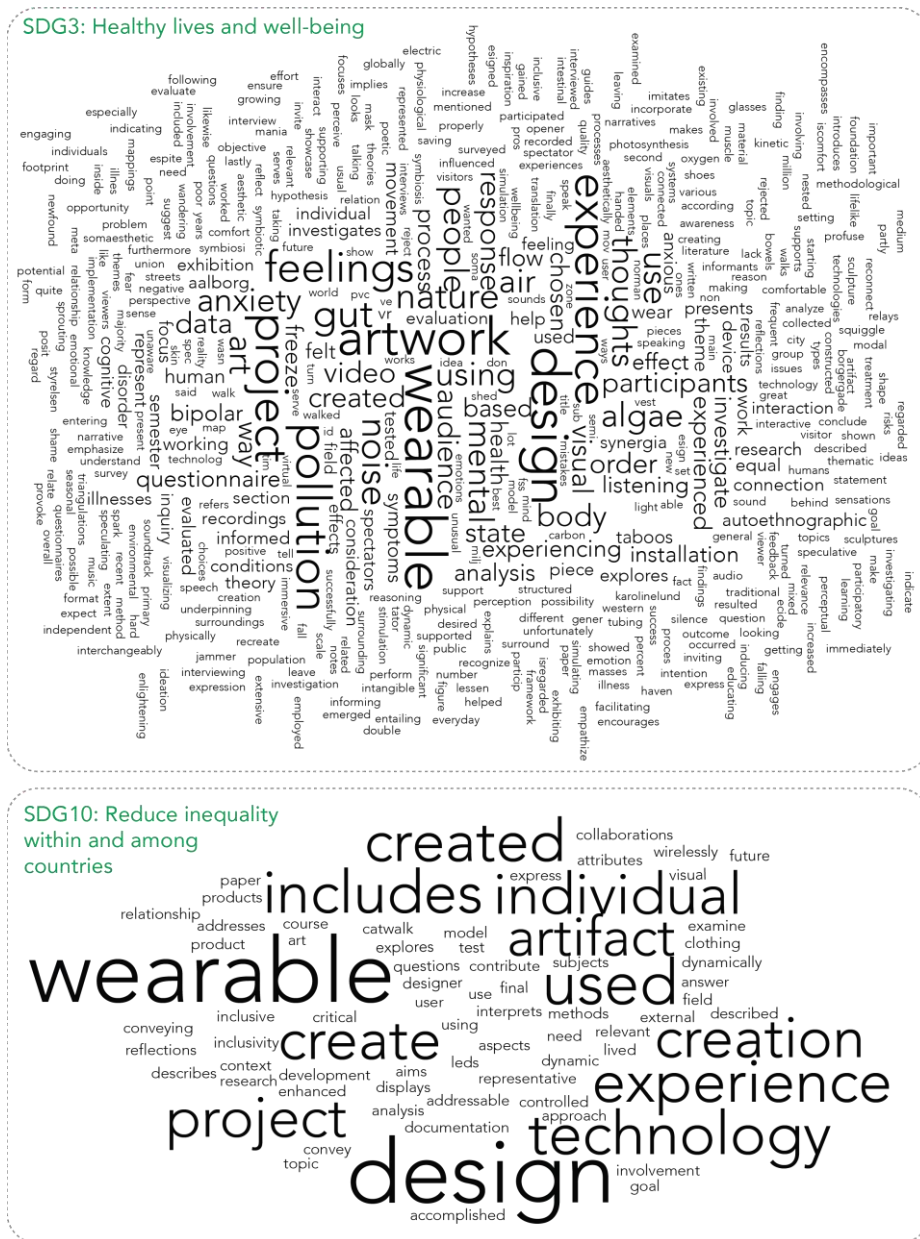


Figure 1. Word clouds created from the abstracts of Art and Technology student projects having SDG3 (top, 10 projects) and SDG10 (bottom, 1 project) as their primary goal.

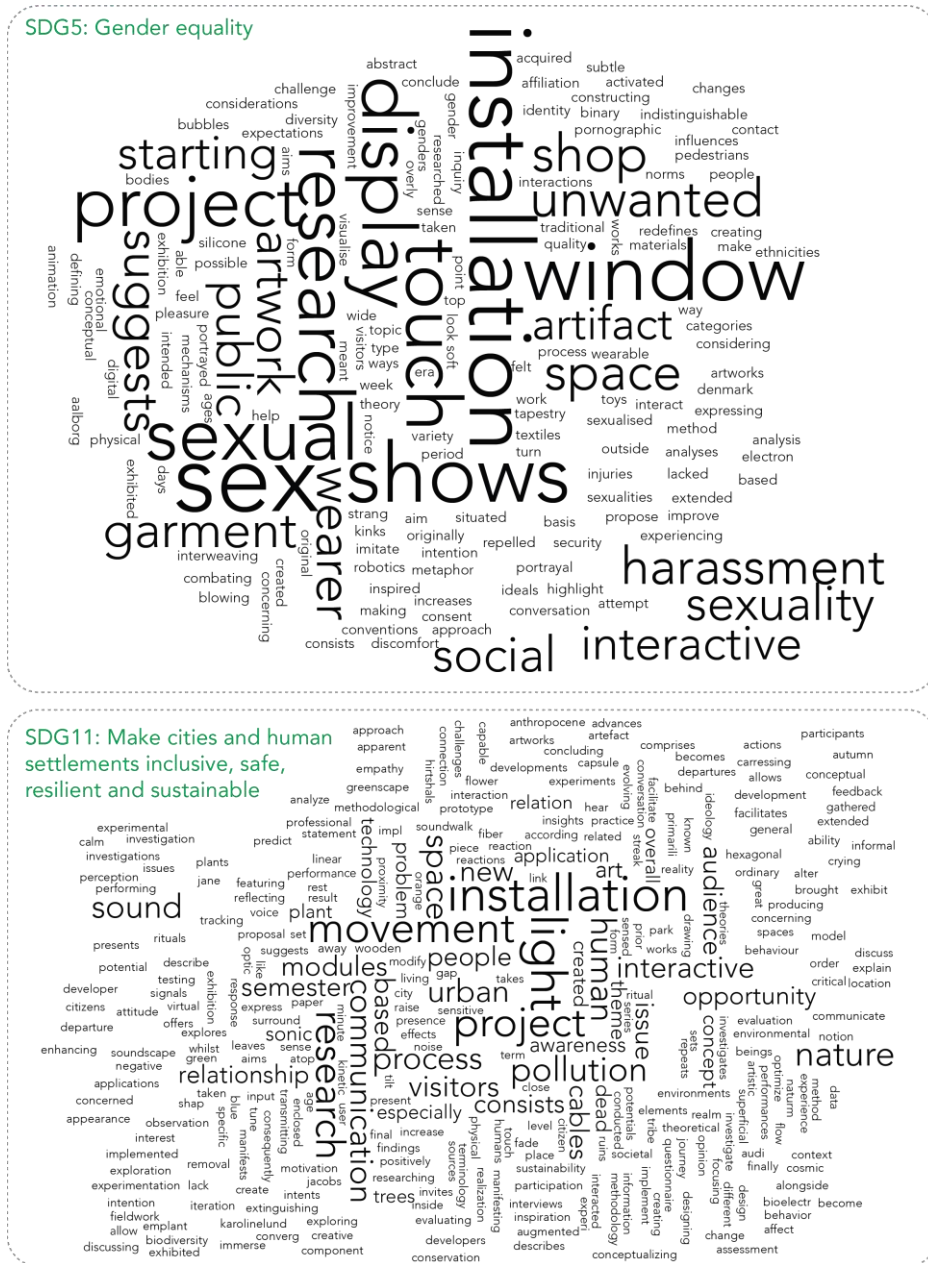


Figure 2. Word clouds created from the abstracts of Art and Technology student projects having SDG5 (top, 2 projects) and SDG11 (bottom, 6 projects) as their primary goal.

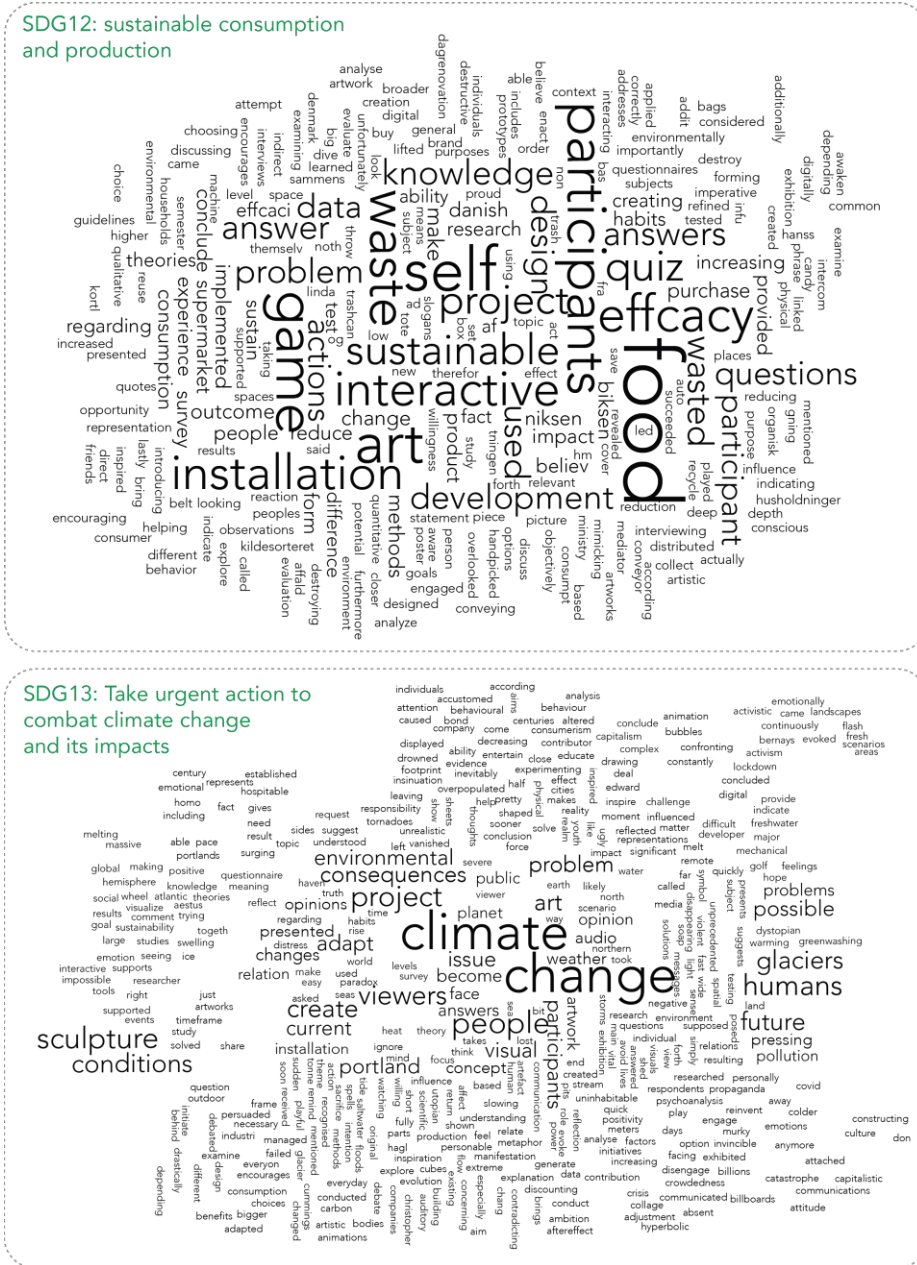


Figure 3. Word clouds created from the abstracts of Art and Technology student projects having SDG12 (top, 3 projects) and SDG13 (bottom, 5 projects) as their primary goal.

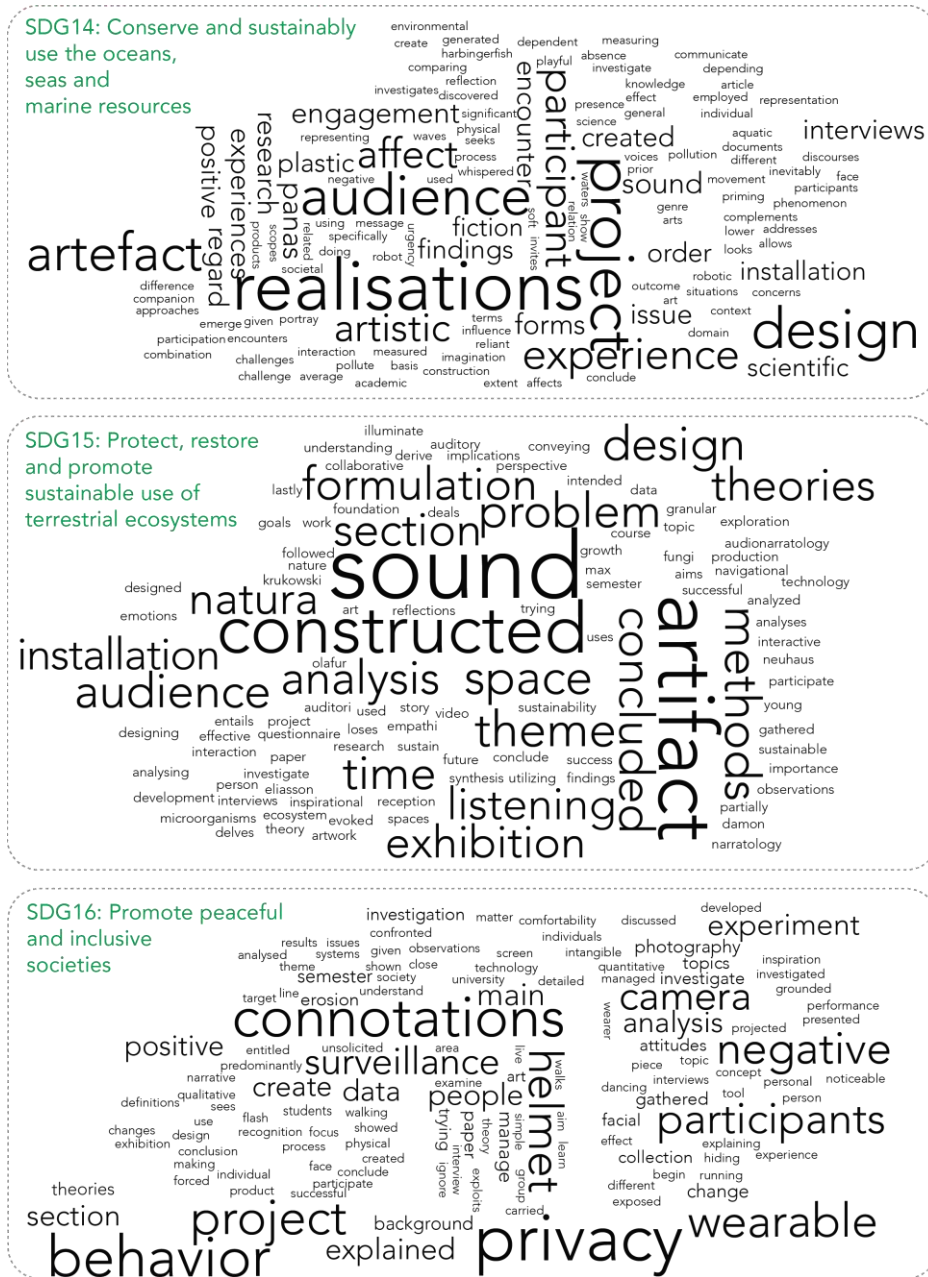


Figure 4. Word clouds created from the abstracts of Art and Technology student projects having SDG14 (top, 2 projects), SDG15 (middle, 2 projects), and SDG16 (bottom, 2 projects) as their primary goal.

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.

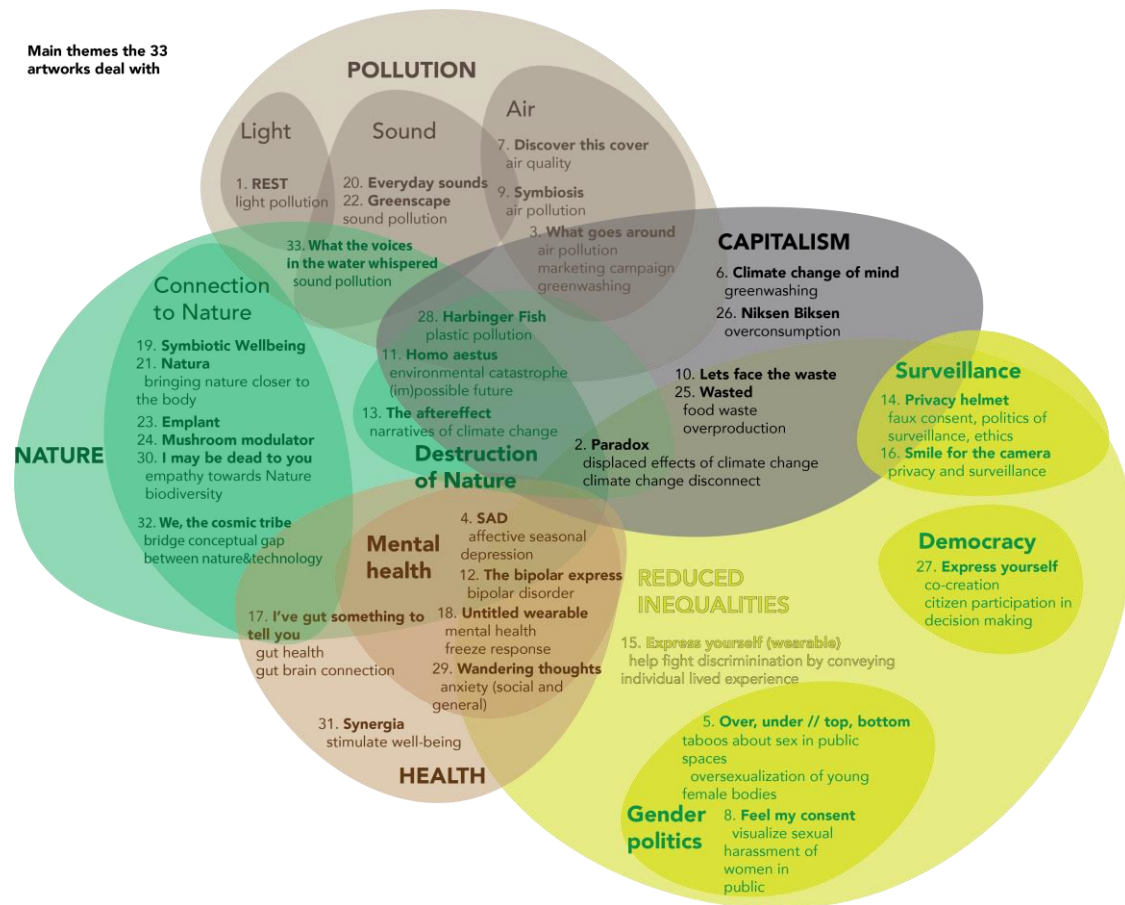


Figure 5. Thematic clusters of Art and Technology student projects categorized according to the primary theme(s) within sustainability and art observed in our analysis.

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

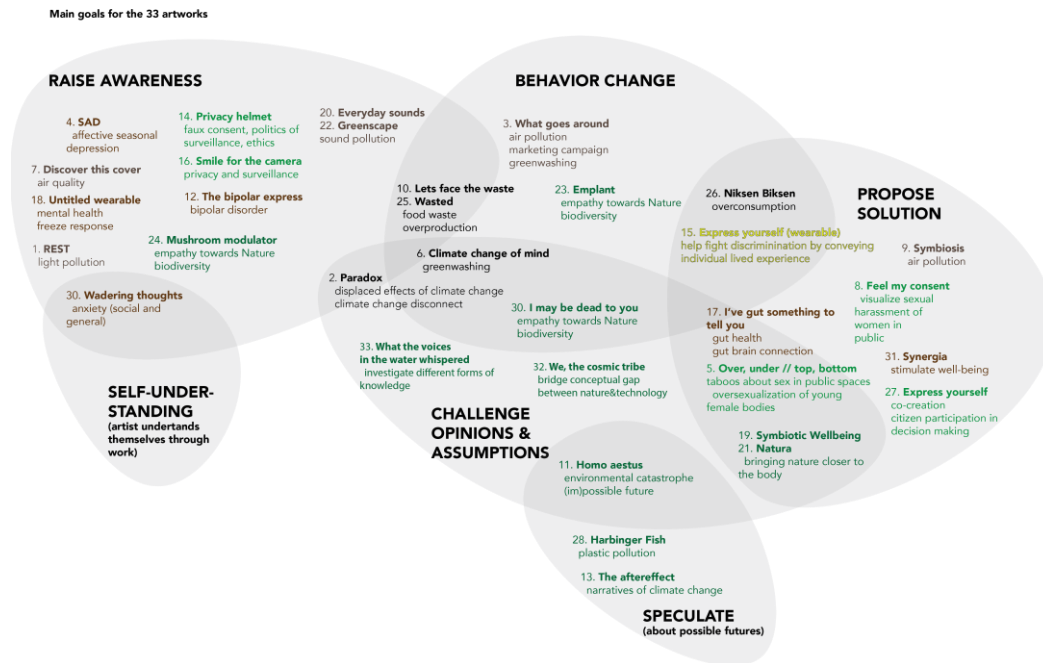


Figure 6. Thematic clusters of Art and Technology student projects categorized according to the research aims observed in our analysis.

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.

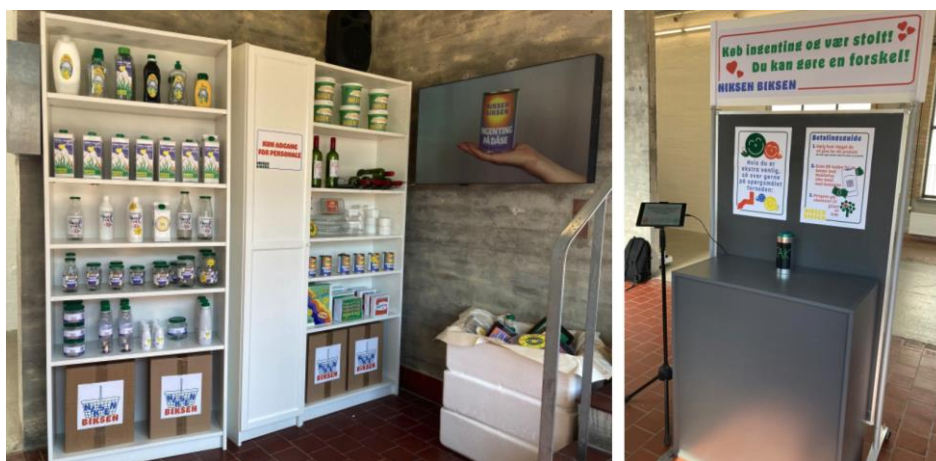


Figure 10. Niksen Biksen, an interactive art installation in the form of a faux grocery store in which a person purchases 'nothing' as a means for becoming more aware of over-consumption while donating to charity in the process. Project and photographs provided courtesy of Johanna Møberg

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 Got 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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**Becoming a Creative Genius:
How a Creative Learning Environment Can Facilitate Transdisciplinary
Engagement and Creative Mindsets in a Life-Long Learning Perspective**

*Søren Hansen, Lykke Brogaard Bertel **

ABSTRACT

The increasing complexity of society's sustainability issues requires new educational approaches that facilitate transversal skills and competencies suitable for the 21st century. Students must be equipped with discipline-specific expertise or technical skill; but also competencies to collaborate across disciplines in creating innovative solutions to complex problems. This paper explores whether a problem-based learning environment focusing on creativity facilitates transdisciplinary engagement and creative competencies and to what extent this manifests into transdisciplinary career paths and creative mindsets in a life-long learning perspective. An analysis of interviews with graduates from a transdisciplinary program, Creative Genius, at Aalborg University indicates that a pedagogical approach focusing on the embodiment of creative competencies helps prepare students to transition from student to professional and equip them to engage in transdisciplinary and complex problem-solving in industry and society. Based on the results, the paper proposes a model for creative transdisciplinary thinking and suggests a focus on creative self-efficacy as an essential learning outcome in transdisciplinary PBL environments.

Keywords: Problem-based learning, creativity, transdisciplinary engagement, higher education

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INTRODUCTION

Traditional discipline-specific approaches to research and education are increasingly challenged and considered insufficient when addressing complex and highly contextual problems in practice. Particularly concerning education for sustainable development, the transformation of scientific and educational settings and their interaction with society is required, combining ecological, economic, technical, and societal components to transcend disciplinary boundaries and strengthen shared understandings in the creation of diverse, culturally-responsive and sustainable solutions to society's grand challenges (Euro-CASE, 2020; UNESCO, 2021). With the implementation of the UN's 17 Sustainable Development Goals (SDGs) in 2015, new visions, guidelines, and shared goals for a joint contribution to a better, more sustainable world have created a call for transdisciplinary approaches to education, research, and practice (Khan, 2021). Thus, higher education institutions across the world are taking action to support the development of students' interdisciplinary problem-solving skills and competencies specifically related to sustainability, e.g., through project models such as Vertically Integrated Projects (Strachan et al., 2019), Experts-in-Team (Otte, 2016) and megaprojects (Bertel et al., 2021), or through new programs (Crawley, 2018; Gombrich, 2018) or even entire new institutions (London Interdisciplinary School, 2023).

Problem-based learning (PBL), originating as far back as the late 1960s and early 1970s (Hmelo-Silver, 2004), argues for contextually embedded and authentic real-world problems as a point of departure for both single-discipline and interdisciplinary learning (Kolmos & de Graff, 2014). However, designing interdisciplinary problems for sustainable development is challenging, even when PBL is implemented at the curriculum level, as it requires researchers and educators to collaborate across disciplinary boundaries and to balance an often academic-centered curriculum with professional, interdisciplinary, and collaborative knowledge and competencies and the tacit presence of sustainability (Guerra, 2017; Kolmos et al., 2020; Bertel et al., 2021).

A call for new inter- and transdisciplinary profiles in education

In interdisciplinary approaches to research and education, a distinction is often made between 'vertical' and 'horizontal' knowledge. Vertical knowledge covers discipline-specific knowledge or expertise within a given field, and 'vertical thinking' is the commonly accepted use of such knowledge within a given discipline. On the other hand, horizontal knowledge is knowledge from other fields that the individual has a generalized understanding of and the ability to access and expand through horizontal thinking. This distinction was used to categorize different professional profiles with various emphases on expert and generalized knowledge, coined as the 'I-shaped' and 'T-shaped' professional profiles (Guest, 1991; Oskam, 2009).

As the complexity of societal problems increases, so does the need for professionals who can expand their expert knowledge to different contexts, bridge disciplines, and create entirely new transdisciplinary knowledge and solutions. Here, we understand transdisciplinarity as creating new conceptual, theoretical, methodological, and translational innovations that integrate academic and non-academic perspectives and transcend traditional disciplinary boundaries to address a common problem (Klein, 2004; Nicolescu, 2010). Thus, in recent years the push for more T-shaped professionals is increasingly expanded to include a multitude of different variations in the integration of vertical and horizontal knowledge in education, emerging as so-called ‘ π -shaped’ or ‘H-shaped profiles’ (i.e., professionals with expertise in two separate but connected fields) and the M- or comb-shaped profiles (i.e., professionals with broad horizontal knowledge and expertise in three or more separate fields to varying degrees of depth) (Demirkan & Spohrer, 2015; Kamp, 2016; Bierema, 2019; Babatope et al., 2020) (see figure 1).

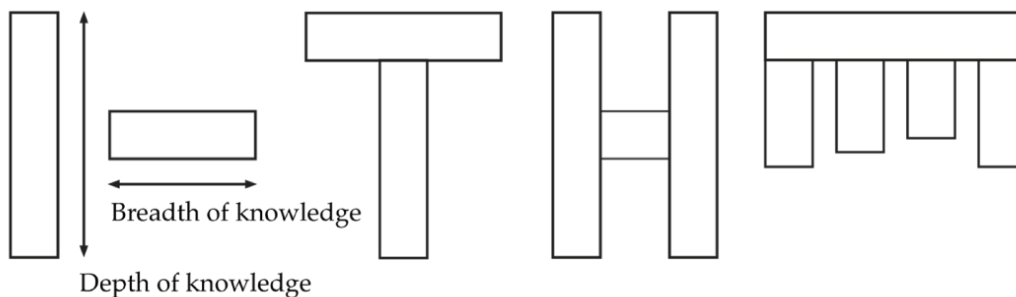


Figure 1. Different transdisciplinary professional profiles.

Creativity and transdisciplinary thinking in higher education

While T-shaped profiles and other variations of inter- and transdisciplinary competencies are increasingly encouraged in engineering education and higher education in general, the models offer little information on what happens in the intersections between vertical and horizontal knowledge and how the transformation of different kinds of knowledge takes place in complex problem-solving in practice. Creativity theory, on the other hand, offers a multitude of concepts related to the ability to identify, connect and make sense of knowledge across different fields otherwise considered unrelated, including competencies such as horizontal thinking (Byrge & Hansen, 2014; Kristiansen et al., 2018), lateral thinking (de Bono, 1992) and conceptual blending (Fauconnier & Turner, 2004). Furthermore, creative competencies combined with creative self-efficacy is previously found to enable teams to address and solve complex problems (Birgili, 2015; Gallagher, 2015; Byrge, 2021), which could be one reason why creative thinking continues to rank among the essential skills of the future in the World Economic Forum's Future of Jobs reports (WEC, 2023).

The Creative Genius (CG) program at Aalborg University (AAU) (2013-2018) aimed to facilitate such competencies by combining PBL with scaffolding techniques derived from creativity theory to prepare students for working with complex problems in transdisciplinary settings (Byrge & Hansen, 2014). The CG program was popular among the participating students, with testimonials emphasizing particularly creative methods of approaching unforeseen and new situations and combining knowledge from different fields (Testimonials 2013-2018); however, little is known about how and to what extent such transdisciplinary competencies manifest into career paths and creative mindsets in a life-long learning perspective. Thus, this study seeks to explore how graduates from a transdisciplinary program such as CG experience the transition from student to professional and what elements in terms of competencies, methods, and creative mindset the graduates bring to their professional life; To what extent do a deliberate focus on creative competencies equip students to enter industry and society and engage in complex problem-solving? What can we learn from the CG program concerning the integration of creativity and transdisciplinarity into PBL environments?

THE CREATIVE GENIUS PROGRAM

The Creative Genius program was based on Creative Platform learning (Byrge & Hansen, 2015; Christensen & Hansen, 2015; Byrge & Hansen, 2014; Byrge & Hansen, 2009; Hansen & Byrge, 2009) and had two paths: the Creative Genius Semester (CGS) and the Creative Genius Professionals (CGP). CGS was a full-time 30 ECTS interdisciplinary study activity offered as an elective to all master students at AAU, hosting 15-30 students from different disciplines each semester. CGP was a 1-year, 50% part-time study activity welcoming professionals already working in industry, either in the private or public sector. More than 200 students from 56 disciplines across Social Science and Humanities (SSH), Science, Technology, Engineering and Math (STEM), and Health completed the program. During the program, the focus was entirely on developing students' creative competencies and how to use them in an interdisciplinary PBL project of their own choice. During the program, CG students did not receive additional lectures within their 'home' disciplines.

Whereas the Aalborg PBL model already naturally embeds a focus on generic competencies related to complex problem-solving (Boelt et al., 2021), the educational purpose of the CG program was to offer students at master-level experience working in an interdisciplinary setting, using creative competencies to solve complex problems. Thus, the program differentiated itself from the team-based AAU PBL model (Aalborg University, 2015) in the following ways:

- Starting with a two-month intense creativity training period (6 hours a day), creative thinking and creative competencies like horizontal thinking, open-

mindfulness, and co-creation were embodied to help students build creative mindsets and creative self-efficacy.

- This training period was followed by a three-month individual project period, where each student was free to choose a problem with high complexity and no known solutions. During this period, the students were scaffolded in working “the CG way,” using tools, methods, and mindset from the training period.
- Students collaborated in shifting, randomly formed group settings. In these groups, they co-created through transdisciplinary processes that informed their individual projects and facilitated a deep understanding of- and experience with doing transformative work.

The program was an educational experiment and research program, and experiences from CG and other interdisciplinary projects and programs are now to be integrated into AAU's strategy to become a mission-oriented university and to support the integration of SSH and STEM at curriculum level (Aalborg University, 2022; Bertel et al., 2021).

Horizontal thinking – a theoretical model for facilitating creative thinking processes

Where vertical knowledge is understood as the dominating knowledge inside the discipline, horizontal knowledge consists of latent knowledge, which becomes relevant and applicable through horizontal thinking. Inspired by the first known innovation model (Wallas, 1926), the horizontal thinking model consists of a series of creative thought processes that identify and transform horizontal knowledge to be used vertically (see Figure 2).

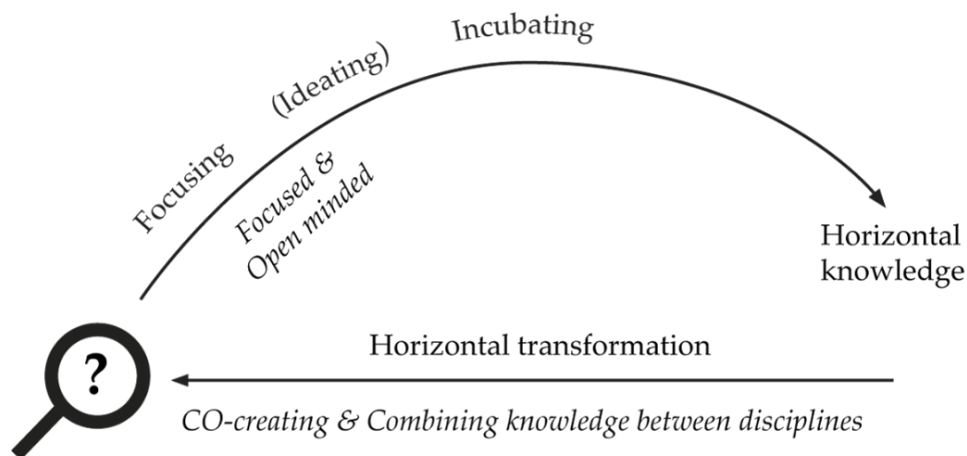


Figure 2. The horizontal thinking model applied at the Creative Genius Program.

As seen in Figure 2, focusing on a problem with an open mind provides new ideas by accessing horizontal knowledge, e.g., from other disciplines, contexts, or similar problems (analogies), and combining it. This combination of knowledge is a

transformative process that often involves co-creation. In CG, the different steps of horizontal thinking were facilitated to enable students to connect and combine knowledge from different disciplines despite their different ontological and epistemological underpinnings (Byrge & Hansen, 2014).

Focusing on a problem

The core of creative work is a continuous effort to focus on the problem at hand. This focus is essential and the first step in a creative ideation process, as it starts multiple chains of associations that will invite all kinds of horizontal knowledge, often initially considered irrelevant to the specific problem (Byrge & Hansen, 2014; Runco & Chand, 1995; Sternberg & Lubart, 1996). In education, facilitating a focus on a problem involves scaffolding the students in deliberately creating a strong focus on the problem by engaging in it and developing a strong inner motivation for dealing with it. When focusing on a problem, whether ideation techniques are applied or not, the unconscious brain will start incubating and return ideas relevant to the focus.

Inviting horizontal knowledge

Accessing and inviting knowledge from another discipline in a relevant and meaningful way becomes much easier when that knowledge is 'released' from its original context, tied to customs, methodologies, theories, practices, culture, and habits. In the form of principles, analogies, metaphors, fantasies, or other forms of horizontal knowledge, knowledge from any discipline can be 'released' and combined with another discipline (Byrge & Hansen, 2014; Kristensen et al., 2018). One such example could be when two disciplines, *in principle*, are dealing with similar issues and have the potential to transfer new knowledge to each other in a transformative process. For instance, when studying the flow in veins and arteries, it is possible to identify horizontal knowledge in the study of flow in pipelines for water or oil. The two fields of study are very different, but, in principle, both deal with "flow in a pipeline," which connects them horizontally and opens for the transfer of knowledge between them if they start interacting and co-creating. In terms of *vertical* and *horizontal* knowledge (figure 1), flow in veins and arteries is vertical knowledge for some professional profiles (e.g., hematologists) and horizontal knowledge for others (e.g., plumbers or petroleum engineers) that can be *transformed* into vertical knowledge using horizontal thinking. Thus, for students to access this horizontal knowledge, they must be scaffolded in broadening their perspective and remaining open and inviting toward other disciplines and professions, which can be challenging, especially since students are still in the process of developing their own professional identities (Bertel et al., 2022).

Horizontal transformation

Initial ideas, especially more radical ones, often will be *out of context* and, therefore, cannot simply be copy-pasted into a solution. The horizontal knowledge in the idea needs

to be combined in new ways or transformed for it to make sense vertically. For instance, if one's usual perspective on taking on a shoe is to 'tie' the shoe, potential solutions for the problem of 'tying shoes' will likely be similar to that of a shoelace. If, instead, the perspective on the task shifts to 'closing' the shoe, several novel ideas might emerge by transferring knowledge or concepts from horizontal disciplines or professions, such as magnets, screws, or other "closing" mechanisms in novel ways that suit the 'closing shoes' task. However, when knowledge is transformed horizontally to another discipline, it will likely not be possible to simply 'copy-paste' it. Instead, it is a transformative process to transfer this knowledge between disciplines; simply using a screw will not close the shoe, but transforming the principal idea of the screw to this new context might result in ideas like the BOA® Fit System. Facilitating horizontal transformation in education thus involves inspiring students to rethink and reframe the problems they are working on and open their minds towards novel understandings and solutions that emerge when latent knowledge from different disciplines is combined in new ways.

A creative learning environment is a psychologically *safe* learning environment

To think horizontally involves creative competencies to stay open-minded, fearlessly combining seemingly unrelated knowledge from different disciplines while working with complex problems without known solutions (Byrge & Hansen, 2014; Byrge, 2021; Scharmer, 2016; Kelley & Kelley, 2012). Even in student-centered learning environments such as PBL, students may experience fear of making mistakes or be exposed to other sources of interpersonal risks, like lower grades or threats towards one's social or professional status. Thus, a creative learning environment with a high degree of psychological safety and acknowledgment of creative thinking is needed (Edmondson, 2019) and contributes to students' development of *creative self-efficacy* (Bandura, 1997; Byrge & Tang, 2015). Creative self-efficacy results from multiple experiences with successful participation in creative thinking, e.g., through training exercises and creative problem-solving (Kelley & Kelley, 2012). Creative self-efficacy increases students' confidence in their ability to engage in creative processes and is an important indicator of students' progression and creative competencies.

Embodied Creativity Training to facilitate creative competencies and creative self-efficacy

At CG, horizontal thinking, open-mindedness, and co-creation were learned and embodied during the initial 2-month training period. Embodied creativity training refers to an approach that focuses on the students *becoming* more creative (Byrge & Tang, 2015). Training exercises were facilitated throughout the day, preparing students for the following 3-month project period. Creativity training shows promising results in developing creative competencies (Scott et al., 2004) and creative self-efficacy (Byrge & Tang, 2015; Hänninen et al., 2020; Strachan et al., 2019; Trujillo & Tanner, 2014). Byrge

& Tang 2015 studied embodied creativity training using the same didactic approach as CG, also called 3D Didactic (Byrge & Hansen, 2014). It is developed to train specific creative competencies while solving small practical exercises (3D cases) using language, body, and attitude (Byrge & Hansen, 2014; Byrge & Tang, 2015). Another study reports that creativity training makes teams more confident in complex problem-solving and develops a creative team culture where team members are more willing to take risks and make mistakes (Byrge, 2021).

In summary, research shows how creative competencies can be learned through training and scaffolding, and creative self-efficacy can be developed and supported in psychologically safe and creative learning environments such as CG. In this study, however, we want to explore to what extent this creative self-efficacy or mindset is sustained in transitioning from student to professional and how creative competencies such as open-mindedness, horizontal thinking, and co-creation are applied in transdisciplinary problem-solving in a life-long learning perspective.

THE CREATIVE GENIUS GRADUATE: CASE STUDY DESIGN & METHODOLOGY

To explore and understand how graduates from the CG program have experienced the transition from student to professional and to what extent they feel equipped to engage in transdisciplinary and complex problem-solving in a life-long learning perspective, we conducted individual, qualitative semi-structured interviews with five graduates from the program. The interviewees were recruited through convenience sampling, and the interviews took the point of departure in an interview guide with open-ended questions about the participants' initial motivation for enrolling in the CG program, their perceptions of the learning environment, and their experiences entering the industry upon graduating as well as in their following career.

Interviewees (pseudonymized)	Educational background	CG line CGS: Full-time semester CGP: 50% 1-year study	Current occupation
A	Mechanical engineer	CGP (2017)	Construction engineer
B	Biomedical Engineering and Informatics	CGS (2016)	Project manager in Health care
L	Computer Science	CGP (2016)	Agile coach
M	Biomedical Engineering and Informatics	CGS (2017)	Quality assurance in healthcare
J	Animal science, PhD	CGP (2018)	Software development Partner in company

Table 1. Interviewee profiles.

The interviews were recorded and analyzed using thematic narrative analysis identifying themes emerging from the data and the stories that participants construct based on their own experience as 'creative geniuses.' These themes include creative processes (alone and co-creating with others), horizontal thinking, facilitation of others' creative thinking, and development of creative self-efficacy.

Limitations of the study

The thematic narrative analysis in this paper is based on in-depth interviews with just five out of approximately 200 CG graduates. Thus, it is not meant to be considered representative for or generalizable across all CG cohorts. Whereas the data aligns with previous testimonials from students enrolled in the program, this analysis focuses on each interviewee's perspective as a unique CG program experience, creative competencies development, and perceptions of creative self-efficacy in the transition from student to professional.

FINDINGS

The following section provides an overview of the five Creative Genius graduates' different motivations for joining the CG program and their perceptions of the learning environment while enrolled as students in the program. The following themes emerging from the interviews are identified and analyzed: transition from student into industry and work, their experience as professional 'creative geniuses' facilitating creative processes (alone and with others) in transdisciplinary settings, their perceived ability to think horizontally and their experience of creative self-efficacy. Neutral pronouns are applied. Quotes are translated from Danish and presented in italics.

Motivations for enrollment in the CG program and perception of the learning environment

The motivations for participating in the Creative Genius Program differentiated depending on whether the graduate followed the CGS or CGP line. A, L, and J all followed the 1-year part-time CGP line for professionals as a deliberate choice to pursue becoming more creative. In contrast, B and M chose the full-time day study, CGS, somewhat 'by accident' and mainly because their fellow students chose to enter an internship or to study abroad, leaving B and M "behind." Thus, they found CGS to be an interesting alternative to internships.

Whereas all graduates positively perceived the CG learning environment, each interviewee highlighted different aspects of the learning environment as particularly important to their experience and development. For instance, A emphasized the many training exercises and the high intensity at CG as essential to developing creative competencies, while B emphasized the many deadlines together with what was

considered as having “enough time” between each deadline as crucial because it supported an experience of being ‘forced’ to take steps into the unknown; Realizing that, using their training and the toolbox, they were able to succeed in getting ideas and solving problems “...because there is always something I can't figure out. Giving me time to be in a frustrating process. That is also something I learned from there (ed: from CG)”.

L and J both appreciated the thorough understanding of creativity theory and a framework for utilizing their creativity. A and L got confirmation of their own creativity and experienced an environmental framework to practice their creativity. L particularly enjoyed being in a learning environment where everybody was accepted and appreciated for their ‘crazy ideas’: “*I am a playful child myself and think it is fun to make things... and I often hit the wall in relation to what others could accept... so this was also a way to get an outlet where I could play with someone who wanted the same*”. J considered CG the best part of their academic life, where they learned to use the rest of their education better.

Career transitions and creative mindsets

All interviewees generally report a smooth transition from the CG program to the professional career of their choice. Furthermore, their experienced creative self-efficacy makes them feel confident in using competencies and methods from CG. A and B, though, mention limitations in collaborative processes with colleagues who are not equally confident about being part of a creative process that requires open-mindedness and creative self-efficacy to be playful and willing to accept new ideas. Interviewee A mentions meetings where especially superiors tend to turn proposals down before exploring their full potential: “*Then we have an innovation manager, and you can say that the way it works is that he is the one talking, and his ideas come forward. So that is just the way it is. It is simply too big a task to throw yourself into getting him converted. Here in the company, plenty of people have 30 years of experience. It does not necessarily mean that they are the ones who get the good ideas, but they are the ones in power, you could say. (...) Breaking out of our roles, or getting someone to break out, is the hard part*”. J, on the other hand, feels confident in using the methods and competencies from CG. As a partner in the company, they are in a position where they can arrange and facilitate meetings with both colleagues and customers as creative processes.

Transdisciplinary engagement, co-creation, and creative self-efficacy

In general, the graduates are confident about engaging in transdisciplinary problem-solving. In the following, we describe examples to illustrate how they use their creative competencies to do that.

Focusing and incubating a problem

A describes that, when facing a problem, their creative method is to first arrange a timeslot free of any disturbance, both physically and mentally, and afterward collect and arrange (by drawing/writing down) all kinds of vertical and horizontal knowledge that could potentially be relevant for the problem. The primary source of horizontal knowledge is old projects from previous jobs and TED talks from different fields of knowledge that A continuously watches for inspiration: *“This collects many different kinds of information. I am interested in all sorts of strange things, watching videos with all sorts of weird technologies. So, you kind of have some things that can be pieced together so that you can make that horizontal transfer and get things from another industry over to what I am doing”*. During this process of focusing, ideas flow even after work hours when A deliberately engages in incubation activities like trivial activities that will keep the mind busy without removing focus from the problem: *“Usually, it takes place outside working hours, going for walks or doing various trivial work tasks, where you sort of switch off your brain.”* This method neatly follows the processes of horizontal thinking in Figure 2. Having their first experiences at Creative Genius, A spent years refining their creative method until today and uses it often, confident that it helps produce the ideas needed to ponder and solve a problem.

M also makes deliberate use of focusing and incubation in the creative process. When working on a problem and for some reason getting stoked, M deliberately puts the task "on hold," takes a break, and starts incubating, trusting that the unconscious mind will come up with useful ideas. *“It has given me such a sense of security (...) to know that you just have to focus a little on it to the extent that you can now, and not go so much in-depth with solving the problem but just gather some information and then trust that when you walk away from it and just have a break or look at something else, then yes, the solutions can suddenly come to you, and that there is actually a reason for that. You often talk about how all the ideas arise in the shower and then know why it is like that and also be able to trust that it IS like that.”*

Transforming horizontal knowledge through co-creation

For most interviewees, the involvement of horizontal knowledge from other disciplines comes from colleagues in other departments, customers that are involved in the creative process, previous personal experiences in (work)life, TED talks, and, as in J's following example from transforming knowledge from horizontal professions as part of the creative process. J is an engineer specialized in designing software for agricultural cattle breeding, often deliberately working on transforming knowledge from people working in horizontal 'breeding fields,' including pigs, goats, and even humans. J also turned the sales process into a creative process called the "discovery phase," in which potential new customers and colleagues are facilitated using different ideation techniques: *“It is fun, but they do*

not want to (ed: work creatively) themselves. I am the one who has to run it, but also because I have gone through that education. I am the one who thinks of it. (...) when you facilitate such a process, you actually get the good ideas or the best things that are said. They are said by people where you did not expect it. We had a meeting about something very technical. Fodder and all sorts of health-promoting things blah blah, but the most important thing that was said in that meeting was by a man who was a salesman but who had previously worked selling two trays. I think he had the freshest input. Everybody else, it was just the same. They really had to be pushed". J also emphasizes the importance of establishing a creative working environment at meetings and, as a company partner, often designs and runs meetings for colleagues and customers as creative processes.

All the interviewees describe different ways of facilitating meetings with colleagues or customers through creative processes. When M is in a meeting, M likes to provide more open-mindedness and ideas by challenging standard views or positions taken by others by using the method of "Six thinking hats" (de Bono, 1985): *"Then we were introduced to the six thinking hats, or whatever it was called. Something like that, I will also take it with me further. Just like trying to see things from a different angle, or you are sitting in a meeting, and there is someone who is taking on a different role in relation to asking the right questions. At least I can become aware of asking some questions I would not ask myself if you can put it that way. Actually, get some different attitudes than the ones I have. To push the others a little".* M uses this method when experiencing resistance towards new ideas: *"I think I have many opportunities to do it myself (be creative, red), but as soon as you try to involve others, then there is a bit of a blockage in it. And, also, the thing about just asking stupid questions to arrive at the best solution. It is very difficult because others say NO because they feel it sounds stupid instead of just running with the idea. So, I think it is really difficult because others do not have the same mindset that now we just brainstorm or come up with wild ideas because something might come out of it".* This quote highlights the importance of persuading colleagues to follow new ideas by pitching them and trying to facilitate small creative processes that reveal the idea's potential and persuade others to work on it.

Creative self-efficacy

All the interviewees emphasized the importance of developing creative self-efficacy, enabling them to face and navigate the unknown as a key takeaway from CG. In fact, creative self-efficacy seems to be one of the most important gains from CG and could be why all interviewees, 5-7 years after leaving CG, still use the creative competencies they learned with great confidence.

For example, B is a project manager responsible for designing a new department in a hospital. They emphasize the importance of allowing oneself to have many ideas before deciding. To be stubborn and tolerate the frustration that often follows deliberately to

refuse to make decisions based on one or only a few ideas, to keep a task open for more and better ideas. This strategy requires creative self-efficacy and confidence that the good idea *will* come sooner or later. B considers this ability the most important competence of attending CG. When asked what takeaways from CG B would recommend to include in any future PBL-based curriculum, they used an analogy used in CG: how to pass a dragon to get to the gold. *“We had plenty of time to do things. I had time to be in the process, to be in the discomfort, and also be forced – because of a deadline – to make some choices and do something. It is like having to defeat a terrifying dragon, and you define how big such a dragon should be. But there is a reason why it is scary, and that is because the dragon hides much gold... and that is self-development. It is a potential in one's self-development. That is why it is very worth it, and it is only if you get past those first steps and defeat the dragon, well then, you will get it. And you have to face the discomfort. And maybe the learning that it is OK that it is uncomfortable.”*

DISCUSSION

The ‘dragon’ in the above analogy represents the fear of dealing with a problem with little idea about how to understand or solve and approach it with an open mind, forcing one to take steps out into unknown territory. This analogy fits well with what Otto Scharmer calls stepping out in the space of nothingness (Scharmer, 2016). In Scharmer’s theory U, the dragon is replaced with three enemies called Voice of Judgement, Voice of Cynicism, and Voice of Fear, i.e., the three inner voices that must be passed to open one’s mind when engaging with problems in unknown territory (Scharmer, 2016). The ‘gold’ you get after passing the dragon or Scharmer’s three voices is a creative self-efficacy that lets you embody a creative mindset as second nature and with self-confidence, equipped with the creative competencies and methodologies to ‘pass any dragon’ in the future in terms of complex problems that defy current understandings and solutions.

A similar emphasis on self-efficacy is found in recent approaches to developing a sustainability mindset, highlighting the need for transformation from resignation, rigid, resistant, and reactive responses to sustainability challenges to innovative, flexible, adaptive, and reflective responses to complex problems (Rimanoczy, 2020). Findings from this study indicate that creativity and creative competencies play a crucial role in this transformation.

Thus, whereas creative thinking is already linked to transdisciplinarity in the act of borrowing from, integrating between, or merging with other disciplines, we would argue that a focus on creativity in PBL goes beyond and transcends the distinction between ‘academic’ or ‘professional’ knowledge and other types of inherent, latent or potential knowledge that could be relevant in complex problem-solving in the pursuit of a sustainable future. This includes horizontal knowledge from other disciplines, but it also

includes horizontal *thinking* and emerging or ‘latent’ knowledge, i.e., memories, imagination, and intuition (De Bono, 1992; Byrge & Hansen, 2014) and encourages risk-taking by embracing “failure” as a positive learning experience and source of new knowledge and ideas (Connor, Berthelsen, et al., 2014; Barile & Saviano, 2013). Thus, in addition to the representation of different interdisciplinary 'T,' 'H' or ‘comb’-shaped professional profiles, we would argue that ‘zooming in’ on the integration of vertical and horizontal knowledge reveals an organic and dynamic interconnectedness of knowledge ‘in use’ (of which some is professional expertise) and ‘latent’ (horizontal) knowledge. Thus, inspired by human biology and our own experience with horizontal thinking and creative exploration of knowledge from other fields following a presentation on genetics research by Professor Eske Willerslev at a science education conference (Big Bang, 2023), we suggest that the integration of vertical and horizontal knowledge can be illustrated as a continuous and transformative creative process, with creative competencies such as horizontal thinking (Byrge & Hansen, 2014; De Bono, 1992), open-mindedness and co-creation (Byrge & Hansen, 2014; Scharmer, 2016) providing the links between these two 'strands' of ‘knowledge in use’ and ‘latent’ or emerging knowledge, much like a ‘double helix’, as a model for creative transdisciplinary thinking (Figure 3).

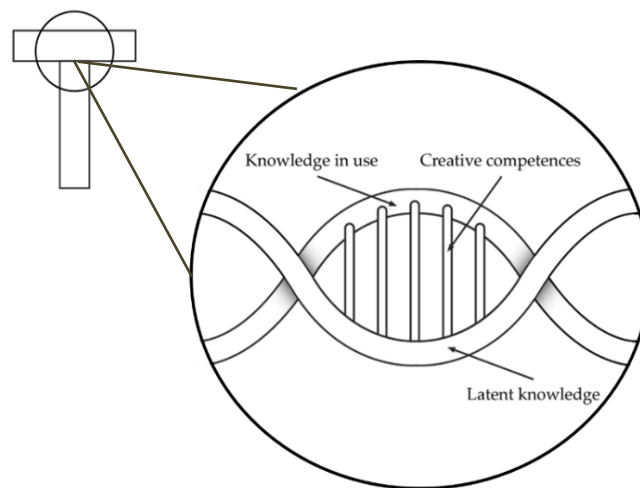


Figure. 3. Model for creative transdisciplinary thinking.

This horizontal thinking model emphasizes the need to support students’ creative approaches to processing knowledge through novel combinations and transformation of knowledge, not just across disciplines but also across tacit and emerging horizontal knowledge that can be made explicit and used vertically through ideation, incubation, horizontal transformation, and co-creation to offer new innovative perspectives and possible solutions to complex problems.

This study indicates that a PBL environment with an added focus on creativity can equip graduates with such creative competencies and creative self-efficacy to use horizontal

thinking in their studies and future professional life. Graduates from the Creative Genius program generally experienced the transition from student to professional as smoothly, using their creative competencies and training from the program to engage in transdisciplinary and complex problem-solving with a creative mindset, especially when working individually and with colleagues who are open-minded and willing to engage in a creative process. The study also highlighted the need for creative leadership in complex problem-solving and how co-creating with colleagues, particularly superiors, who are unfamiliar with creative processes or acknowledge the value of horizontal thinking, can be challenging. Hierarchies and power dynamics can make it difficult to engage in horizontal thinking with colleagues and superiors, even when the candidates have been trained to handle this by engaging and acting as role models facilitating a creative learning and working environment.

Being open-minded and able to co-create across disciplines using horizontal thinking to combine and connect transdisciplinary knowledge in a transformative process was one of the learning goals at the CG program. The study suggests that it is possible not only to educate students with these competencies but for graduates to sustain this creative mindset through the transition into industry and work. All CG graduates did possess a relatively high degree of awareness about creative competencies and processes in their everyday life, expressing a high degree of creative self-efficacy and highlighting this as one of the most critical gains from CG in the transition to a professional work life. Thus, this suggests that creative self-efficacy and the embodiment of creative competencies also outside the classroom or inherently creative learning environment is key when solving complex problems and thus could be an important learning outcome in any PBL learning environment seeking to integrate more transdisciplinary approaches to problem-solving.

CONCLUSION AND PERSPECTIVES FOR FUTURE WORK

This paper introduced the Creative Genius Program as an innovative approach to transdisciplinarity in higher education and, based on interviews with graduates from the program, explored whether a problem-based learning environment with a focus on creativity facilitates transdisciplinary engagement and creative competencies and to what extent this can manifest into transdisciplinary career paths and creative mindsets in a life-long learning perspective.

Whereas results from the study indicate that a focus on the development of creative self-efficacy and the embodiment of creative competencies do support students in the transition from student to professional and help equip them to engage in transdisciplinary and complex problem-solving in industry and society, the study is limited to a small sample of graduates and further research needs to be conducted to verify results, both

across the Creative Genius cohorts and for graduates from other similar transdisciplinary and creative learning environments in higher education.

Furthermore, while the Creative Genius Program was considered a successful educational experiment and research program with high student and stakeholder satisfaction, this does mean that the pedagogical model is a ‘one size fits all’ and applicable to all other learning environments or that CG should be compulsory at curriculum level across all programs. Rather, it suggests a need for PBL environments that seek to integrate transdisciplinary approaches to complex problem-solving, to explore and experiment with establishing creative and psychologically safe learning environments with learning outcomes that explicitly address creative problem-solving to support students in developing creative self-efficacy and embody creative competencies to make the needed connections between their discipline-specific or vertical knowledge ‘in use’ with broader, horizontal and ‘latent’ knowledge through creative transdisciplinary thinking, open-mindedness, and co-creation to address and engage with transdisciplinary and complex problem-solving in industry and society.

The first step to achieving this could be to develop awareness among PBL facilitators and supervisors about their own experiences and capacity as ‘creative geniuses’ and how they might utilize their creative competencies, horizontal thinking skills, and creative self-efficacy when teaching in problem-based and transdisciplinary settings in higher education.

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**The Interplay of Engineering Skills, Aesthetic Creativity, and Ethical Judgement
in the Creation of Sustainable Urban Transformations:
Aristotelean Perspectives on PBL**

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ABSTRACT

This paper examines a PBL project module “Sustainable Urban Transformation” in an Urban Design master’s education. The module combines urban design and hydrology engineering. Within the module, students are supported by lectures and study circles on various dimensions of sustainability, especially vis-a-vis climate change. However, they are left with the freedom to choose how they balance between design and engineering approaches when they give a physical form for sustainability in the site transformation projects with which they work through the semester. This paper discusses the development of their skills building on three Aristotelean concepts: techne (engineering), poiesis (aesthetic form-giving), and phronesis (making of ethical judgments). The last two concepts, the paper argues, are especially important when at issue is design education. Based on an analysis of the student projects in Fall 2022, the paper examines whether and how the students manage to find a balance between engineering skills, on the one hand, and aesthetic creativity and ethical judgement, on the other hand, in their project work.

Keywords: Urban design, design pedagogy, sustainability, engineering, ethical judgement, problem-based learning

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INTRODUCTION

This paper examines a problem-based learning module “Sustainable Urban Transformation”, which is part of the Urban Design master’s program at Aalborg University. Each module in the program combines urban design with some specific branch of engineering science – in this case hydrology. The core of the module is a project where the students work in groups, each group being supervised by one urban designer and one hydrologist. The task given to the groups is to create a design for a sustainable transformation for a pre-selected urban site in the face of climate-change related challenges.

In this paper, the focus is on the theories behind the pedagogical solutions in the “Sustainable Urban Transformation” module. In the design of the module, the relation between knowledge – or forms of knowledge – and action is in a central position, as it typically is in problem-based learning. In approaching the knowledge-action relation, the paper builds on Aristotelean theories in pedagogics. The paper also illustrates and evaluates the pedagogical solutions and the theoretical ideas behind them, based on an analysis of the student projects carried out in the module in Fall 2022.

Given that all the authors of this paper are teachers in the module, and as such, responsible for the design and development of the module, the research approach could be classified as action research (Greenwood & Levin 2007). Action research is not based on any single methodology, but it can draw on various established research methods. In this paper, the research is based on philosophical theories of knowledge, design theory, pedagogical theories, and theory-guided analysis of students’ projects.

In the existing research literature on sustainability-promoting design education, it has been often pointed out that sustainability should be advanced especially by integrating engineering approaches into design thinking (e.g. Altomonte et al. 2014) and that problem-based pedagogy and studio teaching should be used to support this integration (e.g. Moosavi & Bush 2021). Yet, given the differences between engineering and design traditions, integration can be difficult to achieve in practice. Engineering approach has traditionally emphasized universal scientific knowledge and formulas, which are derived from this knowledge, and which provide the basis for problem-solving (e.g. Schön 1983). Within this approach, it has been traditionally assumed that problems or tasks can be clearly defined, and that there are relatively clear criteria for judging whether the problems have been correctly solved (Rittel and Webber 1973). Within design approach, by contrast, knowledge often runs short, and creativity and imagination are needed so that the outcomes are not only well-functioning but also aesthetically appealing, innovative, and fitting their physical and social environment.

These two approaches – engineering and design approach – are discussed in this paper in light of neo-Aristotelean philosophy and pedagogics. Engineering approach is discussed in the framework provided by the Aristotelean notion on *techne*, referring to technical skills. Design approach is discussed in light of two different concepts: *poiesis*, referring to skills needed in creative arts and aesthetic aspects of design, and *phronesis*, referring to the capability for ethical judgment and practical wisdom. *Poiesis* has not thus far gained much attention in neo-Aristotelean pedagogical theories, perhaps because the concept of aesthetic creativity – or human creativity in general – was not yet matured in the ancient Greek, but began to gain attention from scholars only during the emergence of Renaissance humanism (Jauss & Shaw 1982, 598–599). Nonetheless, as this paper argues, when at issue is design education, *poiesis* cannot be excluded from the typology of ways of knowing. *Phronesis*, in turn, has been a much-discussed concept in pedagogical literature (e.g. Lennartson & Sundin 2001; Gustavsson 2002; Birmingham 2004), and it is undoubtedly a central concept of design education where the students as future urban designers need to learn to take responsibility for the future generations and natural environments, on which the future of humans depends.

As regards the concept of sustainability, the pedagogical solutions of the course module are designed to leave the students with a freedom to define and concretize the meaning and scope of “sustainability”, and to give it a physical form in their design projects. This is expected to support the development of their *phronetic* skills and creative design thinking. In this process, the students are supported by lectures, literature and reading circles where sustainability is discussed in relation to climate change and urban context. Urban planning and design have typically relied on two different types of responses to climate challenges: mitigation and adaptation (e.g. Davoudi et al. 2009; Howard 2009). Research has shown that climate change can be mitigated especially by densifying urban structure and thus reducing transport-related emissions. Adaptation to climate-change related threats such as extreme weather conditions can be advanced, for instance, by designing green structures that make the urban environment more resilient in the face of flooding. Mitigation can be integrated into adaptation solutions. Nonetheless, knowledge-based mitigation and adaptation do not always align. For instance, adding more green structures often decreases density that is needed for mitigation-related goals, and increasing density often consumes green structures needed for adaptation (cf. Larco 2016).

In addition to climate change mitigation and adaptation, global biodiversity loss has been an emerging theme in the discourse concerning sustainable urban transitions. Biodiversity loss has been argued to result from climate change (e.g. Bellard et al. 2012), but even though densification of urban structure might mitigate climate change globally, it often leads to local biodiversity losses.

Mitigation, adaptation, and prevention of biodiversity loss are types of action through which sustainability can be advanced in urban transformation, but there are also other possible ways of working for sustainability. For instance, the social and cultural aspects of sustainability need to be accounted for alongside the ecological aspects of sustainability. The tricky part of design work is that responses to one sustainability goal often create new problems in relation to some other aspect of sustainability. As such, designing for urban sustainability is a field saturated by “wicked problems” (cf. Rittel & Webber 1973; Lawson 2009). Wicked problems cannot be definitively formulated, but they keep on changing while they are being solved or re-solved. Wicked problems do not have one correct answer that could be derived from universal scientific knowledge and calculated by formulas coming from engineering sciences (Rittel & Webber 1973). Even though engineering approaches are helpful in indicating potential solution candidates for wicked problems, sustainable urban transitions require also creative design thinking – resulting as wild ideas – and skills for practical-ethical and aesthetic judgment through which ideas can be critically assessed.

In what follows, the theoretical background, the structure, and the expected learning outcomes of “Sustainable Urban Transformation” module are discussed drawing especially on the Aristotelean typology of skills or knowing in action. The research question is whether the course design of this module advances a balanced development of students’ *technical*, *phronetic*, and *poietic* skills, or are some of the skills emphasized at the expense of others. More precisely, the aim of the paper is to find out whether the strong engineering orientation in this module reduces the space left for *poiesis* and *phronesis*, the ways of knowing and acting that seem to resist any simple “from problem to solution” or “from knowledge to action” structures. And vice versa, the question is also whether design education, where *poiesis* and *phronesis* have been traditionally important, turns out to be a problematic context for teaching systematic and knowledge-based problem solving typical for engineering sciences. These questions are answered by analyzing the Fall 2022 class’s project reports, which showcase the actual learning outcomes of the project module. Finally, suggestions are made for the further development of the module, and for the development of PBL in general.

THEORETICAL BACKGROUND: ARISTOTELEAN VIEWS ON KNOWLEDGE AND ACTION

While scholars typically agree on the fact that students attend university education to acquire knowledge, there is typically no consensus over how the knowledge acquisition should ideally take place. This sub-section takes as its point of departure the interconnectedness of the questions concerning the appropriate methods of acquiring

knowledge, on the one hand, and the questions concerning the academically relevant types of knowledge, on the other hand.

The proponents of problem-based learning argue that the traditionally popular methods in academic education such as attending lectures and reading books do not foster learning efficiently enough. Though these methods can support learning to a certain extent, the theorists of problem-based learning argue that to promote efficient learning, education should primarily take place through problem solving in groups of peers with the help of tutors or teachers, so that learning is student-initiated and there is sufficient time for self-study (Schmidt et al. 2019). When knowledge is acquired in the context of action, and turned into action through project work, the students learn to contextualize the knowledge in a meaningful way, assess the knowledge acquired against this context, and connect new knowledge to the knowledge that they already have (Moust et al. 2021). In this way, they are also typically more motivated to learn than they would be in traditional lecture-based courses or when reading books for exams (Rotgans & Schmidt 2019).

Traditional university education emphasizing learning through lectures and books has been concerned especially with propositional or theoretical knowledge – *episteme*, as it was called by Aristotle and other ancient Greeks. However, already Aristotle recognized that there are also other types of knowledge or knowing. Contemporary scholars in pedagogics have discussed alongside *episteme* the two Aristotelean forms of practical knowledge, *techne*, and *phronesis* (e.g. Lennartson & Sundin 2001; Gustavsson 2002; Birmingham 2004). These types of knowing have been seen as forming the core of such practice-oriented disciplines as urban planning and design (Davoudi 2015).

Modern engineering education has relied primarily on the tradition developed around the concept of *techne*, a concept that refers to technical knowledge where at issue is not primarily “knowing what” as it is with *episteme*, but “knowing how” (Davoudi 2015, 320). This type of knowing is needed for manufacturing products, and it is concerned with the means for achieving certain outcomes (Gustavsson 2002, 16). The notion of *techne* is the origin of the modern concept of technology, but also of the Latin word *ars*, which originally referred to art as craft, but which has also become to mean high arts in the modern world (Schatzberg 2018, 16).

Even though Aristotle differentiated between *techne* and *episteme*, the concept of *techne* was not disconnected from knowledge altogether. *Techne* did not refer primarily to embodied, non-conceptualizable skills such as the skill of riding a bike, but it was grounded in propositional knowledge and included “specifiable principles toward a definite end” (Ford 2015, 144; see also Schatzberg 2018, 21). As such, *techne* can be argued to anticipate modern understanding of technology as a science-based activity. The conception of *techne* as a skill based on specifiable principles aligns with the traditional

conception of problem solving in engineering, where the problem, or the end, is known beforehand, where solutions can be justified with explicit principles based on universalizable knowledge, and where it is thus relatively easy to judge whether the problem has been adequately solved.

The concept of *phronesis* brings us closer to the tradition of design education where the existence and status of specifiable principles of production can be contested because of the wickedness of design problems. Whereas in the case of *techne* at issue is the production of an external object, in *phronesis* – often translated as practical wisdom – the goal is not an external object but the political and ethical action, that is *praxis*, in itself (Gustavsson 2002, 16). *Phronetically* skilled planners and designers are capable of making practical judgements based on their personal experience, which means that “*phronesis* goes beyond analytical (episteme) and technical (*techne*) knowledge” (Davoudi 2015, 321).

While *techne* and *phronesis* have already gained attention in neo-Aristotelean pedagogical literature, this paper – being focused on design education and on the production of aesthetically good-quality urban environment – adds to the discussion the concept of *poiesis*, which is used in this paper to refer to the art of “producing beautiful artefacts” (Volanen 2007, 79). In this case, this means aesthetically appealing urban design. The fact that the Ancient Greeks’ concept of *poiesis* has not been much discussed in the theories of education is probably due to the dual nature of this concept. On the one hand, Aristotle used the concept of *poiesis* to refer merely to one specific stage of *techne*, the “making” of the object, without discussing the specific poetic or aesthetic dimensions of such making in the modern meaning of aesthetics (e.g. Dewar 2016, 27); on the other hand, *poiesis* is a concept in which the word poetry is rooted, and as such, it seemed to refer already in the Ancient Greek to the specific artistic dimensions of action and knowledge, dimensions dealing not only with *what* the poets said but *how* they expressed their messages (Murray 2015, 159). At issue was not the production of just any objects of use, but such pieces of work that had specific experiential qualities and that were meant to impress the audience by “enchancing their souls” (Ford 2015, 145–146).

While Aristotle held that the production of these responses could be knowledge-based and follow at least some technical principles, many other Greek philosophers – Plato being the most famous of them – held almost the opposite view in arguing that in such production, technical principles are interrupted by a divine intervention that sets the poet “out of his mind” (Murray 2015, 159). Modern aesthetics has largely departed from the company of Aristotle as it has emphasized the autonomy of aesthetics, that is, the disconnect of aesthetics both from knowledge and ethical or moral considerations. Nonetheless, while the modern idea of autonomy of aesthetics may function in the context of high art, it does not work in the domain of design where aesthetic dimensions of the

creation and experience cannot be dissociated from the technical and ethical-practical concerns. This being the case, Aristotle's concept of *poiesis* – with its connections to *techne* and *phronesis* – may provide a more fruitful point of departure for discussing the aesthetic dimension of urban design than does modern aesthetics conceived of as philosophy of art.

An interesting aspect in the Greek concept of *poiesis* is that unlike *techne* that is oriented towards the object produced, *poiesis* captures the process of making or “leading things into being”, resembling in this sense *praxis* rather than *techne* (Whitehead 2003). *Poiesis* therefore can account for the changing nature of objects, which in turn seems to be necessary when at issue is the environment, instead of the traditionally static and fixed works of visual arts. Following Heidegger, who has influenced greatly the 20th century aesthetics of architecture and environmental design, Whitehead (2003, n.p) concludes his description of the procedural nature of *poiesis* in the following manner: “working with the raw materials of the imagination (ideas, concepts, schemata) and those of the material order (paint, clay, or stone), constitutes a means of renegotiating our sense of 'place' with a renewed and placeful place of poietic and non-exploitative encounter.”

In our view, design education should promote the idea of aesthetics as *poiesis* in the meaning encapsulated in Whitehead's description. Aesthetic aspects in design should involve creativity where knowledge can be left behind, and room is made for radical experimentation, but it should also include such negotiation of radical ideas where at issue is their appropriateness in relation to their social and cultural context as well as to their natural environment. When compared to the ways in which aesthetics of visual arts are conceptualized in contemporary philosophy of art, the Aristotle-inspired concept of *poiesis* has the advantage that it can accommodate the temporal aspects of landscapes and townscapes, the constantly changing experiences of the users of the environment, and the narratives related to the human and non-human origins of the environmental change. Here, the concept of *poiesis* can bring added value for instance to landscape aesthetics, a discipline that has typically drawn on the tradition of landscape painting, and as such, it has had difficulties in conceptualizing change in the environment (e.g. Waldheim 2016). However, the problem with educating students to work with temporality is that design practice cannot ignore such traditions that build on non-temporal, “frozen” images of environments, given that design needs to be represented through fixed visualizations. This is one of the central problems or dilemmas to which the pedagogical solutions of “Sustainable Urban Transformation” wished to provide answers.

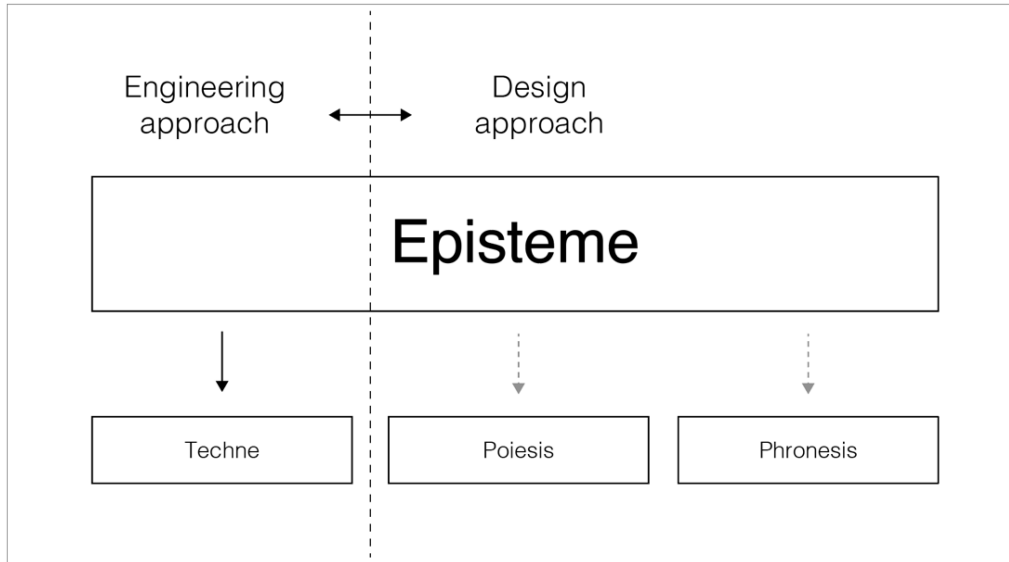


Figure 1. The relation between engineering and design approaches portrayed in terms of episteme, techne, poiesis and phronesis.

THE STRUCTURE AND THE EXPECTED LEARNING OUTCOMES OF THE PROJECT MODULE

The theme of the first semester of the master's program in Urban Design is urban transformation: the constant re-making of the urban environment, where sites change their function and character, adapting for instance to the changing society, culture and climate. The semester consists of two course modules (5 ECTS each), which are followed by a project module (20 ECTS). The first course module is an introduction to urban design, and the second is about the basics of hydrology.

Urban design and hydrology are then combined in the project module "Sustainable Urban Transformation". The assignment in the project module is to create a design proposal for a site in need of transformation. In fall 2022, the site was an urban waterfront area in Aalborg, Denmark. The site is characterized by a diverse maritime life, including a leisure boat marina and green recreational structures. The topography of the site is low, making it vulnerable to flooding due to rising sea levels. In addition to the sea level rise, the students are expected to respond to challenges such as storm surges, changing ground water levels, and cloudbursts.

The learning goals of the project module include both knowledge (*episteme*) and skills (related to *techne*, *poiesis*, and *phronesis*). Firstly, the students must gain knowledge about sustainability in the context of urban planning and design, especially knowledge concerning climate-change mitigation, local climate-change adaptation, and the prevention of biodiversity loss. Secondly, the students must learn about the dynamics of climate in the Danish context to understand the implications of climate change on

hydrology in the local scale and to target their climate adaptation strategies to specific periods. In Denmark, we expect more frequent and extreme weather events of precipitation and storm surge, along with rising groundwater and sea water levels (DMI n.d.). Whereas a storm surge and extreme precipitation have a short time horizon, sea water level rises slowly over centuries. There are climate projections available in relation to different return periods. Hence, the students need to reflect critically on which climate scenario/scenarios they use as background material for their design proposals.

Project work can be additionally backed up with scenarios concerning other themes than climate-change, such as social, cultural, or economic changes, even though climate change is typically considered to be the most crucial factor when the future of the earth is at issue, being also a factor that might have major social and economic consequences. To support the students' understanding of future changes in the environment and in society, and the implications that these changes have for urban planning and design, they were given a workshop on scenario planning (e.g. Goodspeed 2020). Scenario planning literature typically discusses three types of scenarios. First, there are evidence-based scenarios, which indicate how the world will be likely to look like at a certain point of time if there are no interventions that change the current line of development (e.g. Ravetz & Miles 2016). Climate scenarios are typically an example of this. However, the future is always characterized by uncertainty, and some scenario planning scholars have suggested that there might be some unlikely but possible trajectories that we might want to consider when planning and designing our environment. To form "exploratory scenarios" charting out these unlikely changes, both knowledge and imagination are needed (Avin & Goodspeed 2020). Finally, scenario planning includes normative scenarios, visions of an ideal future state of affairs. These scenarios form the core of urban planning and design, because planning and design are disciplines that are purported to make the world a better place, and to halt those trajectories that lead to undesirable scenarios. However, if we want to avoid the creation of utopian urban designs that cannot be implemented in practice, normative scenarios should be conditioned at least to some extent by evidence-based scenarios, and perhaps also by explorative scenarios.

In addition to scenario building, scenario planning literature discusses the method of backcasting, where the steps required for the attainment of desirable future visions are determined (Robinson 1990, 822–823). The students were encouraged to produce phased designs, reflecting on what would be the phases that are strategically important for the attainment of their design goals and when those phases should be carried out.

Temporality is an aspect that is important not only for strategic planning, but also for the physical design on the site. Students need to understand the landscape, its topography, and the movement of water on the site over time. The designs must perform under different conditions such as rising sea level, extreme weather events, and dry periods.

Yet, the designs are not only purported to support sustainability conceived of in terms of climate-resilient physical structures, but they should also advance social and cultural sustainability. While these aspects of sustainability can also be supported by knowledge – for instance, social-scientific knowledge or local knowledge obtained from the users of the site – the final judgments concerning the needs and preferences of future local communities require *phronetic* skills from the students. Furthermore, when the students design environments that are vulnerable to flooding, knowledge about climate dynamics in relation to hydrology and practical-ethical judgments concerning the needs of future citizens need to be combined with imaginative creation of new waterscapes, landscapes, and townscapes. Hereby, *techne* and *phronesis* become integrated with *poiesis*.

Finally, the students are expected to learn to communicate their professional knowledge and skills via their project report and scale models. In this article, the focus is on visual representations such as diagrams, maps, technical drawings, sections, and renderings, all these instruments being useful not only in representing the final design and its justifications but also in testing the initial design ideas during the design process. Many of these instruments also facilitate the integration of technical knowledge into design narratives containing both *phronetic* and *poietic* elements, enabling designers to effectively communicate these narratives visually to the public.

ANALYSIS OF THE STUDENTS' PROJECTS

The method and the theoretical framework

In what follows, three out of the total five design project reports from the Fall 2022 project module are analyzed, including the final design proposals, illustrations and texts. The three projects were selected because they represent three quite different approaches on advancing sustainability and climate-change resilience.

The analysis utilized the framework consisting of knowledge or *episteme*, on one hand, and generic skills related to *techne*, *phronesis* and *poiesis*, on the other hand. More precisely, this framework of knowledge and *generic skills* formed a lens for looking at the ways in which the students had practiced in their projects the following *specific skills* needed in sustainable design vis-a-vis climate change, skills that we have defined to be the key learning outcomes of the course module “Sustainable Urban Transformation”: 1) the ability to understand, define and give a physical form to sustainability, 2) the ability to understand, work with, and influence different temporalities related to climate and the environments, and 3) the ability to develop and present the design proposal by the means of visual representation and communication. The aim of our study was to find out whether the students are able to practice the generic skills related to *techne*, *phronesis* and *poiesis* in a balanced manner within our course design, or would the balanced development of

these skills require an update of the course design including the pre-defined learning outcomes of the course.

The analysis was conducted in three steps. First, each of the three members of the research team went through all three project reports by analyzing the contents in the framework described above. Secondly, the individual analyses were followed by a discussion between the team members to find out whether the interpretations made in the content analyses were commensurable and whether the conclusions drawn by the team members aligned. Thirdly, given that each team member had acted as a supervisor for one of the groups, and all researchers had taken part in the interim reviews, the researchers complemented the analysis with such pieces of knowledge about student groups' design processes that were not directly traceable from their project reports.

Approaches on sustainability

When discussing sustainability, the first thing to ask is what needs to be sustained (Larco 2016). Is it for instance human culture, man-made environment, or ecosystems? The project by Group One introduced a nature-centric solution to climate change adaptation as an alternative to the prevailing human-centric solutions. The primary aim of this design proposal was to sustain and improve the aquatic habitat in the Limfjord that faces the project site.

Group One had an ethically oriented mindset right from the beginning of the project. Rather than creating a feasible and developer-friendly proposal, the group aimed to spark “conversation about life in the fjord and future climate change” with their project (Høgild et al. 2022, 42). This could be interpreted as a *poietic* move where the design has a story to tell for its users. Nonetheless, in the beginning of the process, this group relied heavily on natural-scientific knowledge. The more they studied marine ecology, the more difficult it became for them to propose any design interventions, because these interventions seemed likely to disturb natural processes. *Episteme* thus did not turn into *techne* easily for this group.

In the end, Group One decided to create one “classic” masterplan of the on-ground design and another masterplan of the seabed, the designed habitat for the non-human life in the fjord (Figure 2). The group aimed to foster interaction between the two “zones” by making the fjord more accessible for the users for instance through sea gardens and promenades raised above the sea. In so doing, the group wished to provide for the local community opportunities for recreation and learning about marine ecology, thus encouraging the community to act for the restoration of the balance of the aquatic ecology in the fjord.

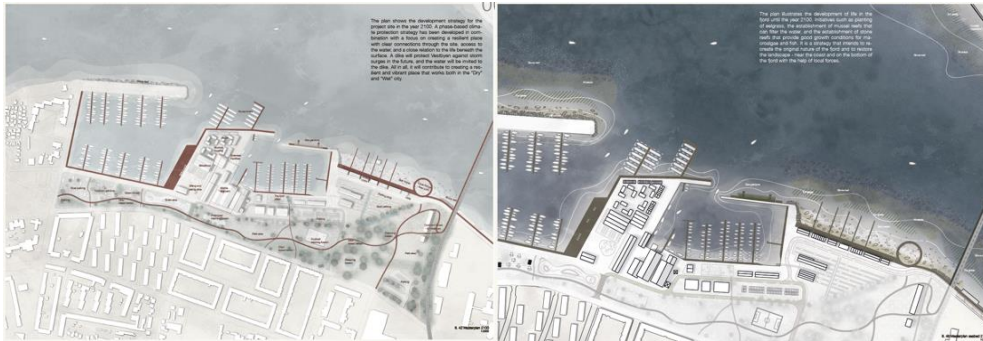


Figure 2. A classic masterplan of the dry-land side and a masterplan of the seabed by Group One (Høgild et al. 2022).

Ethical orientation was present also in the project of Group Two, but this group did not aim at nature-centric development, as did Group One; for them, *phronesis* was primarily about balancing the needs of nature and humans and about adding value to the site by enhancing the connections between nature, local communities, their daily practices and facilities and the existing built heritage (Figure 3).

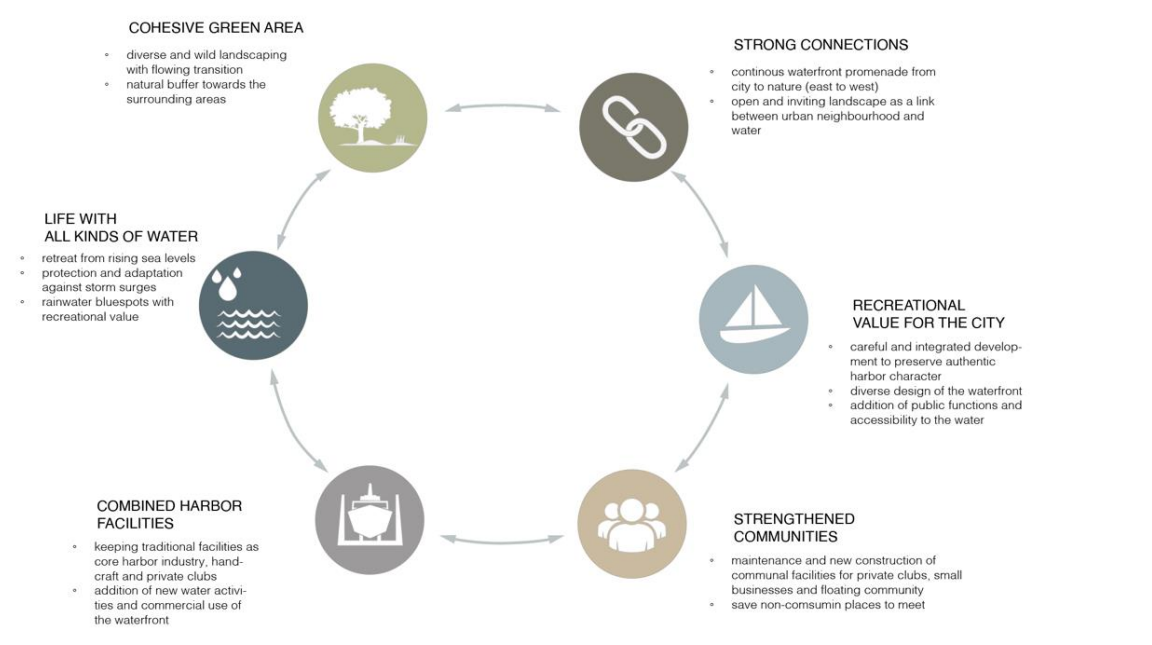


Figure 3: A graph by Group Two demonstrating how they balance between various objectives contributing to the sustainability of the site design (Fisker & al. 2022).

By leaning mostly on *techne*, the group combined three types of climate adaptation solutions: they invited water into the designed built environment in a controlled manner (adaptation), they kept the water out of the urban area by using hard engineering structures such as dikes and sluices (protection), and they moved some flood-prone urban

structures away from water (retreat) (Figures 4 and 5). Nonetheless, *phronesis* was also represented in the design process as the group wanted for instance to secure the continuation of social processes of the city dwellers when enhancing the resilience of the site in the face of the “behavior” of the water. Furthermore, *phronesis* was combined with *poiesis* when the group balanced the preservation of architectural heritage and the replacement of old buildings with new ones to serve the local communities’ new and emerging needs.

Group Three’s design proposal reflects an approach on sustainability that is more human-centric than the other two proposals. It embraces nature as an aesthetic and recreational component, as it increases the room given for water elements to be used for recreational purposes and for introducing housing on water (Figure 6). Thus, it concretizes sustainability in terms of new ways of living by making room for the water instead of protecting existing urban areas by keeping the water out. However, the implementation of this design proposal would demand radical human interventions and hard engineering solutions, as the project works against the existing terrain, making notable excavation of soil necessary.

This project also relies to some extent to the strategy of climate change mitigation through the densification of urban structure, unlike the other two projects. All in all, the *phronetic* considerations of this group are quite anthropocentric. The aesthetic aspects of the project, in turn, highlight the aesthetic value of human-designed structures. Given that the group does not wish to design with nature, but rather wants to maintain the authorship strictly in their hands, this group does not conceive the aesthetic aspects of urban design in the same dynamic sense that we understand them through the concept of *poiesis*.



Figure 4. Plan showing different protection levels by Group 2 (Fisker et al. 2022).

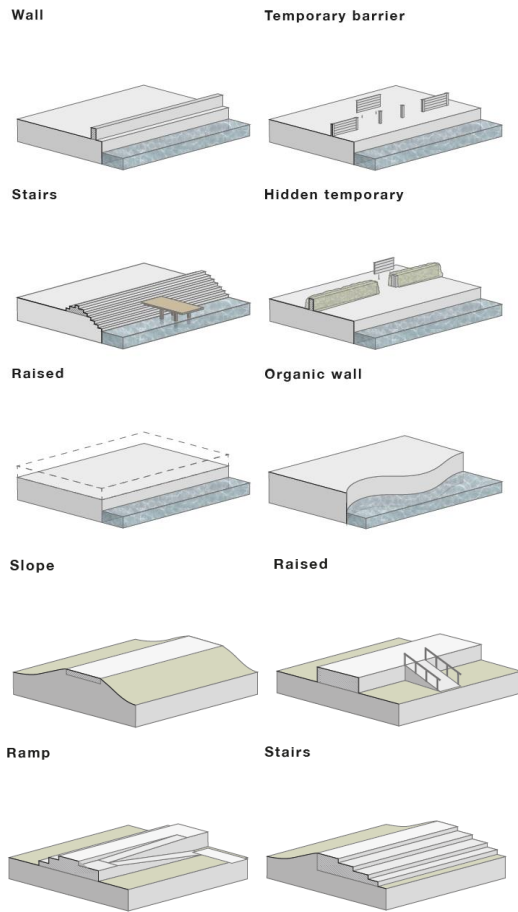


Figure 5. Various designs of coastal barriers and dikes by Group 2 (Fisker et al. 2022).

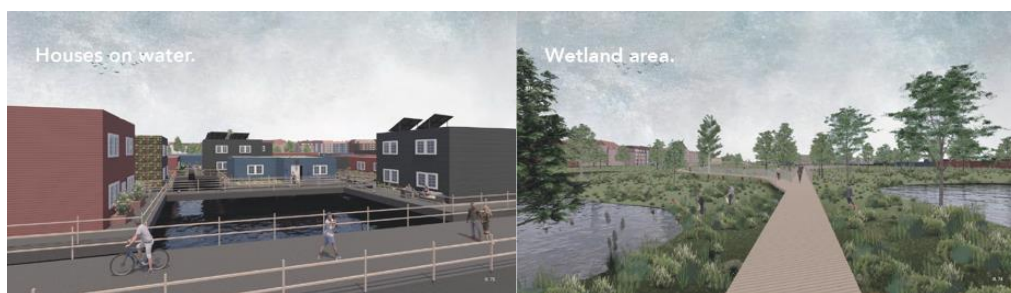


Figure 6. Renders by Group Three showing how water is an active element in the future's recreational environments and housing solutions (Krøis et al. 2022).

Working with temporality in relation to climate change dynamics

The three projects represent two ways of working with temporality in design. The first way is the integration of design and different climate scenarios. When using climate scenarios to support design work, the functioning of the design must be assessed under different hydrological conditions. The design must function under different sea levels and

extreme events that might occur over time, and it should not be developed primarily for such conditions that would for instance appear once in every hundred years.

Another way of working with temporal aspects is by phasing of the design proposal. Large-scale urban development takes place over several years or even decades, which makes it important to sequence the development. In this sequencing, backcasting might prove useful, as through this method it is easier to see what phases are needed and when they are needed if we wish to achieve the desired end-state on the site. Phasing also allows designers to adjust their designs to future uncertainties regarding climate change by leaving certain decisions open until more precise knowledge is obtained.

An example of the first way to work with temporal aspects can be found in Group One's project that presents three renders of a final design area (Figure 7). It illustrates how the area is affected by three different water conditions. The first one shows how it would appear in the near future, the second shows how it would appear in the year 2100 where the sea level has raised 50 cm, and the third shows how it would appear under a 100-year storm surge event in year 2100 with a sea level of about 240 cm (from left to right). Here knowledge of hydrological dynamics and climate scenarios is used to develop designs that function under different sea levels and extreme events, ensuring long-term design value.

Another example is the technical diagram presented by Group Two (Figure 8). The diagram folds together technical knowledge of sea level rise, storm surge scenarios, and the site's topography. It becomes a design-guiding diagram, opening the discussion concerning the level of protection needed for the designed structures and the required types of protection solutions. The group decided to use one scenario for 2050 (RCP 4.5) and another, more extreme scenario for 2100 (RCP 8.5). This manifests the concern about the increase in the uncertainty of climate projections the further ahead we look in time. Furthermore, the diagram communicates technical aspects of climate change affecting the local context. Both examples show how technical knowledge of climate change becomes a key factor in the design process, where the design must find its form in a changing waterscape.



Figure 7. Renders showing a design proposal affected by different climate scenarios by Group One (Høgild et al. 2022).

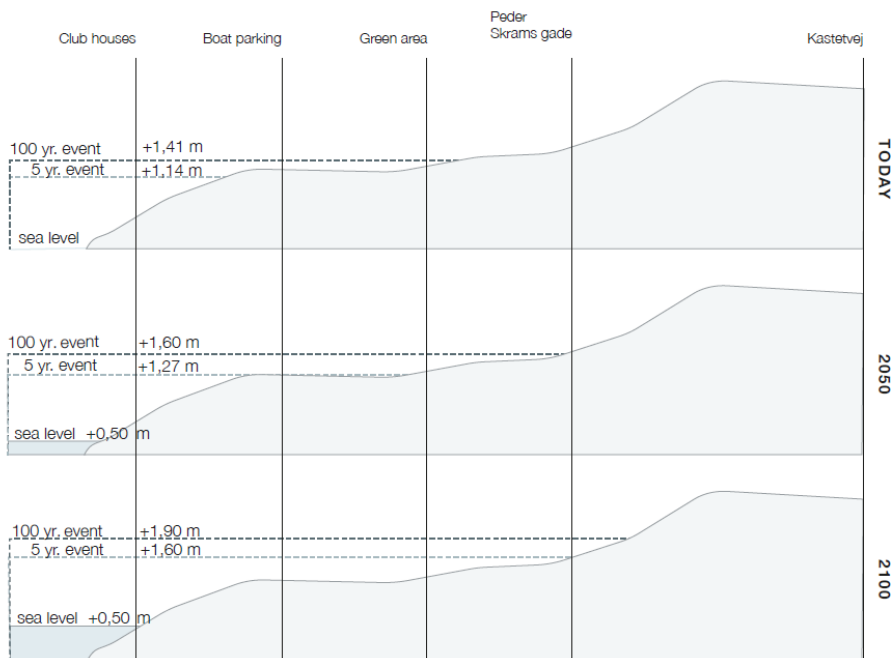


Figure 8. Diagram of sea level rise and storm surge affecting the site and its immediate surroundings by Group Two (Fisker et al. 2022).

Group Three builds on future climate scenarios just as Group One and Group Two, but Group Three’s main concern with regard to temporality is the phasing of their radical and comprehensive site transformation. In sequencing the transformation of the site, they look both at the requirements stemming from construction engineering and at the possibilities to sustain the functions on-site through the transformation process. Group Two has also

programmed the phasing of their design based on the time needed for distinct stages of the construction project and the possibilities of maintaining the functions on the site while the construction goes on. Group One, however, has chosen an alternative strategy: they reflect when it is relevant to start to adapt the site to climate change, while the other groups implement climate adaptation from the start, whether or not there is an urgent need to do so. Group One prioritizes the establishment of recreational functions and the improvement of marine ecosystems as the most urgent interventions, and only after these interventions would they start the construction of the structures needed for climate adaptation.

An approach that is missing from all groups is the development of climate adaptation designs that would accommodate changing climate predictions by incorporating flexibility in design. By allowing the designs to flexibly change as we become more certain about the future predictions, the groups could have avoided the construction of potentially “oversized” or “undersized” climate adaptation solutions. The lack of flexibility in the designs shows that working with dynamics and change is a new and difficult topic within urban design, a discipline that has traditionally focused on fixing the details of the physical forms of the city, whereas the discipline of planning has been concerned with strategic flexibility already for decades (e.g. Taylor 1998). However, as we have argued, designs could be usefully seen rather as narratives than as fixed pictures of the desired end-state, especially when at issue is environmental design. The environment, after all, is always in flux.

Visual representations integrating technical and design approaches

Visual representations provide one way of integrating engineering approaches (*techne*) into design approaches (*phronesis* and *poiesis*). Visualizations such as diagrams, mappings, sketches, and drawings are all tools for design thinking (Nijhuis et al. 2017). Through different types of visualizations, designers gain knowledge about spatial patterns, structures, conditions, potentials and problems of a site. However, visualizations are also tools for constructing and testing new design ideas and for communicating design ideas to the public (Schön 1983; Lawson 2008).

In Group One’s project, scientific and technical knowledge of marine life is translated into a design narrative of the coexistence of marine ecosystem and the local community. Figure 9 communicates – in addition to the changing sea levels – knowledge of what a healthy seabed consists of compared to an unhealthy one. It also demonstrates *phronetic* thinking as it makes an ethical statement concerning the urgent need to promote the health of marine ecosystems, attracting attention to this statement with an aesthetically appealing, *poietic* visualization. The knowledge comprised in this visualization is used in the final design where a salt marsh is created underneath footbridges, which make the area accessible (Figure 10).

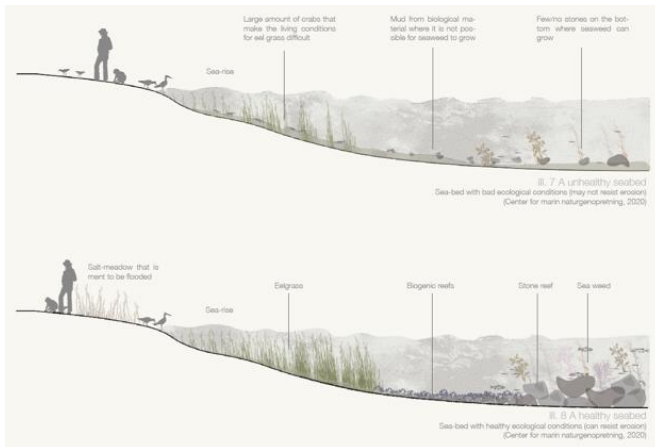


Figure 9. Section by Group One communicating principles of building a healthy seabed to improve marine life (Høgild et al. 2022).

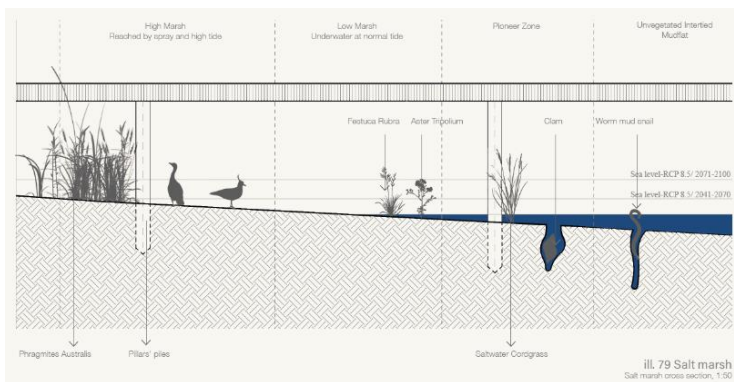


Figure 10. Technical section of a salt marsh by Group One (Høgild et al. 2022).

In Group Two’s project, the section in Figure 11 shows how technical calculations of pond size in relation to water amounts (*techne*) are incorporated into the visualization of the user’s environmental experience represented by the human walking in between the ponds (*poiesis*). The additional plan shows the user’s alternative paths and experiences, representing also technical considerations concerning water flows from pond to pond. Likewise, in Figure 12 three sections communicate technical knowledge of the dimensions of ponds and dikes as well as experiential qualities of the interaction between the users and the water elements. When the ponds are not filled with water, they can be used for recreational purposes. This is indicative of Group One’s *phronetic* considerations concerning the balancing of different kinds of needs in the design proposal.

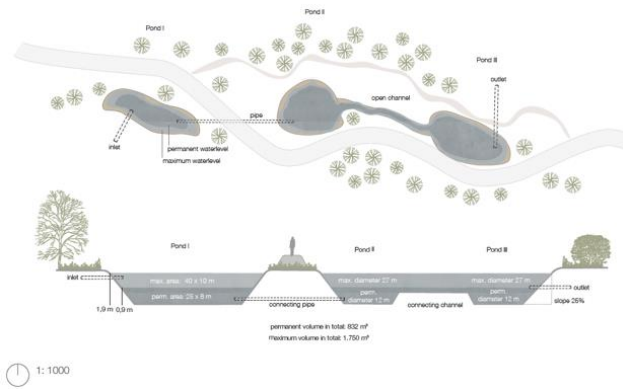


Figure 11. Plan and section of a rainwater management system by Group Two (Fisker et al. 2022).

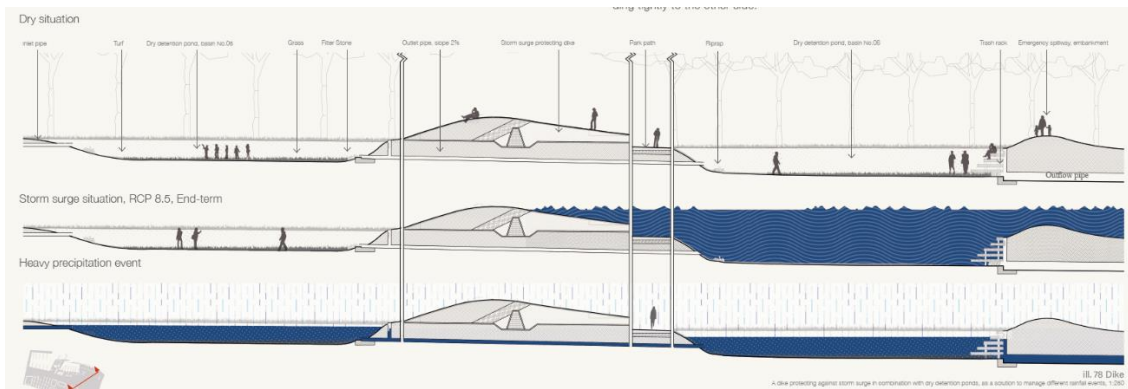


Figure 12. Sections of ponds and dikes affected by different climate scenarios by Group One (Høgild et al. 2022).

Group One and Group Two have used multiple sections in their projects to communicate the integration of technical knowledge and design. When working with climate adaptation in urban design, the topography of the urban landscape is a key to understanding hydrological principles. Contour lines on the map indicate how high or low the terrain is in relation to the average normal sea level. Thus, the topography and its contour lines inform the designer of how the water flows, what areas are vulnerable to flooding, and to what level of climate adaptation is needed. Therefore, sections as design instruments have the potential to communicate design narratives alongside the technical aspects of design.

DISCUSSION AND CONCLUSIONS

“Sustainable Urban Transformation” module has been designed to develop the students’ technical skills in hydrology engineering, on the one hand, and design skills, on the other hand. As teachers of the module, we initially thought that the students end up prioritizing technical skills in their design work, since the technical knowledge and natural-scientific

perspectives occupied central positions in the course description, and since at least some students expressed their concerns that this might narrow down the possibilities to be creative in the design work. In the end, however, all groups succeeded in practicing *techne*, *phronesis* and *poiesis* in quite harmonious ways.

Group One focused in the beginning mostly on *episteme* to be able to recognize and respect natural processes with which they were working rather than to control these processes technically. In the end, knowledge did not paralyze the group, though, but they managed to *phronetically* balance between the needs of nature and the needs of the users of the site in their design proposal. For Group Two and Group Three, by contrast, it was clear from the beginning that knowledge alone is not going to provide a sufficient basis for the design process and that they would need to take the responsibility of making design choices based on *phronesis* as well as on knowledge.

The aesthetic or – in terms of this study – *poietic* form-giving skills were important for all groups, which was not surprising given that many students had a background in architectural design. In this module, students' design skills were expected to develop mainly through sketching and building models. These ways of working helped the students to understand, evaluate and enhance the experiential qualities of their designs.

The understanding of *poiesis* introduced in this paper departs from the traditional understanding of visual arts especially as it accommodates the temporal dynamics of the environment. All the analyzed projects dealt with temporality in some ways, though not always in relation to *poiesis*: for instance, the groups explored the future of the site through different knowledge-based scenarios vis-à-vis climate change, or they worked with technical phasing of the site transformation reflecting the technique of backcasting. What was missing was the flexibility of design proposals, flexibility that could have made it possible for the design to adapt to changing conditions at some later point of time when there is less uncertainty about the future, for instance, about the sea level rise. This lack may be indicative of the strong impact that visual arts with their inbuilt ideas of static images have had on design education. However, flexibility was present when the students tested and concretized their ideas through sketching during the design process. The takeaway from this observation is that the students should be constantly reminded of the fact that their designs are hardly ever final, but that works in environmental design change over time, even after their implementation. Designs, we have argued, could be usefully viewed as *poietic* narratives rather than static pictures or sculptures.

Even though our contribution to Aristotelean pedagogics has been in this article the concept of *poiesis*, we are fully aware that there are risks involved in emphasising the *poietic* aspects of design expertise. Already the Ancient Greeks discussed critically the fact that *poiesis* includes a possibility to communicate in an appealing and persuasive way

things that are not true or ethically right. In the class of 2022, all groups had solid technical knowledge and *phronetic* thinking behind their designs and visual communication. Especially Group One utilised very consciously the aesthetic appeal of their plan to communicate scientific knowledge and ethical care and concern for the natural environment to the users of the site. Nonetheless, it is also common that appealing storylines and visualisations are used to support urban designs that only appear as ecologically or socially sustainable, while in reality, their primary guiding values may be economic ones. For this reason, the takeaway of our study for related disciplines such as civil or environmental engineering is that the *poietic* dimensions of design should be assessed within problem-based learning also in those disciplines that are not directly educating professionals who produce aesthetic artifacts. After all, also technical professionals need to be able to critically read and evaluate visual communication of information and ideas. In addition, technical professionals might benefit from skills of visualizing the knowledge that they produce, skills that they should use in an ethically responsible way, though the lack of ethical responsibility in engineering practice should not be a major problem today, given that *phronesis*, unlike *poiesis*, has already made its way to engineering education in many countries (e.g. Lennartson & Sundin 2001; Kim et al. 2019; Frigo et al. 2021).

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**Elicitation and Empathy with AI-enhanced Adaptive Assistive Technologies
(AATs): Towards Sustainable Inclusive Design Method Education**

*Nora McDonald, Aaron Massey, Foad Hamidi **

ABSTRACT

Efforts to include people with disabilities in design education are difficult to scale, and dynamics of participation need to be carefully planned to avoid putting unnecessary burdens on users. However, given the scale of emerging AI-enhanced technologies and their potential for creating new vulnerabilities for marginalized populations, new methods for generating empathy and self-reflection in technology design students (as the future creators of such technologies) are needed. We report on a study with Information Systems graduate students where they used a participatory elicitation toolkit to reflect on two cases of end-user privacy perspectives towards AI-enhanced tools in the age of surveillance capitalism: their own when using tools to support learning, and those of older adults using AI-enhanced adaptive assistive technologies (AATs) that help with pointing and typing difficulties. In drawing on the experiences of students with intersectional identities, our exploratory study aimed to incorporate intersectional thinking in privacy elicitation and further understand its role in enabling sustainable, inclusive design practice and education. While aware of the risks to their own privacy and the role of identity and power in shaping experiences of bias, students who used the toolkit were more sanguine about risks faced by AAT users—assuming more data equates to better technology. Our tool proved valuable for eliciting reflection but not empathy.

Keywords: Adaptive Assistive Technology, Privacy, Intersectionality, Design Justice, Participatory Toolkit, Elicitation Toolkit, Problem-based Learning, Computing higher education

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INTRODUCTION

AI-enhanced Adaptive Assistive Technologies (AATs) that collect user data to improve functionality, present potential benefits and usability gains for people with disabilities (Hamidi et al., 2018). These systems can also pose risks to users who are particularly vulnerable to privacy violations and resulting harms (McDonald et al., 2021). However, it is unclear how future creators of such technologies (i.e., students) should be sensitized to the complex design tradeoffs these systems pose. In this paper, we explore this space in the context of problem-based learning in higher education and make several contributions. First, we describe a novel, and in-progress, approach (toolkit plus intersectional method) to eliciting intersectional privacy considerations about AI-enhanced AATs and other AI-enhanced technologies with students. Second, we respond to the growing need to incorporate non-normative methods into privacy design thinking for populations with disabilities, particularly when those designs are based on software already in use (where vulnerabilities may be less visible or taken for granted). Third, we reflect on the shortcomings of the activities' toolkit for empathic use without, as student participants suggest, direct contact with vulnerable AAT users, and offer recommendations for improving our process. Fourth, we present a problem-based learning solution that balances the increasing call for more inclusive and participant-driven intersectional design with the realities of classroom (and corporate) settings. Ultimately, our goal is to develop a toolkit and an accompanying methodology to capture the privacy-related tensions around disability and AI so that designers can better account for the needs of users with disabilities using a sustainable method. Our approach is meant to complement, rather than replace, existing face-to-face design and educational methods by investigating new approaches that allow for nuanced, ongoing, and participatory dialogue between technology designers and user populations. We aim to support empathy and perspective-taking while still being mindful of the burden that participation may place on users.

The potential for AI-enhanced systems to compound intersectional discriminations for those with disabilities or with changing health conditions is increasingly being recognized (Whittaker et al., 2019). For instance, data collected by AATs could be used by third-parties in ways that may limit opportunities or lead to other harms for these individuals. We are motivated to investigate what happens when a system could determine that you had visual impairments *and* were a minority simply by using your typing data and triangulating it with other data. What *then* if that information got into the hands of a bad actor, or an employer, or an insurance company? The discriminatory possibilities compound, yet the extent to which vulnerable users grasp or feel capable of mitigating these risks remains unclear.

Consideration of the possible harms caused by AI-enabled systems raises questions about how to teach a new generation of developers about designing for those with complex abilities in a way that is, both sensitive to their unique needs and intersectional vulnerabilities and respectful of their investment (of time, emotion, etc.). It also offers valuable opportunities to engage students in problem-based learning projects that encourage reflection and consideration of real-world scenarios. Researchers like Shoshana Costanza-Chock (Costanza-Chock, 2020) have articulated important agendas for inclusive design and the need for human-computer interaction (HCI) scholars to find ways to integrate those ideas into scalable and sustainable paradigms for learning and designing. Moreover, the benefits of problem-based learning approaches in computing pedagogy (Karan & Brown, 2022), particularly in integrating critical thinking and consideration of societal problems (Scholkmann et al., 2023), have been demonstrated.

Indeed, in the study of older adults with disabilities, the emphasis on technology innovation has traditionally been on inclusivity, but the growth of AI applications requires a broader focus on other harms that could affect these intersectional populations. Where before, the concern may have been focused on accessibility, it is now also about being the target of discrimination by insurance companies and advertisers. There is growing urgency for sustainable and scalable interventions in the classroom to introduce ethics curriculum to future designers of these systems. However, there are some challenges:

First, the current state of AI ethics education is underdeveloped and suffers from a lack of attention and coverage in academia (Saltz et al., 2019). This has repercussions for the technologies that are developed in the market, where scholars point to limited thinking in the way that AI might behave after deployment and the people it may harm (Webb, 2019). While computer science educators have long acknowledged the importance of ethics, only recently has there been a demand for a rigorous and integrated curriculum—and even that presents challenges for instructors who may not be equipped to incorporate ethics in their classes (Fiesler et al., 2020). Perhaps as a result, when ethical perspectives are taught, they are often standalone courses and not embedded throughout the curriculum (Fiesler et al., 2020).

Second, widespread, indiscriminate data collection poses serious ethical considerations beyond simply enabling an AI system (Mak, 2018). Storing, managing, and securing data is not a trivial undertaking, making it a rich but challenging area to draw on for problem-based learning projects that are rooted in current and real-world issues.

Third, the systems that help those in need of AATs are increasingly built on existing data and capabilities that, when enhanced, might breed yet more paradoxical relationships to our technology: the more adaptive and helpful, the greater the potential for harm. The “dual use” nature (e.g., technology that connects us can be used to surveil us) of our technologies presents important opportunities and risks (Chatterjee et al., 2018).

Relatedly, technologies reify and reproduce inequalities and heteropatriarchal norms in part because of the data they are trained on and which is reinforced time and again by study (e.g., through A/B testing) of their existing user base. Yet, while there is support for personalized systems that break with the model of the single user, personalization has its downsides—e.g., surveillance, tracking, and filter bubbles (Costanza-Chock, 2020).

Building on our previous use of this elicitation toolkit with AAT users (Hamidi et al., 2020; McDonald et al., 2021), this study looks specifically at international and/or minority technology students—both of whom experience risk with adaptive text AI because of their marginalized identities. Among issues that overlap for both older AAT users and non-native language speakers is the way in which AI-generated language tools could both normalize speech and reduce credibility when their users are very dependent on them (Hancock et al., 2020). Both of these communities interact with technologies that collect and adapt to personal data with a kind of reliance that falls outside what is normative because of different challenges (e.g., vision and mobility vs. language and cultural pressures). We consider that despite their distinct experiences and identities, students and AAT users share in common relationships to surveillance power and risk, through algorithmic technology, relationships that innovative design learning methodologies could draw on.

With this study, we investigated the possibilities and limitations of a participatory approach for enabling technology students to consider and empathize with the perspectives of a vulnerable population—older adults who use AATs. We found that students expect that a system designed for AAT users would likely collect the same amount of data, or possibly more for older AAT users. And while older AAT users told us in our previous research (Hamidi et al., 2020) that they assume that an adaptive AI system would easily identify their disability or disease, students did not. Even those who did entertain that assumption felt that it would benefit, not harm, the user. In contrast to what we learned in our previous research with older adults with Essential Tremors (ET) (Hamidi et al., 2020), students were more certain about institutional surveillance but believed that there was nothing they or anyone else could do about it. Students all agreed the activities toolkit was helpful in eliciting reflections about themselves. However, the students also reflected on its limits in allowing them to consider risk on others' behalf without engaging with them personally.

In the following sections, we first report on the AAT privacy research landscape and describe the intersectionality conceptual frame that we utilized alongside this toolkit to elicit thinking on AAT users' behalf. We then describe an elicitation toolkit and accompanying interview instrument we have developed for students' intersectional reflections. We next present results from our interview study using the toolkit with seven IS graduate students. We conclude with implications for future iterations of the toolkit.

RELATED LITERATURE

AATs and Data Capitalism/Colonialism

The possible scope of discrimination resulting from the widespread deployment of AI/ML systems is, indeed, alarming. The AI/ML technologies used in policing and immigration enforcement (Adzima, 2017; Buolamwini, 2019; Ferguson, 2017; Hao, 2018), crime risk assessment (Angwin, 2015; Richardson, 2014), and welfare benefits (Eubanks, 2006, 2018) exacerbate inequalities like income, gender identity, race, and class. Most critical to our understanding of the tensions in the new AI horizon is that they cannot be solved merely with technical approaches (*Algorithmic Accountability Policy Toolkit*, 2018; Hagendorff, 2020; Wong, 2020). That is because these tensions emerge from a dominant social and political matrix that necessitates awareness of social and political context and an understanding of power (*Algorithmic Accountability Policy Toolkit*, 2018) and data/surveillance capitalism or colonialism—the mechanism of capitalism and the colonizing impulses that undergird the treatment of user data as commodities to extract, trade, exploit, and sell (Couldry & Mejias, 2019; West, 2019; Zuboff, 2015, 2019). When user data are repackaged, they profile groups of individuals based on socio-economics, race/ethnicity, and other identity vulnerabilities. According to a US Senate Report, a data broker creates and sells consumer groups based on, for example, financial vulnerability, ethnicity, and age with categories like: “Rural and Barely Making It” and “Ethnic Second-City Strugglers” (*A Review of the Data Broker Industry: Collection, Use, and Sale of Consumer Data for Marketing Purposes*, 2013).

End-user Perspectives toward Adaptive and Personalized Technologies

A growing body of research on user perceptions and attitudes towards privacy tradeoffs of adaptive and personalized applications has emerged in the last few decades (e.g., Ur et al., 2012). Many of these projects focus on online marketing (Shklovski et al., 2014), Internet-of-Things (IoT) and wearable applications for health (Gorm & Shklovski, 2016; Zhou & Piramuthu, 2014). In several studies, users expressed feelings of “creepiness” when they learned (or considered) how their data could be used outside of the original context of an application’s use (Angulo & Ortlieb, 2015; Seberger et al., 2022; Shklovski et al., 2014; Ur et al., 2012). Researchers have identified a mismatch between users’ mental models and how personal data is actually collected that can lead to unpleasant surprises and discomfort when users learn about discrepancies between their expectations and the actual privacy characteristics of an application (Gorm & Shklovski, 2016; Kang et al., 2015; Ur et al., 2012; Zhou & Piramuthu, 2014), though scholars argue, convincingly, that this disconnect is more a product of manufactured “resignation” than misunderstanding (Draper & Turow, 2019; Seberger et al., 2021; Seberger et al., 2022). While awareness of bias with commercially available AI among disabled users was found to be low, the same users express discomfort with AI systems’ collection of personal data

and its use by third parties and institutions and are worried about the discovery of hidden disabilities (Park et al., 2021).

AI-enhanced Technologies and Ethics in Education and Design

As emerging technologies increasingly integrate AI and other automation systems in design, scholars have begun to warn of the lack of ethical education in the technology design and development curriculum (Hagendorff, 2020; McDonald et al., 2022; Webb, 2019). Also frequently missing from conversations about AI ethics in classrooms is a consideration for technologies that impose discriminatory practices once AI is deployed (Whittaker et al., 2018), and the way in which political systems and attendant moral norms and deliberations shape AI. One of these norms is the idea that “free” AI-enhanced tools (email, grammar tools, etc.) come with a price—user information like contacts, content, and web activity. What is missing from much of AI ethics is an understanding of the relationships of power in which AI systems are situated and the contexts in which they interact with individuals (Hagendorff, 2020; McDonald et al., 2022).

When AI designers adapt software engineering best practices, they fail to appreciate the difficulty of ethically managing vulnerable populations with intersectional concerns. For example, the use of explicit personas, rather than roles, to better understand stakeholder concerns has been used widely in industry for almost two decades (Miller & Williams, 2006). Use of personas has proven so successful that software engineers now apply it to refining their own development processes (Ford et al., 2017). However, after years of use in industry, when researchers examined how personas applied to stakeholders with complex disability identities, the technique was found to be inadequate (Edwards et al., 2020).

According to Costanza-Chock, “far too often user personas are created out of thin air by members of the design team (if not autogenerated by services like Userforge), based on their own assumptions or stereotypes about groups of people who might occupy a very different location in the matrix of domination”—i.e., their relationship to power is different and likely privileged (Costanza-Chock, 2020). Costanza-Chock is equally critical of “disability simulation,” where a non-disabled person navigates a space as if they were disabled to locate challenges and elicit empathy. First, they cause researchers and designers to respond to their own experience, subverting the experience of those that designers intend to help. If something seems real, we may be even more inclined to “turn it off,” to distance ourselves from the disability that we have the privilege to remove with, say, our blindfold. Alternatively, we might overstate certain constraints while overlooking others. Bennet and Rosner and Edwards et al. say that while empathy activities and personas are important, there is a difference between “being like” (helping) vs “being with” (supporting and empowering) (Bennett & Rosner, 2019; Edwards et al., 2020). Although well-intentioned, empathy exercises and personas reduce disability to obvious and ergonomic constraints, and distance us from or subvert the disabled other,

they may fail to take into account the overlapping oppression of identity and disability in relation to structural inequality.

Notably, a number of approaches have been developed for assistive technology and accessibility design education, that recognize the importance of including people with disabilities at every stage of the design process. These approaches include User-Sensitive Inclusive Design (Newell et al., 2011), Design for User Empowerment (Ladner, 2015), and Ability-based Design (Wobbrock et al., 2011). Shinohara et al. developed an approach, Design for Social Accessibility, that recognizes the importance of supporting student awareness of socially usable aspects of a design in addition to its functionality (Shinohara et al., 2018). Additionally, recognizing the importance of empathy as a key aspect in accessibility design, this approach calls for the inclusion of perspectives from users with and without disabilities in the design process, and the use of methods that support consideration of social factors in accessible design (Shinohara et al., 2018).

While efforts to include people with disabilities in design education are effective, they are difficult to scale, and also dynamics of participation by people with disabilities need to be carefully planned to avoid putting unnecessary burdens on users solely for the benefit of students. There is, indeed, no substitute for the “real” user with disabilities, but their experiences might get abstracted as design activities advance and form the basis of innovative problem-based learning experiences connected to real-world issues. These considerations motivated us to see how we could explore complementary ways to insert user perspectives in the process and contribute to more sustainable, inclusive design methods, while also better understanding the limitations that these approaches may entail. Deciding who is *most* responsible (designers, institutions, or regulators) is beyond the scope of this paper. However, we do focus on influencing the ethical process of students who will someday be designers employed by technology companies designing AI.

Given this landscape, there is a need to study how to elicit intersectional thinking from vulnerable, current, and future technologists on behalf of vulnerable others who may use their technologies, with the goal of moving closer to developing methods that sensitize students and AI design practitioners to structural inequalities. In the next section, we discuss how intersectionality builds on this inclusive perspective to argue that we must seek out the perspectives of those who are not privileged and understand their experiences of power.

Conceptual Lens: Intersectionality

Intersectionality can play an important role in helping students understand the way AI technologies exacerbate discrimination—particularly for those who are disabled with other identity vulnerabilities—through profiling and surveillance by powerful institutions (Collins, 2019; Collins & Bilge, 2016; Crenshaw, 1989, 1991; Eubanks, 2018). It offers a useful framework for designing the current study to explore how AI students approach

the relationship between their experience of identities and institutions that impose power and those of other vulnerable populations.

Collins positions intersectionality as a theory that is perpetually becoming—and a “way of thinking” (Collins, 2019). In that spirit, we adopt Collin’s matrix of domination, a paradigm that focuses on how power is organized, and which integrates with her thinking about intersectionality. We use it to understand whether experiences with a intersectional oppression can sensitize student designers to non-normative identities. The core constructs of Collins’ matrix of domination are: interpersonal (how people’s actions shape power relations), disciplinary (which rules apply, to whom, and when; e.g., bureaucratic organizations perform routine surveillance for the sake of efficiency), hegemonic or cultural (conditions under which power takes hold) and structural (how powerful institutions are organized; e.g., laws, policies, etc.) domains of power (Collins, 1990, 2019; Collins & Bilge, 2016). Domains of power (particularly disciplinary and structural domains) usefully describe the way we engaged (or had hoped) to engage users with our elicitation tool to find common ground around power mechanisms that may act on different identities. Disciplinary domains and structural domains are shaped by business logics and privacy-invasive algorithms that fuel the accumulation of data for advertising. One way that the matrix manifests is through surveillance capitalism, reifying inequality through algorithmic-enabled surveillance that disproportionately harms certain marginalized groups.

A PARTICIPATORY ACTIVITIES TOOLKIT FOR ELICITING END-USER PRIVACY PERSPECTIVES AND INTERSECTIONAL REFLECTIONS

To facilitate conversations about privacy considerations for diverse and vulnerable individuals, we adapted a toolkit used in (Hamidi et al., 2020) consisting of a set of low-fidelity cards, strips, and charts. In this study, we rendered the toolkit pictured in Figure 1 as a remote tool (the only viable way to interview students during COVID-19), using software elements designed in Axure Share (*Axure Share.*, n.d.) to help students think about privacy considerations on behalf of themselves and on behalf of vulnerable AAT user groups—those with mobility and vision impairments. We chose to characterize AAT users as experiencing difficulties with typing and pointing devices due to mobility or vision impairments, though we refer to them as AAT users throughout this paper. Our motivation was to deemphasize having a specific condition to help to focus more on the experience of having difficulty when accessing a computer (i.e., pointing, typing, seeing). Figure 1 (Right) shows the paper version of the toolkit we adapted for this study (please see (Hamidi et al., 2020) for details of how the toolkit works). We also created a remote version of this toolkit (Figure 1, Left) that formed the basis of the one we used in the current study with the students.

Adaptive Assistive Technology (AAT) Prototypes

The remote kit (adapted from Figure 1, Left) includes two software prototypes that represent AATs that participants might use to help access the web. The first system is the popular cloud-based writing assistant, Grammarly (*Grammarly.*, n.d.). For our second system, we used the Pointing Interaction Notifications and AdapTations (PINATA) (Hamidi et al., 2018) to help users who experience difficulty when using pointing devices. It consists of a dynamic bubble cursor (Grossman & Balakrishnan, 2005) that simulates the functionality of dynamically changing size in response to users’ pointing performance and the location of the cursor. PINATA monitors a user’s pointing behavior over time, and when errors are detected (e.g., a link is missed while it is being clicked) increases the size of the cursor.

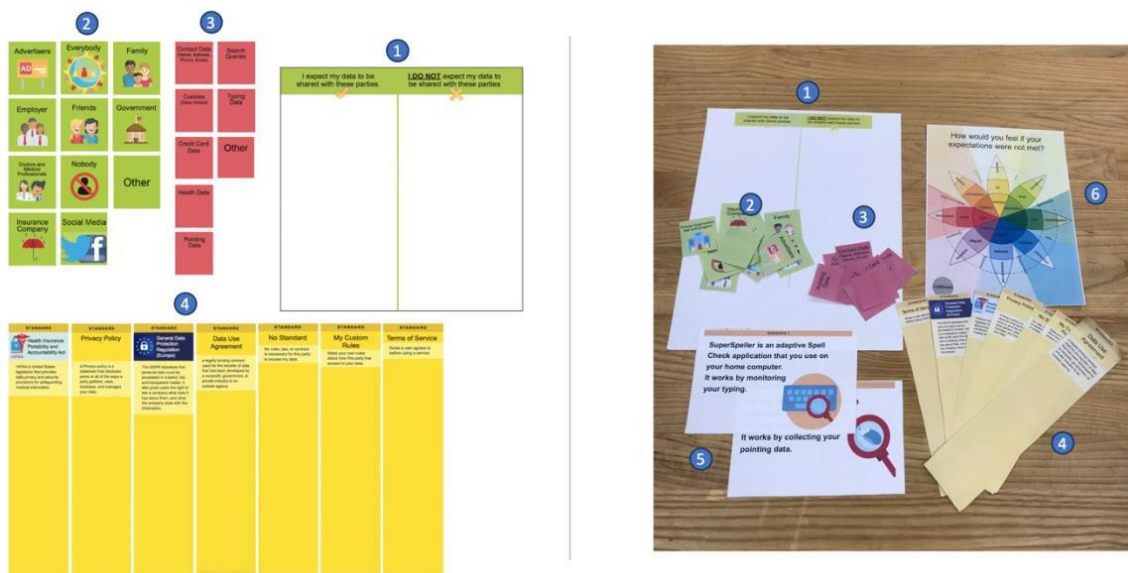


Figure 1. Two versions of the Participatory Activities Toolkit (paper version, on the right; remote version on the left). The paper version was developed for our earlier study with ET older adults. The toolkit included the following elements: (1) Expectations Chart, (2) Third Party Cards, (3) Data Type Cards, (4) Privacy Standard Strips, (5) Scenario Cards (replaced in our study with application demos), (6) Wheel of Emotion (adapted in our study with students as a verbal exercise to elicit intersectional reflections about disability and powerful institutions that linked to students’ own experience of discrimination in the context of data capitalism).

Participatory Activity Procedures

The kit includes a series of four activities (described below) for three scenarios:

- (1) a Grammarly system built for students,
- (2) a Grammarly system for older individuals with vision/mobility impairment that use AATs, and
- (3) PINATA system for older individuals with vision/mobility impairment or Essential Tremors (ET) that use AATs.

We described ET to students as a condition that can make it difficult to steady one's hands and control their cursor.

Activity 1: What data should an AAT collect?

We first asked the participant what types of data they expected the AAT we demo'ed to collect. We gave them the **red Data Type Cards** and asked them whether they expect the application to collect them or not. We asked participants to elaborate on why each of the data types would be collected by the application in the given scenario.

Activity 2: Who should access my/their data?

We next gave them **green Third-Party Cards** and asked participants to place them on the **Expectations Chart** to indicate which parties they expected had access to their data collected by the application in the given scenario. We asked them to explain their reasoning when placing the green Third-Party Cards in the chart. For both activities, blank cards were offered if participants wanted to include new items.

Activity 3: What standard(s) should protect my/their data?

In the last activity, participants selected **yellow Privacy Standard Strips** to protect their data and were asked to explain which standards they would like enforced.

Activity 4: Eliciting Intersectional Reflections.

To elicit the intersectional reflections of technology students, we asked them to consider the scenarios of (1) the Grammarly system being designed for them, (2) Grammarly being designed for an older individual experiencing typing or pointing difficulties, and (3) PINATA being designed for an older individual experiencing typing or pointing difficulties. We had students reflect on their own privacy vulnerabilities (particularly, those stemming from their visa status). We then asked them to "imagine" being visually or motor impaired and what that might mean for dependency on technology and also on the privacy risks. We asked them to reflect on how AAT users would "feel" about data collection and access by third-parties given their own experiences of surveillance with them. Our goal was to facilitate students drawing parallels with the intersectional perspectives of vulnerable individuals with respect to how automated and adaptive systems may collect both their data and who might have access to that data in ways that could result in harms.

Participants and Interview Procedures

We recruited 7 university students (5 international from Asian countries; all of non-white ethnicity; all under 30; 3 females) who were completing a degree in Information Systems at our university and were taking a course in algorithm design at the time of the study. While demographic information can be relevant in qualitative research, we have decided to include only summary data since they were attending a small class, and triangulating their data may result in de-anonymization. We conducted remote, semi-structured video

interviews with students that lasted an average of 59 minutes. We refer to these participants as G1-G7 in our reporting of results.

Data Collection and Analysis

We audio recorded and transcribed each session using a video conferencing system and took screenshots of participants' completed Expectation Charts. Notes and memos were taken before and after each interview. We took an iterative thematic analysis approach to identify and synthesize themes within the interview transcriptions. For each study, the team member who conducted the interviews reviewed transcripts and notes and wrote memos which were organized into themes that were both emergent and based on the interview framing. The interviewers revisited videos and transcripts of key noted themes and anecdotes for use in this paper. All research was approved by our institutional regulation board (IRB).

RESULTS

Already our Privacy is Exposed to Everybody

Overall, technology student participants assume the same amount of data collected for them by Grammarly and PINATA would be collected for AAT users. When it comes to considerations about who the data is being shared with, students expressed concerns about being targeted by the government and advertisers, but these concerns were reserved largely for themselves and not AAT users. Our analysis shows how students refer to various encounters with power in relation to their privacy but do not imagine that those risks or harms exist for AAT users. Students did not worry about government access to AAT users' data and assumed that targeted advertising and oversight would be welcome to these groups. When given the scenario for PINATA, students expressed even fewer concerns about privacy for AAT users—rather, they just saw the software as only helpful.

Grammarly

We asked students to consider both the case of older adults using Grammarly and themselves using the application. When considering their own use scenario, students expected that Grammarly collects their typing data (the content of what they write), but they don't connect these mechanisms with monitoring and profiling of AAT users. Most also assumed it collected their contact data, and potentially their cookies and search history. In their view, the data collected about them by Grammarly was comparable to, or maybe just a little less than, what is collected for AAT users, whom they tend to believe, either would not be harmed or not understand enough to worry or care.

If students did worry about the nefarious use of data collected by Grammarly, it was in the context of their use. For instance, one student worried about their data being used for visa and immigration surveillance, which has caused them to limit or eliminate its use in

certain settings: “There are spaces that are more intimate or more privacy sensitive, and one of those is email.” [G3]. These students generally understood themselves to be operating in an unequal playing field, where their activities could be more heavily scrutinized and used against them in ways, unlike their privileged counterparts. By contrast, even if students suspected that AAT users might have some reservations about the collection of their data, their expectation was that they would “make peace” [G6] with the data being used because they rely on it. These misconceptions about people with disabilities needing AATs, even at the cost of privacy, are reminiscent of misconceptions previously identified in accessibility research (Shinohara & Wobbrock, 2011).

Some students found reassurance in their belief that a system like Grammarly could not detect that a user has a disability or a medical condition, though they did imagine that it could detect language ability, including being foreign or young. One student spontaneously pointed out that Grammarly could not tell the difference between, say, an AAT user who was blind versus a non-native English speaker, or someone with learning disabilities. They reasoned that because so many identities are possibly mistaken for vision impairment, having a separate user interface might be necessary to learn more about the user’s health condition to improve the system and also for advertisers to more effectively advertise vision- related items: “It could be a child. It could be a person from another country whose first language is not English ... If you have the second version of your software that is solely for the people with vision impairment, then, you know the degree of his impairment ... and based on that, you're sending the advertisement to that particular person” [G3]. Only one student believed that Grammarly could reveal patterns of behavior through pointing data (which they assumed would be collected for Grammarly) that would expose disability, leading to opportunity loss and other discriminations: “If they're tracking the pointing data of users, they know the patterns of their users, and it can be used as evidence of impairment ... If this is exposed to other organizations, those companies could deny them health insurance, position of employment, that kind of thing” [G5].

PINATA

We did not ask participants to think about how PINATA would use *their* data, only how it would use the data of someone who experiences pointing difficulties. Students typically assumed that PINATA would collect more data than Grammarly. For instance, they tended to agree that PINATA would have to collect cookies in order to work because the system would have to know what links were clicked. One student speculated that if PINATA worked by image processing, then it would collect all the red Data Cards provided in the toolkit.

While a few concluded that PINATA would collect clicking and/or image data, only one pointed out that it would make them very uncomfortable if the tool did this (“Taking

images from my computer. I'm very uncomfortable" [G5]). The other students seemed to entertain the possibility that all sites collect those data for marketing purposes. The student who did express discomfort went on to say that they are helpless to do anything about who sees their data: "I still feel uncomfortable, but honestly ... our privacy is exposed to everybody" [G5].

For the most part, students' discomfort reflected their own privacy concerns and not necessarily those of AAT users. When thinking about users with pointing difficulties, students expected PINATA data to be shared with more parties—e.g., healthcare professionals, family, and friends—than would be shared by Grammarly. They expect that doctors, family, and friends would want to know if the individual was progressing. One student expected the government would also want to know how many people have the condition saying: "[The] government needs to know that" [G4].

With PINATA, concern for the medical needs of individuals overrode any concerns about privacy. It may be that students viewed PINATA as akin to medical equipment and, thus, subject to a set of standards different from those used for technologies they use, available to the general public.

Regulations

We asked students to talk about what regulations they wanted to impose on these tools. Discussions about regulations did not prompt increased concern for individuals with disabilities. If anything, some students were convinced that tools designed specifically for disabilities—like PINATA—are harmless and, thus, would consider imposing fewer regulations: "If nothing bad happens, then a data use agreement is not needed either." [G6]

Domains of Power

Students convey implicit awareness of *disciplinary domains of power* (what rules apply, to whom, and when) as well as *structural domains of power* (how immigration institutions operate and use AI infrastructures). They nevertheless do not consider these domains of power for older AAT users. For instance, they don't consider the monitoring of text, typing, and pointing data by insurance companies and other advertisers profiling to offer different services as problematic. For instance, one student reflected on how these data are useful for national security: "The most obvious one is national security ... If we're looking at AI, Grammarly, and stuff like that, any sequence of words that might raise a red flag in terms of national security, that could be information that the government cares about" [G1].

Knowledge of *structural domains of power* did cause students to alter their practices, but they did not imagine that these same structures (e.g., in the form of insurance companies or advertisers) threatened AAT users.

Positive, not Intersectional Thinking

Students identify power imbalance in their own interaction with AI and powerful institutions that deploy it but not necessarily in those of AAT users; and even when they do, they assume that these privacy breaches are all for the best. For instance, students assume that personalization is not only an appropriate privacy tradeoff for someone with disabilities but may not consider it a tradeoff at all. The following student expressed a sentiment shared by others that while they wouldn't want to share certain data with PINATA, for a user with disabilities, more data would improve the tool: "You ended up feeling like, 'no, maybe I don't want to share that information for myself.' But if I had visual impairment, I would want to share more information to make the system work" [G4].

Students might have been moved to think about the struggle of individuals who rely on adaptive systems, but they tended to suppose that data would ameliorate these problems. For example, they imagined that the data these tools collected would improve the experience and provide the benefit of interventions by doctors, and families, as well as more targeted advertising. By way of rationalization, students also seemed convinced (paradoxically) that the data these tools collect would not expose *specific* vulnerabilities (despite having just speculated about the benefits such a system would impart by inferring this information) and thus did not represent a risk. Only one student worried that the data these systems collected could be used for discriminatory practices, like denying health insurance. While a few students considered that an adaptive system might be able to determine that one was having "difficulties," they were fairly confident that it would *not* be able to tell the difference between, say, visual impairment or being a non-native speaker, or having dyslexia.

There is a Limit to "Being With" Other's Oppressions using this Tool

Student participants found the elicitation tool helpful in making them reflect deeply about data use and regulations: "I did enjoy the interview because it definitely opened my mind. So just kind of like ... aimlessly using technology, especially if it's backed by AI" [G1]. They considered the activities toolkit effective at making them think differently about how they designed AI systems, but also, admittedly, limited in helping them struggle with taking other's perspective—with being in the other persons' shoes: "I cannot step forward [in their shoes] by considering all these issues" [G4].

Yet some asserted that if they were to design a product for people with visual or motor disabilities, they would want to have them on the team (or interview them) to understand their "struggles" and "stories" as well as their "needs": "For other people? No, I feel like I don't know their struggles or their stories. You would need to have someone like that on board ... If you actually have someone who is visually impaired or semi visually impaired, at least then you know, and you'll have a better understanding of what their needs

are” [G2]. One posited that they would do this in an iterative way to understand their comfort with the system at each step: “I would have to ask them their expectations, then design. After designing, I would go to them and I ask them if they are comfortable, then we can go to the final system” [G4].

Students’ obliviousness to the potential misuses of technology for AAT users, coupled with a genuine and deep desire to involve the vulnerable AAT end-user in design, has several implications for this toolkit going forward, which we will discuss in the next section.

DISCUSSION AND IMPLICATIONS FOR ITERATION

While students often imagined that Grammarly and PINATA collected the same data for different populations (e.g., both themselves and AAT users), they also tended towards thinking that the more disabled the user, the more important and helpful it would be to collect and utilize their data. They described, for instance, how having access to more data would help advertisers target people with disabilities with products that were better geared toward them and would help the AI work better. Others considered that more data would be useful to doctors or governments who wanted to monitor the condition of users with disabilities and possibly intervene. This notion of technology as being only of service, rather than also potentially harmful, to people with disabilities, might be the product of an idealistic frame of mind that a game-like elicitation activity potentiated, or it might be a kind of rationalization in the face of domains and structures of power they feel helpless to control.

RELATIONSHIP TO INTERSECTIONAL NOTIONS OF STRUCTURES OF POWER AND DATA/SURVEILLANCE CAPITALISM/COLONIALISM

Most of our student participants were adamant that third-party organizations collect data. Students sometimes, when prompted, noted their discomfort with the amount of data that may be collected about them—how it flows (*structural domain of power*) and what might be done with it (*disciplinary domain of power*)—but largely considered that there is nothing they can do about it. Students’ ideas about powerful institutional oversight evidence certain contradictions. They expressed concern about government and advertiser oversight *of them* (though not of AAT users) while, at the same time, expressing resignation about that oversight, deeming it a given, something that cannot be helped or stopped and even perhaps a legitimate “right,” whatever uncomfortable effects it might have on their behaviors. As they shift the focus of conversation from themselves to AAT, however, they seem to conclude that the use is simultaneously less capable of individuation, and also more benign. Very few considered the ways in which systems of power might abuse the data collected about vulnerable users. For them, the *cultural*

domain of power rested on the idea that those with disabilities operate in a world where the data collected about them is not intended for nefarious use. This framing was “plausible” because, in their view, these technologies were designed to help AAT users, while they could be used to jeopardize their stay in the US.

Future research might explore educating students about surveillance capitalism so that they can more readily make the connection between the use of surveillance and data by the government (they experience) and its use by insurance companies and advertisers (which AAT users experience)—perhaps even also drawing connections with this disciplinary power to structures in our laws, policy, and economy that systematically overlook those who stand to lose the most. Students who did think about the potential for these systems to identify users’ disabilities, were convinced it would be indistinguishable from other vulnerabilities and, therefore, not a problem. Putting the best case on it, students imagined these tools would collect data that led to improvements for AAT users. Perhaps including interactive elements in the toolkit that combine data types and illustrate how they may be triangulated by powerful institutions or stakeholders can help students reflect on the implications for intersectional identities.

INTERSECTIONAL FRAMING AND FUTURE TOOLKIT DESIGN AND RESEARCH

We attempted to connect the experience of algorithmic oppression by one group to their interpretation of another’s and found these experiences were not readily transferrable. Students ultimately wanted direct contact with those whom they were designing for.

What is not clear is whether having overlapping experiences of oppression can be leveraged. One step towards that end would be to *more clearly delineate and elucidate mechanisms and risks in our design and activities*. In future iterations of this tool and protocol, we need to do a better job of eliciting consideration of identities and power. Our intention with the tool is not only to enlighten student technologists about the experiences of vulnerable populations through problem-based learning, rather, it is also to create opportunities for reflection on one’s own experiences and how they may relate to those of others who experience privacy threats in relation to AI-enabled systems. We hope this will lead to increased empathy.

LIMITATIONS AND REFLECTIONS

We have just discussed several ways to “do better” in future studies. But this research also raises some uncomfortable questions. For one, should we be looking to marginalized individuals to recognize the struggle of others simply because they experience similar forms of violation (e.g., surveillance of their typing data that has more salient or meaningful consequences)? Second, information Systems and HCI graduate programs may also historically be partly to blame for instilling students with a notion that all

technology means well. It is thus no surprise that the students we spoke with expected that designs for accessibility were made with the best intentions. Do we need to radically reframe our mission and/or curriculum to account for the ineluctable harms caused by technology in the context of our current economies and political systems? Finally, the onus cannot be on those who suffer disproportionately to be the agents of change (and be the subject of research that singles them out) and so studies like this must ultimately find ways to negotiate parallels with those who are more privileged. Social justice in design must be a multi-pronged effort.

CONCLUSIONS

We explored the utility of a privacy elicitation toolkit with graduate information systems students and found it useful to elicit reflections about the risks of collecting data to enable AI technologies on a student's own behalf but not necessarily on behalf of others—real-world AAT users. Students were sometimes able to associate their own risks with aspects of their identity that leave them vulnerable but did not extrapolate those identities or vulnerabilities to diverse real-world AAT users. Future work should explore interview, and activity prompts that focus more on identity-based exploration, for instance, incorporating more intersectional interview methods where one's identity and contexts of power are linked to specific experiences of risk (Windsong, 2018) as well as tools for eliciting empathy and thinking about risk, like scenarios. We heard from several student participants that being able to actually talk to individuals they were trying to imagine would help to improve the tool. We will need to explore ways of incorporating feedback from AAT communities into our elicitation activities while still adhering to our goal of sustainable methods.

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**Interconnected Agencies for Sustainable Futures:
A Discourse on the Notion of Adaptation and Space**

*Pia Fricker, Friederike Landau-Donnelly, Constantinos Miltiadis, Shubhangi Singh **

ABSTRACT

This article presents a nuanced discussion of four episodes on the complexity of possible trajectories for sustainable futures through diverse but intersecting practices and discourses as heterogeneous but complementary articulations of ‘adaptation and space.’

As design and creative processes evolve, new tools and methods, often adopted from science and technology, are integrated into art, design, and architecture. However, knowledge flow in these developments tends to be unidirectional, with science and technology influencing these fields more than vice versa. The diverse developments relating to the concept of ‘space’ have profound impacts on industries, urban habitats, design approaches, and the arts within the expanded field.

This article engages in a conversation from four different disciplinary perspectives, each articulating its own voice in relation to the broad notion of ‘adaptation and space.’ Through this multidisciplinary dialogue, presented in four episodes, it critically contributes to the ongoing discussion on sustainable futures, offering new trajectories for Problem-Based Learning (PBL) beyond disciplinary boundaries. In an era dominated by umbrella terminologies like sustainability, the field of higher education faces the challenge of integrating different expertise to foster new solutions for complex challenges. This article highlights the need for diverse fields such as architecture, art, and social science to engage in a dialogue about perception, interaction, and manipulation of space. Its purpose extends beyond the

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exploration of novel solutions, instead inviting multifarious perspectives that shape interconnected agencies for sustainable futures and their impact on education.

Keywords: PBL for Transformative Learning, Interdisciplinary Perspectives, Complex Challenges, Adaptation, Space, Public Sphere

INTRODUCTION

By reviewing principles of co-living strategies with complex systems across scales in a dialogue format across disciplines and scales, we discuss concepts, definitions, and interpretations of space and of spatiality (Harvey, 1989). The article format shares traces of a larger discussion, focusing on different perspectives on how we construct the world, and by extent how we create means to intervene into that world, with our day-to-day practices (Latour, 2005; Law & Urry, 2004). The shared viewpoints in this article attempt to transcend technological solutionism, and instead invite the integration of new perspectives for addressing complex and dynamic challenges of today and the future. They invite for a new perspective to be integrated into defining solutions for complex and dynamic challenges of today and the future.

In this context, the concept of ‘adaptation’ can be a useful lens through which to view the design of Problem-based learning (PBL) activities, adding on the discussion by Fischer (2013, p.15) who states that “different kinds of problems require different kinds of learning approaches and different socio-technical environments to support them”. Adaptation refers to the process by which systems or individuals adjust to changing circumstances in order to optimize their performance. In the context of PBL, adaptation offers the possibility to refer to the ability of individuals (human or non-human) to adjust their approach to problem-solving in response to the evolving nature of the problem (Illeris, 2003). The learning of concepts and principles, to support critical thinking and the creation of transferable skills, has proven to empower transdisciplinary collaborations beyond academic institutions.

The combination of the terms ‘adaptation’ and ‘space’ into a dynamic construct exemplifies critical pathways for negotiating the ‘why?’ rather than the ‘how?’ in support of a new way of thinking beyond established solution strategies (Cantrell and Mekies, 2018, p. 16). As Alpaydin (2016, p. 17) states, “a system that is changing its environment should have the ability to learn; otherwise, we would hardly call it intelligent. If the system can learn and adapt to such changes, the system designer need not foresee and provide solutions for all possible situations.”

In the field of Artificial Intelligence (AI) enhanced design methods, Problem-Based Learning (PBL) offers the possibility of applying machine learning algorithms to develop predictive models for future scenarios dealing with the impact of complex sustainable challenges. This data-driven design methods use computational heuristics applied at various stages throughout the design processes, which offers new challenges for the field of education, as the creative part is extended towards the definitions of algorithms and relational models (Essary, 2021). While a comprehensive analysis of existing learning theories in the field of computational design is beyond the scope of this article, this digression in a multi-layered theme presents the current situation with respect to the increasing number of complex challenges imposed on the spaces we encounter and live in (Chen et al., 2020).

Thus, 'space' accumulates plural constructs, poetic artifices that we collectively produce and reproduce through time, within our cultures, sciences, and arts. Through the dimension of time, these spaces serve as vehicles for adaptation and transformation, from the individual to the collective societies and the environment at large (Fenton-Glynn, 2019).

METHODS

This contribution is structured over a multimethod approach and follows a format of four snapshots, called episodes, that intersect perspectives into 'space' from distinct and different disciplinary and methodological standpoints. The following four episodic snapshots originate in a collective discussion on 'adaptation and space' intended to communicate and demonstrate the nuances, sensibilities, and capacities of different epistemological frameworks to 'read,' investigate, tap into, and intervene into 'spatiality' in its manifold manifestations, scales, and materialities.

Through this approach, we aim to highlight the imperative of intersecting multidisciplinary perspectives for both identifying and for addressing the complex challenges of our times. Furthermore, against technological solutionism which all too often poses new inventions as panacea, we propose the notion of 'adaptation' in a twofold manner. On the one hand, adaptation entails a critical examination and cultivation of our epistemological frameworks and mental models pertaining to how we perceive and conceive the world, which follows how we also practically engage with the world (episodes 1 and 4). On the other hand, adaptation suggests a means for intervening to the world without negating its current state and complexity or necessitating its violent reconfiguration. Rather, the adaptation of our practices, structures, and infrastructures has a profound impact on how we produce and reproduce our lived environment, and how we participate in perpetuating or positively contributing to its current problems (episodes 2 and 3).

The rest of this section is devoted to a brief introduction of each contributor's background, and an outline of their contribution:

Constantinos Miltiadis is a transdisciplinary architect whose research concerns spatial constructs experienceable only through digital media such as virtual reality, through which we can explore the capacities of the human sensorium. In "The Complexity of Notions of Space" he unfolds an epistemological discussion of heterogeneous notions of space to set the ground for the subsequent episodes and the framing of this contribution. Through historical examples the episode shows that a shared agreed-upon concept of space is impossible. Rather, notions of space depend on discipline, context, and application, and follow different constructions of the world, different modes of engagement, and different repercussions. This complexity is by no means a nuisance or obstacle, but instead serves to highlight the multimodality required to account for the different aspects and modes of engagement with space.

Assistant Professor Dr. Friederike Landau-Donnelly is a political theorist, urban sociologist and cultural geographer. In "Infrastructuring Vulnerability" Landau-Donnelly discusses practices of infrastructuring as political practices to enact adaptation within ongoing systemic (and pandemically reinforced) crises. After introducing 'infrastructuring' as a political verb, rather than infrastructure as a noun, she proposes an analytic of vulnerability as the much-needed political trajectory to be considered in future-oriented discussions about societies, spaces and politics in multiple processes of adaptation.

Shubhangi Singh is a visual artist who works with moving images and text. Her work considers ideas of absence and absencing as a way of reflecting upon what is visible, particularly in relation to the shared spaces, history and memory. In "A Space of Micropolitics" Singh observes public spaces as sites of hegemony, power and nuanced interactions, a view that provides valuable data correlating to the larger social settings that surround the space. It adopts spatial strategies such as loitering that has been employed by groups of women in India and Pakistan in Finland as a tool to not only be present and claim 'space', but to further make embodied observations and collect notes about experiences that traverse class, race and gender in the mixed use and shared public domains. The title of the episode is a reference to Deleuze and Guattari's term 'micropolitics' (2013, pp. 208-231), who claim that "life is spatially and socially segmented" (2013, p. 208). They point to our participation in the order of the social structures that have been laid before us (through caste, class, generational and familial networks), which by extension, also influences our participation in the segmentation that these existing structures hold us to. Deleuze and Guattari are driven by their purpose to classify this unwritten, often unspoken lines of subjectivity by further characterizing the lines that constitute our ability to become subjects as well

as actants that uphold or control the segmentation beyond the (more visible) macropolitics.

Dr. Pia Fricker is professor of Computational Methodologies in Landscape Architecture and Urbanism at Aalto University. “Mind meets Machine” draws from research and teaching within the area of computational design thinking., to discuss pedagogical strategies directed toward skill development for the purpose of addressing current and future challenges. It proposes a shift towards systems thinking, and the abstraction from specific operational skills and mental models, as a means to better reason with the complexity of the challenges of our times.

EPISODES

Episode 1: The Complexity of Notions of Space

Whichever the context or discipline, notions of space are inevitable constructs for reasoning with where we are, who we are, and what we could do. Constantinos Miltiadis explores the term space, and the impossibility of a shared and agreed-upon definition. Space therefore emerges as a species of variations, that we occupy in time through the different realms: the physical, the conceptual, the sensory, the social, the emotional, and so on. Borrowing examples from the sciences and the arts, the following unfolds space as a qualitative substance, one that we can think through, examine, compare, but also play with, construct, learn, unlearn, and get a feeling for.

Space matters. Space is the place; space is where things happen; space is what we can inhabit; space is what we can fathom. But if space is the answer, what do we actually mean when we talk of space? This brief passage will discuss the variability of notions of space that follow different ways of engaging with space. This, also to suggest and highlight the richness of our different views through which we come to understand space, also as a discursive topic, and mode of engagement.

The inherent complexity of the very notion of space, according to David Harvey, comes not from the keyword itself, but from the contingency of its meaning which is dependent upon the context and application:

Space, is, of course, one of those words that frequently elicits modification. The complications perhaps arise more out of the modifications (which also frequently get omitted in the telling of the writing), rather than out of any inherent complexity of the notion of space itself. [These] seem to render the meaning of space itself entirely contingent upon the context. [We] seem to be saying that the arena of

applications defines something so special about the meaning of space as to render any general consideration of its properties a hopeless task (Harvey 2006).

SPACE
 OPEN SPACE
 ENCLOSED SPACE
 OUTER SPACE
 SPACE SUIT
 SPACE AGE
 LIVING SPACE
 PROJECTIVE SPACE
 SPACE CAPSULE
 LACK OF SPACE
 SPACE BAND
 SPACE HEATER
 DEEP SPACE
 SPACE ODYSSEY
 SPACE SALESMAN
 EUCLIDEAN SPACE
 SPACE CADET
 SPACE STATION
 BLANK SPACE
 SPACE OUT
 PARKING SPACE
 SPACE INVADERS
 SPACE WALK
 SPACE TIME CONTINUUM
 SPACE BAR
 LOST IN SPACE
 STARING INTO SPACE
 WATCH THIS SPACE
 SPACE CURVE
 SPACE LATTICE
 SPACE OPERA
 CATCHER SPACE
 SPACE SICKNES
 BUNCHER SPACE
 THREE-DIMENSIONAL SPACE
 HAIR SPACE
 SPACE RACE
 NULL SPACE
 LEAVE A SPACE
 SPACE OF A MOMENT
 INTERCOSTAL SPACE
 AVAILABLE SPACE
 SPACE NEEDLE
 POSITION IN SPACE
 EDGES OF SPACE
 SPACE WRITER
 WIDE OPEN SPACES
 LACK OF SPACE
 SPACE SAVING
 ENCLOSED SPACE
 SPACE FILLER
 WASTED SPACE

In the first pages of his book *Species of Spaces*, Perec ([1959] 2008, ii–iii; Figure 1), provides a demonstration of exactly the same problem discussed by Harvey. That permutations of the word space are inherently ways to frame things, to provide a container as context, which render space itself a rather elusive keyword. With this complication established, let us briefly look into formal categories, or paradigms of space through history and epistemology.

First is Euclidean space, the space that most of us know and love, taught continuously in schools for millennia. As geometry, this mode of space served as the first form of mathematics, the first scientific method, and a form of philosophical meditation (Miltiadis 2019). Euclidean geometry was also the basis of Renaissance perspective, and the modern scientific revolution (Edgerton 1985; Longo 2019), and as such is ingrained in Western culture. We can observe its predicates in Isaac Newton's (1642-1726) universal laws of motion, which suggest the idea of universality: of a space that is absolute, uniform, with all positions equal, dictated by the same rules, and organised around a centre, the Cartesian origin point that distributes difference and meaning (Wertheim 2010).

Figure 1. Collage from *Species of Spaces and Other Pieces* (Perec 2008, ii–iii).

Another flavour of space is relational space that we got from Gottfried Leibniz (1646-1717). Space here is composed of relations between objects,

with the implication that it cannot exist in the absence of matter. This space only exists when we have two or more things, so that we can articulate relationships between them. It is a space of flows, of social networks, and of interconnected global economies and events (Castells 1997).

Then we come to relativistic space from non-Euclidean geometry, which came to us from the 19th century to overcome the ‘parallel postulate’ of Euclidean geometry (Riemann 1854; Keyser 1906). Relativistic space is an altogether different beast, as we can see in its application in relativity theory (1905; 1915), which we try to understand from its paradoxes. Perhaps the most counterintuitive of all, it does away with space and time, and introduces their interweaving in spacetime. Relativistic space has no outside, no objective vantage point or origin as with Euclidean-Cartesian space. Each position resides on its own reference frame, all differences are local, relative, and equally subjective.

What we want to highlight with the previous is that whichever notion of space we ascribe to, serves different applications and purposes, and, inevitably, follows completely different repercussions. Since we are spacetime natives, notions of space are models, at least as much as they are philosophies; philosophies of being. Moreover, whether conceptually or practically, space is essential. We cannot do without space:

The very sense of self depends on its sensory relationship to the external world. Everyone exists someplace, conversely, sensory deprivation disconnects our internal reference frame from the physical and social environment, and rapidly produces hallucinations. The experience of spacelessness does not exist as a normal state; it produces disorientation (Blessner and Salter 2009).

Notions of lived spatiality is an intriguing topic that can be explored empirically. An experiment staged in an architectural workshop, attempted to question the primacy of the visual, by focusing instead on the contribution of aural faculties in the perception of space (Miltiadis and Sharma 2021). In that, we handed architecture students blindfolds as instruments for investigating spatiality through hearing (Figure 2). We came to study a binaural spatial audio piece blindfolded and explore what we can ‘see’ through our ears. Surprisingly, the experiment yielded vivid hallucinations of space, which were transcribed from mental images to sketches and then into spatial-temporal scenes of a virtual reality (VR) experience (Figure 3).



Figure 2. Blindfolded listening sessions of a spatial audio music piece. OSSA Architectural Festival, Łódź, 2018.

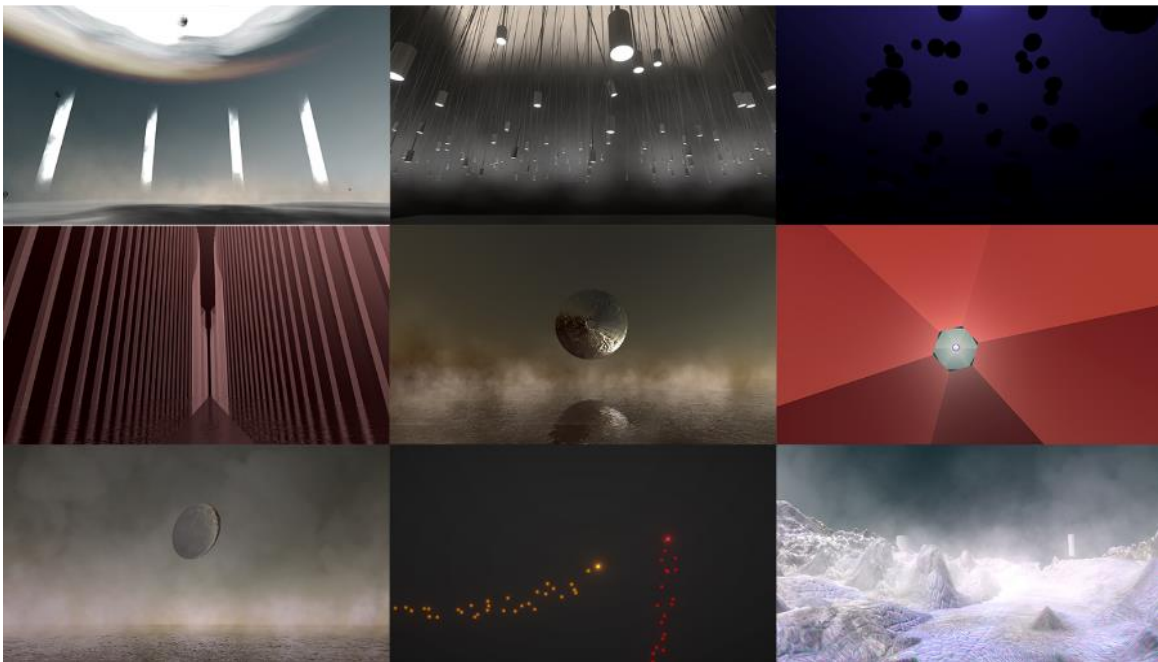


Figure 3. Screenshots of VR scenes conceived through blindfolded listening. OSSA Architectural Festival, Łódź, 2018.

Eventually, spatiality is inescapable — ever-present in everyday life, deeply ingrained in our culture, professional practices, arts, and sciences. It is also multiple — dependent on discipline, application, and worldview. Moreover, spatiality is an intersubjective

sensibility and a skill that can be learned, unlearned, trained, and cultivated to tap into further, unexplored potentials:

It is necessary to unlearn space in order to embody space. It is necessary to unlearn how we see in order to see with our bodies. It is necessary to unlearn knowledge of our body in three dimensions in order to recover the real dimensionality of our body. Let's dance space. Let's re-space our bodies. Let's celebrate the felt feeling of presence (Eliasson 2014).

If we may add to that, this we need to do collectively, together.

Episode 2: Infrastructuring Vulnerability: Politics of Adaptation beyond Pandemic Times

This episode by Friederike Landau-Donnelly reflects on the impact of the COVID-19 pandemic and its constraints for limited but also growing possibilities of the adaptation of spaces. It suggests shifting gears from the concept of “adaptation” to the lens of “infrastructuring”. More specifically, it proposes to move from the terminology of “infrastructure” as a noun to “infrastructuring” as a verb to better grasp the complex and politically charged transformations of public spaces in times of multiple crises. By examining the concrete socio-spatial example of pandemic experiences in urban public spaces in Vancouver, Canada, which have revealed significant disparities between bodies situated in uneven conditions of vulnerability, mobility, and creative expression, this episode seeks to explore the politics of infrastructuring.

The pandemic has exposed the vulnerability of many social institutions, which are often viewed as rigid and solidified entities. This crisis of institutions has opened a possibility to think of institutions rather as infrastructures, which are eager to respond and adapt to socio-spatial crises. The closure of museums, for example, has confronted us with limited accessibility to art collections. The shutdown of theaters has also contributed to accelerate transitions in thinking culture not through the lens of institutions, but rather malleable infrastructures. Notably, this attunement to adaptation, change or transformation has certainly preceded the COVID-19 pandemic, but has certainly been fast-tracked by it.

Zooming in on the shift from viewing infrastructure as a noun to the concept of “infrastructuring” as a verb, Matthias Korn and his colleagues (2019) propose the notion of “infrastructuring publics”, which emphasizes the relationality of infrastructuring. For Korn et al. (2019, pp. 1-2):

infrastructuring publics as a new research perspective that (1) is practice-oriented (instead of starting with strong assumptions on the shape of things); (2) is aware of the common scaling of infrastructures and publics as a media-his-toric constant (instead of beginning and stopping at digitisation); (3) acknowledges the inevitable interrelation of social and material agencies (instead of a technosceptic “people only/people first ontology”); (4) addresses the shape and practical usage of infrastructural media and the omnipresent, but often hidden and invisible infrastructural and bureaucratic work (instead of primarily focusing on the contents and the aesthetics of public media); (5) highlights testing, experimenting and projecting publics as important modes of infra-structuring publics (instead of following a teleological approach); and (6) takes a cautious approach to placing normative demands, but has its own normative bias in the efforts of making infrastructures and practices of infrastructuring public (instead of leaving the black box unopened).

So, how are we connected through practices of infrastructuring? How are human agents infrastructurally entangled with non- or more-than-human actors, places, things? How are we implicated in different materialities? What kind of poetics of relation, or poetics of infrastructuring, emerge through infrastructuring?

While these multiple interrelations are poetic, affective, multi-species, they are political, too. Hence, the question this episode addresses so how the trope of infrastructuring, as opposed to infrastructure, can help to advance understanding of new practices to adapt, or to infrastructure politics and space. In this context, Korn et al.’s (2019) notion of infrastructuring is not least informative because it emphasizes the practice-orientated dimension of infrastructuring. Furthermore, the authors argue that infrastructuring, as opposed to infrastructure, allows us to acknowledge the inevitable interrelation of social and material agencies.

Instead of being techno- skeptical, however, this episode proposes that we might find new ways of understanding how we influence technology, and technology influences us, via the lens of infrastructuring. It allows to broaden the scope of where to look for beginnings, reasons and pathways for adaptation or change. More specifically, Korn et al. (2019, p. 2) argue that infrastructuring pushes us to think about testing, experimenting, and projecting publics, broadly defined, as important modes and moments of infrastructuring.

These introductory thoughts on the *political* underpinnings of infrastructuring cautiously lead to approaching practices of infrastructuring as a political activity , broadly defined as negotiation between realms of ‘politics’ and ‘the political’ (Marchart 2012). As manifestation of the political, the notion of infrastructuring points to collective acts of constructing, but also deconstructing, or dismantling, institutions or systems that build

and sustain but also limit and oppress human, and more-than-human life. In the field of socio-spatial adaptation and change, we need to consider both the built and materially lasting, tangible aspects of infrastructuring, but also its immaterial, or more-than-material, intangible, ephemeral and affective aspects. In sum, infrastructuring might heighten sensitivity about who and what matters in designing socio-spatial realities, which are always undergirded by political negotiations for meaning, space and belonging.

Besides an increased focus on infrastructures and infrastructuring as porous practices of institutional response to multiple crises, the pandemic has also brought about a (renewed) engagement with the trope of vulnerability, which certainly has existed and been inscribed into our different bodies prior to the pandemic (Butler, Gambetti and Sabsay 2016). But it is interesting to see that a lot of cultural institutions and discursive reflections of pandemic time have taken up on the notion of vulnerability or uncertainty, “Verletzlichkeit” and care in research, political claims-making, strikes, descriptions of the crisis etc. There seems to be a political and emotional momentum now to respond to vulnerability as something that affects us all. In short, the pandemic has jumpstarted a more or less collective awareness and acknowledgement of vulnerability as a constitutive dimension of human, or more-than-human, life.

After briefly unpacking thinking of infrastructuring as a political verb and vulnerability as shared yet hugely different condition, let’s push these terms into the conversation about space, adaptation, or the spatial politics of adaptation. How, who, why, and where do we adapt space? What is the purpose and teleology of adaptation? Are we stuck in a short-sighted trajectory of transformation if we speak of adaptation? Is the rhetoric of adaptation falling prey to wanting to fix something that cannot be fixed?

These questions led to question the term “adaptation” as it felt limited to maintaining the status quo, or nail down a singular goal or way of being. The term seemed teleologically constricted and does not seem to embrace the radically open-ended nature of spatial dynamics, or processes of transformation (see Landau et al. 2021). The search for alternatives led me back to the term infrastructuring. Through this concept, transformative potentials for more fluid, contingent and in that sense, more adaptable socio-spatial or socio-technological arrangements, spaces, places, as well as built environments, can emerge.

Tracing the above-mentioned politics of vulnerability, Landau-Donnelly refers to her empirical field work conducted during a postdoc in Vancouver, Canada, on the unceded territories of the Musqueam, Squamish, or Tsleil-Waututh peoples, where commissioned murals in the downtown Chinatown neighborhood were examined (see Landau-Donnelly 2021).



Figure 3. *Eight Immortals Crossing the Sea* by Bagua Artist Collective 2019, photo: courtesy of Bagua Artist Collective.

Zooming into the *Eight Immortals Crossing the Sea* mural, commissioned by the City of Vancouver in the first-ever Chinatown Artist Call (2019), painted by the local Bagua Artist Collective, which consists of the artists Sean Cao, Xingyue Feng, Yuan Liu and Katharine Meng-Yuan Yi, one gains insights into the politics of spatial adaptation and contestation (Landau-Donnelly 2021), or in the context of this episode, the politics of infrastructuring. Part of the mural construction process can be seen in Fig. 3, whereas the final result appears in Fig. 4. The motive, *Eight Immortals Crossing the Sea* references an antique Chinese myth of eight different types of immortals or saints, crossing the sea, each equipped with special powers to survive the strenuous journey. The myth tells stories of very different capacities, motivations, dreams and experiences of trans-local migration and movement. In Vancouver's contemporary Chinatown, which is arguably also a site of arrival of Chinese Canadian travel, migration, struggle, and survival, it was interesting that the emerging artist collective chose this motif.



Figure 4. *Eight Immortals Crossing the Sea* (2019) by Bagua Artist Collective. photo: Friederike Landau-Donnelly.

It relates poignantly with contemporary anti-Asian discrimination as well as spatial crises such as gentrification, displacement, and upscaling. Examining the above image more closely (Fig. 3), which occurred during the construction of the mural in the summer of 2019, the graffiti tag stating *Refugees Welcome* almost uncannily interconnects the final motif of the mural – advocating for intergenerational intersectional bonds of solidarity – with the contemporary plea for embracing trans-local migrations.

This enmeshing of motifs and messages can be viewed as an encounter of different vulnerabilities, being inscribed into an artistic work-in-progress. Instead of a narrowly defined goal of spatial adaptation, the mural unravels the open-ended, multiple logic of infrastructuring. More precisely, the infrastructural dimension of the mural, or its multiple practices of infrastructuring, become visible in the various claims for visibility and requests to make voices heard and seen in and on the very same wall. While the official commission was maybe instructed with a straight-forward mindset of spatial adaptation (e.g., to brighten up an alleyway, to institute a happy motif, to celebrate Chinese Canadian culture), the logic of infrastructuring exceeds this rationale and writes the walls differently. While it remains unclear whether the graffiti writers knew that the final mural would be embracing migration and, in a sense, conjure a century-old iteration of *Refugees Welcome*, the incident shows how socio-spatial, contemporary, and historical vulnerabilities can collide in public space.

In sum, this episode suggested to think about the adaptation in and of space in terms of infrastructuring. Infrastructuring, in my view, allows us to systematically and systemically embrace vulnerability, rather than suppressing it. In doing so, we can approach space and spatial transformation in a non-teleological manner. This intertwines

with a notion of ‘politics’ in the sense of ‘the political’, which is broader, more unruly, radically open-ended and exceeding the ready-made institutions and apparatuses of politics, power and space (see Landau et al. 2021). From the cursory discussion of the Chinatown mural images above, we have seen different layers of meaning, power, historical hardship, discrimination arising from this palimpsest of public art in Vancouver. The logic of infrastructuring might also bring to forth other memories, voices, positionalities into public space – those which might have been forgotten, neglected, but maybe also those that continue to fight for trans-local solidarity and diversity. At last, an infrastructural approach to both spatial and political adaptation might forge for problem-based learning, broadly (re)defined.

Episode 3: A Space of Micropolitics

The places that we live in do not only influence us but are, in turn, equally affected by our contact with them. Far from being static, these shared landscapes are in fact, in a state of constant flux caused by the agents responsible for building, reframing, and breaking existing structures. Shubhangi Singh observes and reiterates through examples how public spaces are far from being a neutral site that is co-inhabited by a host of individuals or groups but instead, they are charged contact zones that have the everyday ability to challenge, subvert or reproduce the existing social hegemony.

While the streets are sites where social hegemony is exerted, expressed, reinforced, or challenged, they are also a fertile ground of study – a space of micropolitics (Deleuze and Guattari 2013, pp. 208-231). Being locations of where existing social hierarchies can be viewed as well as experienced, one’s body and its mobility in cities are matters of urgent inquiry within the larger context of how public spaces can be developed or reviewed for gendered and racial inclusivity.

Within the discourse of one’s right to the city, how can we address the historic exclusionary patterns that continue to exist in our everyday life? Moreover, how can we remedy this imbalance in public spaces that are normalized and reinforced through the policies we make or plan for our public spaces, which may further affect these shared interactions?

It does not take long for certain minorities in cities, say, gender and caste in India, and racial and class in Finland, to realize how coded public spaces really are. The position which these individuals then hold in these spaces may as well be one of being mere travelers, where we are always transiting, and never staying. But this does not mean that it has to stay that way. Spaces can be influenced through sustained engagement. They can

be trained to include paths retreaded. For instance, by loitering to reclaim and recalibrate the established order within public spaces.

The term ‘loitering’, brought to India through its colonial legacy, has since expanded in definition within social, as well as domestic spaces. The irony of this invisibility in public spaces is brought to attention by some existing feminist actions that call for assertion and visibility of marginalized bodies in public spaces, in order to resist existing social and gender hegemony. By the act of women occupying these spaces and visibly *doing nothing*, they are asserting their right to safety, to leisure, and to visibility in these shared public domains. In their seminal work, ‘Why Loiter?’ (2011), activists, academics, and feminist writers, Shilpa Phadke, Sameera Khan, and Shilpa Ranade write about the importance of loitering as a tool for women to reclaim public spaces. ‘*Meet to Sleep*’, a feminist action initiated by Blank Noise (Bangalore, India) take their cue from the provocation offered by the authors of ‘Why Loiter?’ as they invite women to bring themselves – individually or collectively – to parks, or any other open spaces that they may find, in order to sleep, to nap, to rest, and to visibly ‘do nothing’. By undertaking the gesture of rest and leisure, the actants thus shift the responsibility of personal safety from themselves on to the public, as a collective. On the other side of the border, in Pakistan, *Girls at Dhabas* (loosely: Girls at the tea stalls) expand upon this strategy, by spending leisure time at tea stalls — either alone or with groups of friends. These forms of loiterings transform otherwise sequestered spaces into subversive, salon-like spaces.

Though it may appear counterintuitive, by lowering their guards and exhibiting a sense of trust in the other, the actants are denouncing their fear and exercising their right to safety. By occupying these spaces, the women hence, are becoming a regular and new visual in the parks. The politics of pleasure defy social order that quantifies individuals solely as contributing members of society. The acceptance of women in public spaces (or the lack thereof) has historical distortions encased in the language of patriarchy. That is, the reiteration of power through social order subjugation. Thus, as much as loitering is a tool to claim leisure, it is just as equally an act of resistance. A Hannah Arendt way of looking at publics, social, and commons would mean that the publics are often formed in the presence of others making the public sphere a necessary condition for the practice of politics (Arendt, 2019). This would also mean that one's understanding of self too, does not occur in a vacuum but is largely formed in relation, in realization, and in retaliation to others. Interactions could be shaped such that the publics are training together, collectively, and constantly, in learning how to negotiate and interact with the shared spaces. Here, we are learning and unlearning together as a (dys)functional collective, updating and renewing our social contracts, in perpetuity. In an (imperfect) call-and-response, we are affecting while simultaneously being affected. It is a constant feedback loop.

Not surprisingly, several areas in a city seem to have certain coded ways of enquiring whether one may belong there. This though can be adjusted through affecting, sustained engagements and appropriating spaces that could diversify the spaces. This way, also keeping the spaces dynamic, activated, and always a little unpredictable. A wide range of engagement, however minor, affect how spaces then get planned, occupied or mobilized thus enabling multi-use of these shared spaces, ground up. The responsibility of this however does not lie with an individual or a community alone but rather, with a larger society that must demand, and the structural powers and authorities that must provide.

The Puotinharjun Ostoskeskus “Puhos”, a shopping centre located in Helsinki’s Itäkeskus district, opened in 1965, designed by architect Erkki Karvinen (Fig. 5). It was the first, and for a very long time after, the only shopping mall that had escalators incorporated within the building’s design that fall outside of the building in the open air.



Figure 5. Puuhos Shopping Center: Original escalator and glass roof from the late 1960s. Image Credits: Helsinki City Museum, photographer unknown.

After 1984, when a newer shopping mall opened across the street, Puuhos slowly began to lose its customers to this new indoor shopping space. Around the 2000s however, Puuhos started to gather some interest again when immigrants began to open multicultural stores at Puuhos. To this day, there are several stores, bazaars, and halal butchers, specialized sweet shops and restaurants in Puuhos which, at this point in time, makes it the biggest multicultural food and grocery market center in Helsinki. This also means that many people of immigrant background (still just mostly men, however), hang around the mall

visibly and are seen simply spending time with their friends and companions. It is one of the few places in the city to casually congregate and not necessarily spend much money while doing so.

In an urgent need of renovation, the future of Puhos remains uncertain. The city plans to renovate one part of the Puhos in line with its original design and will go ahead with demolishing the other part (the newer part added in the 1980s) that will be converted into residential buildings.

Though the development plan (proposed by Puotinharjun Puhos Oy) intends to retain the shops that are currently in the premises, what this would mean in terms of the shops rents as well as free open spaces remains to be seen.

The original outdoor escalators at Puhos have been in a state of disrepair for close to ten years now (maybe even more). If this tells us anything it is that if the same escalator were to be in a predominately ‘white’ neighbourhood of the city as opposed to the demographic that frequent it, then perhaps it would have been repaired and cared for until the very end of its lease. The building’s steadily declining condition is a testament to how public spaces, when occupied by immigrants or minorities, fall out of grace and funding for upkeep from the planning authorities. The ignored state of the site makes the occupants themselves seem responsible for its condition, putting the blame squarely on the people who occupy the space. The state of overall dilapidation only further legitimizes easy evictions and a higher rate of policing, surveillance and force. Not too different then, from the women and their challenges in (re)claiming safety in public spaces mentioned earlier – a responsibility of which should not have to lay entirely with the users of the space. This case study of Puhos highlights the complexities in generative coexistence – an argument for co-adaptability of common spaces, and the range of potentiality (and challenges) that a single space could offer.

A broken escalator can never completely be out of use. It simply becomes a stairway.

Episode 4: ‘Mind meets Machine’: From Formalized Learning towards Systems Oriented Learning for Adaptive Spaces

This episode presents research and teaching findings conducted by Prof. Dr. Pia Fricker in the field of Computational Design at the Department of Architecture at Aalto University, Finland. The discussion expands on the topic of adaptation and space towards a discourse on the topic of future-oriented computational design thinking for education, which requires a combination of practical and theoretical discourse, enhanced by problem-based learning (Fricker & Kotnik, 2023a, De Graaf et al., 2003). Specifically, this discussion explores the relationship between architecture, landscape architecture, and information technology, in an era characterized by an overwhelming influx of data

(Fricker, 2022, Nunez et al., 2016). As these fields have an integrative character, the exploration lies in the integration of computational thinking to develop new hybrid forms and solutions that are as sustainable as they are versatile (Figure 6). “Computation is not introduced as technological topic but primarily as a way of thinking and cross-disciplinary link, as unifying common denominator of discourse, as locus of production and systematization of knowledge within the discipline of architecture across various scales of application” (Fricker, 2020, p. 686).

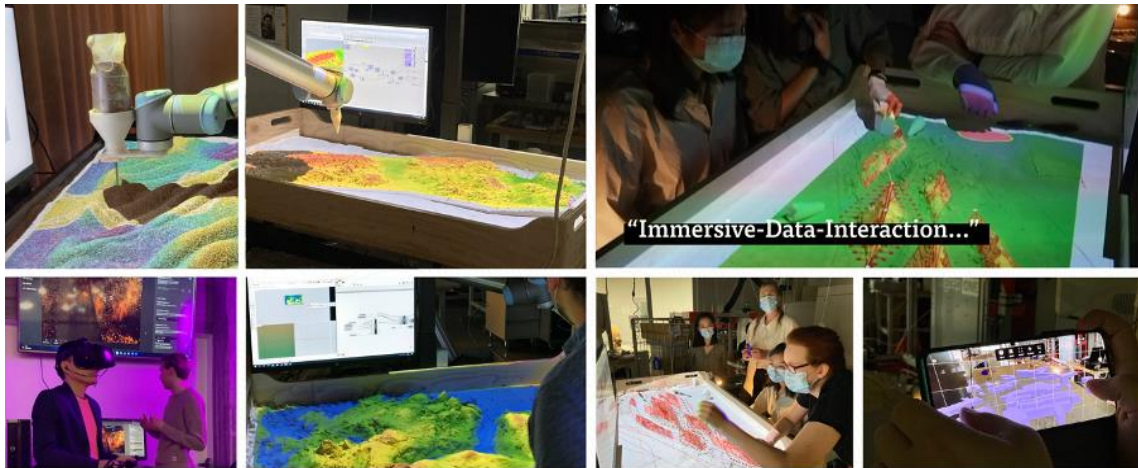


Figure 6. The developed teaching pedagogy is rooted in a comprehensive understanding of the theories that underlie algorithmic definitions. This approach integrates elements of systems thinking with classical theories from the field of computer science (Fricker, 2018). The accompanying series of images depicts an interactive data-informed design method, which utilizes a sandbox as the co-design platform with a robotic arm (Hermansdorfer et al., 2020). The system is complemented by real-time feedback projected on top of the sand and displayed in the 3D modeling software. Image Credits: Pia Fricker.

For the field of Architecture, thinking in systems offers a bridge to incorporate AI-informed methods, like Machine Learning from the perspective of a creative curator (Yang et al., 2022). As the challenges are getting more global and dynamic, the process to create possible sustainable solutions for the future needs to build upon the classical understanding of PBL, in particular focusing on the creation of immersive methodologies that facilitate the development of competences essential for effective collaboration and problem-solving on virtual communication platforms, achieved through dialogue and interaction (Jensen, 2017). The findings by Forrester employ didactic principles from the area of “System Dynamics” in order to simulate the relationships and interaction of diverse objects in a dynamic system (Forrester, 1969). As outlined by Fisher (Fisher & Margolis, 2002), the three main objectives of system dynamics education are defined as:

- Development of personal skills in relation to the challenges of a complex world by understanding the interrelationships and active search for the interconnectedness that gives meaning to the parts of systems.
- Understanding the benefits and limitations of mental models and the potential to combine the mental model with a computational model.

- General understanding of complex systems and their existence in nature, which enables them to make better-informed decisions for problem solving.

The system dynamics approach allows for a shift in thinking towards system thinking. The next level of learning takes place in observing and understanding patterns, described by Forrester as 'generic or transferable structures' (Forrester, 1992). This skill allows for quickly de-coding a certain structure and its underlying set of rules and to apply this knowledge to another field, which might have totally different variables, but nevertheless operates according to the same rules (Figure 7). Currently we are faced with questions like: “How to develop better and ecologically more relevant forms of engineered nature that could enhance social cohesion while establishing a stronger bond between society and nature, encouraging good governance, environmental stewardship and respect” (Giot, 2016, p. 314).



Figure 7. The image series describes the newly developed co-design methodology, driven by a creative interaction with elements of Machine Learning and robotic interaction. By incorporating computational thinking into design education, students are empowered to think more systematically and holistically about design problems across scales and temporal dimensions (Fricker, 2016). This systems-oriented approach to learning emphasizes the importance of understanding the interdependencies between different elements of a system, as well as the dynamic relationships between those elements over time. This approach enables

students to design solutions that are not only innovative but also sustainable and adaptable to changing conditions. Student project by: Antti Rantamäki, Kaisa Koskinen, Laura Tuorila, Teo Rinne.

De-coding spatial patterns provides a platform for discussing the development of systems that can withstand the test of time. This phenomenon of "generic structures" is widely used in biology and has become a common practice in computational landscape architecture (M'Closkey & VanDerSys, 2017).

As introduced by Sarah Williams, data can be regarded as the new infrastructure, and it is vital for our profession to explore new ways of creatively engaging with the fields of artificial intelligence, robotics, and mixed reality to create adaptive solutions for the challenges we face today (Williams, 2020). As stated by Picon, "the entire city could be considered intelligent in a new way, founded on the interaction and composition of the perceptions and deliberations of multiple entities, human, non-human, and often a mix of the two" (Picon, 2015, p. 12). To make the most of the wealth of data available, it is essential to focus on the "why" of the design process. This requires a critical discussion of the choice of method, to ensure that the design process is data-informed rather than data-overloaded (Fricker & Kotnik, 2023b).

The symbiotic integration of computational thinking and problem-based learning (PBL) stands as an imperative stride in preparing students for the multifaceted challenges of the future, where artificial intelligence (AI) and advanced technologies play pivotal roles. Embracing a systems-oriented approach to education empowers students to cultivate the essential skills and knowledge required for designing sustainable and adaptive solutions. As AI continues to shape our world, students adept in computational design through PBL will be at the forefront of crafting a built environment that not only withstands but thrives amid the intricate and ever-evolving complexities of the 21st century. This transformative pedagogical approach resonates with the emerging educational paradigms, laying the foundation for a generation of adaptive, forward-thinking designers and problem solvers.

CONCLUSION

In this multidisciplinary exploration, we have delved into the intertwined concepts of adaptation and space in the context of sustainable futures and Problem-Based Learning (PBL). Our journey has revealed the intricacies and diverse interpretations of space, highlighting its crucial role in addressing the challenges of our contemporary environment and the spatial boundaries we inhabit.

Throughout our discussion, we have emphasized the importance of embracing diverse perspectives and approaches to problem-solving. By integrating the principles of adaptation into the design of PBL activities, we can create a dynamic learning

environment that enables individuals to adjust their problem-solving strategies in response to changing circumstances (Christiansen et al., 2013). This adaptive capacity not only enhances critical thinking, but also cultivates transferable skills necessary for collaboration across disciplinary boundaries.

We acknowledge the transformative changes that have occurred in fields such as art, design, architecture, science, and technology. While historically knowledge and innovation have predominantly flowed from science and technology to these realms, we recognize the growing reciprocal knowledge exchange and interdisciplinary collaborations that have emerged in recent years. Examples include the integration of artistic and design principles in scientific research and technological advancements, as well as the application of scientific methodologies in artistic and architectural practices. These collaborative endeavors demonstrate the potential for knowledge transfer and innovation across disciplines, open towards different viewpoints and interpretations (Savery, 2006).

As we have embarked on speculative explorations, we have observed the interconnectedness of various fields such as art, design, architecture, science, and technology. While these fields have undergone transformative changes, it is vital to acknowledge that knowledge and innovation have predominantly flowed from science and technology to the realms of art, design, and architecture.

Whether in public discourses, policymaking, or even through available research funding, today, fields of science and technology appear to be given significantly more gravitas, even monopolize the responsibility in the task of tackling the challenges of our times. This, often via captivating products of rapid technological advancement, which follow Promethean attitudes promising to address current problems by creating the world anew. In contrast, fields of design, architecture, and the arts, offer finer lenses for identifying and engaging with today's complex challenges, in their different scales and scopes, through sustainable operations of adaptation, that don't necessitate the negation of our current challenges. What we mean to suggest is not a binary dilemma between 'the arts and the sciences,' but instead that the complexity of our contemporary lived environment requires both. To fully harness the potential of adaptation and space, we must foster reciprocal knowledge exchange and interdisciplinary collaborations that enrich all involved fields.

In our quest for sustainable futures, Problem-Based Learning emerges as a catalyst for transformative learning experiences. By integrating the notions of adaptation and space into PBL frameworks, we empower individuals to tackle complex challenges and envision innovative solutions (Van den Akker, 2006). This expanded perspective beyond

disciplinary boundaries opens up new trajectories for PBL, enabling us to address the urgent and interconnected issues of our time.

In conclusion, this article has sought to contribute to the discourse on sustainable futures by emphasizing the significance of adaptation and space. By embracing interdisciplinary perspectives, engaging with the complexities of space, and fostering adaptive learning environments, we can navigate the challenges of our world and work towards a more sustainable and inclusive future.

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**Embedding Digital Data Storytelling in Introductory Data Science Course:
An Inter-Institutional Transdisciplinary Pilot Study**

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Justin Thai, Sarah Jewett **

ABSTRACT

With the emergence of data science as an inherently multidisciplinary subject, there is increasing demand for graduates with well-rounded competence in computing, analytics, and communication skills. However, in conventional education systems, computing & quantitative, and communication skills are often taught in different disciplines. Data storytelling is constructing and presenting data stories to highlight the analytical insights to achieve the communication goals to a specific audience. Digital data storytelling leverages digital storytelling techniques and best practices in communication to deliver stories that can be shared in digital formats to a wide audience. In this paper, we describe and reflect on a semester-long project-based learning pilot using Digital Storytelling as a framework to allow students to explore topics themed around human flourishing and sustainability with the end goal of constructing data stories delivered in digital or video format (i.e., Digital Data Storytelling). The pilot work was conducted in an introductory data science course at a 4-year Minority Serving Institution in collaboration with students studying non-STEM disciplines at a partner community college. Our pilot demonstrates the potential benefit of this sustainability-aware Project-Based Learning design in raising students' awareness of sustainability issues, increasing confidence in cross-disciplinary communication competency, and at the same time

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deepening their understanding of data science concepts. We further reflect on the significant role of an effective program model as well as challenges and opportunities for building transdisciplinary communication competency to prepare for a diverse data science workforce.

Keywords: Data Science Education, Communication Competency, Data Storytelling, Digital Storytelling, Transdisciplinary Collaboration

INTRODUCTION: WEAVING SUSTAINABILITY INTO DATA SCIENCE EDUCATION

With the technology affordance and computational power for collecting, storing, and processing data, individuals with data skills are in high demand (Nicolaus Henke et al., 2016). A sustainable society needs a diverse and inclusive workforce equipped with the skills to extract insights from large and complex dataset and turn them into actionable narratives that inform the design of sustainable solutions to benefit humanity. Data science education is such a field that has the potential to answer the call. However, the current data science education in higher education typically focuses on a few narrowly defined technical competencies, such as programming and quantitative reasoning. Still, those skills alone are insufficient to support the vision toward a sustainable future. For data science education to integrate sustainability, we argue for leveraging student-centered active learning pedagogy, such as project-based learning to encourage students to be engaged in data science problem-solving with sustainability implications. Specifically, we propose three aspects of sustainability that can be woven into data science education by considering the domain aspects of data science (Domain Sustainability), the process of doing data science (Disciplinary Sustainability), and the diverse student population to be engaged in data science education (Educational Sustainability).

Domain Sustainability: Data science is an empirical science that solves data-driven problems in specific domains. One straightforward approach to embed sustainability into data science education is to motivate students to launch authentic inquiries into domains closely connected to sustainability issues. One overarching domain framework is human flourishing (VanderWeele, 2017), which concerns living well sustainably, both as individuals and collectively as communities. A flourishing society largely depends on the sustainability of the environment and human capacity, which are enabled by infrastructure in education and healthcare, and beyond. By engaging students in data-driven projects exploring datasets in those related domains, we begin to build a platform for students to launch data-driven inquiries and answer their own curious questions, thus

motivating them to hone in on data science skills while simultaneously deepening their understanding of the sustainability aspects that the data and problem provide.

Disciplinary Sustainability: A core competency of data scientists is communicating and collaborating confidently with people from diverse backgrounds and disciplines. A data science project team in the real world comprises domain experts and stakeholders with various degrees of data acumen. They practice distinct norms and speak the languages of their discipline. Sustainable data science education thus needs to be deliberate in training students to work in a multidisciplinary environment, developing intellectual humility to quickly adapt to the culture of the discipline where the problem is situated. Moreover, to encourage data science students to develop essential competency in communicating with data, i.e., data storytelling skills (Dykes, 2019; Knafllic, 2015), data science educators could benefit from methodology and approaches from other disciplines, such as communication and literacy, where theory and practice of narrative and storytelling are well developed (Bietti et al., 2019; Risam, 2018).

Educational Sustainability: Data science and analytical professionals, like many other STEM disciplines, will have the highest chance of being sustainable if students from underrepresented groups can actively participate and have their voices heard, and ultimately be well equipped to discover and solve problems emerging from their communities (Norman, 2023). A diverse workforce has more opportunities to create sustainable and inclusive products and services (Williams et al., 2019). However, so far, students from minority groups are disproportionately underrepresented in the data science workforce (National Science Foundation, 2021). Educational institutions must intentionally implement educational interventions to engage students from diverse backgrounds; this includes students from minority backgrounds, first-generation students, and students transferred from or currently enrolled in community colleges.

This framework is inspired by the principles of sustainable education, also known as Education for Sustainable Development (ESD), as outlined by The United Nations Educational, Scientific and Cultural Organization (UNESCO). ESD embodies educational practices that integrate key sustainable development themes into teaching and learning processes. UNESCO has identified five priority action areas to achieve these objectives¹. Of these, Priority Action Area 2: Transforming Learning Environments and Priority Action Area 6: Empowering and Mobilizing Youth, have particular relevance for undergraduate data science education, which is the primary focus of this paper.

While ESD provides an over-arching goal, we would like to operationalize in the context of data science education, thus providing educators with a framework, referred to as "Sustainable Data Science Education," to guide their strategic and practical pedagogical decisions. This framework encompasses three interconnected components of suitability

in domain, discipline, and education, which can be explicitly linked to most of the Sustainable Development Goals (SDGs) as illustrated in Figure 1.

Domain Sustainability encourages educators to present sustainability as a subject of study in data science education. At least nine SDGs can intersect with data science education, either through exploring datasets and problems related to these indicators or through in-depth investigations to inform policies that could enhance these indicators. Considering the complex and multidisciplinary nature of solving problems related to SDGs, students need to be challenged to equip themselves with the necessary knowledge and skills for problem-solving with multidisciplinary teams - a concept referred to as **Disciplinary Sustainability**. **Educational Sustainability** advocates for intentional efforts to promote inclusive participation from a diverse range of backgrounds, ensuring that all students can engage in data-driven inquiry, whether as professionals or as global citizens. This can be directly linked to four SDGs: Quality Education, Gender Equality, Decent Work and Economic Growth, and Reduced Inequality.

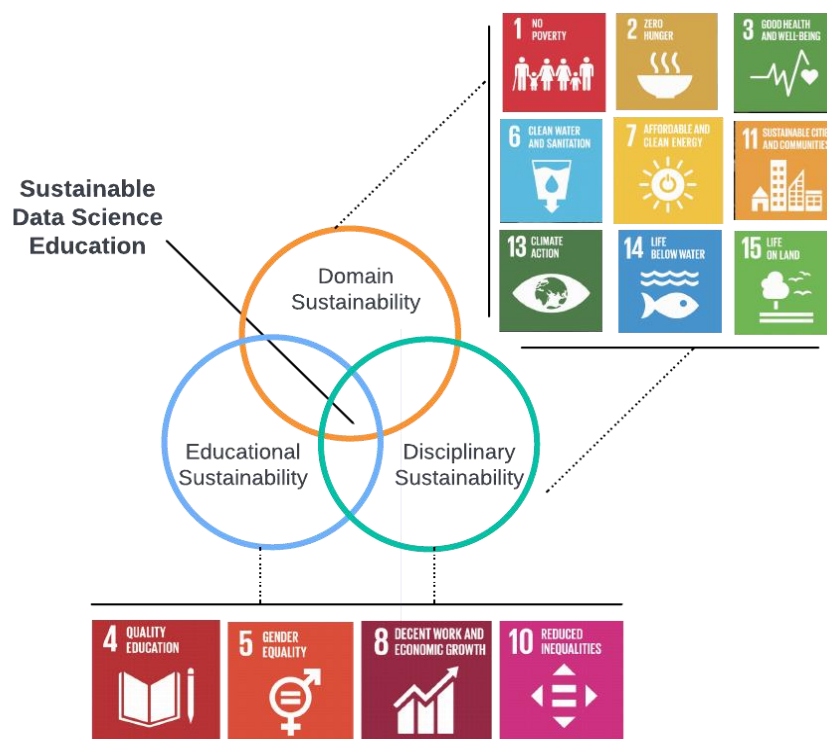


Figure 1. Illustration of three components defining Sustainable Data Science Education, including Domain Sustainability which is linked to nine of the Sustainable Development Goals or SDGs², and Educational Sustainability and Disciplinary Sustainability, as relevant to four of the SDGs.

In this paper, we describe a pilot study in an introductory data science course in a 4-year Minority Serving Institution (MSI) in collaboration with a Digital Storytelling Internship program from a community college with Hispanic Serving Institution (HSI) designation. This pilot operationalizes the three layers of sustainability through a project-based

learning approach. Along the dimension of **domain sustainability**, students are invited to launch a data storytelling project within an overarching theme of Human Flourishing, which is largely centered around environmental sustainability topics, such as climate change, and human society sustainability topics, such as happiness, well-being, and mental and physical health; meanwhile, it explores the **educational sustainability** by engaging students from a university and a community college college, with the majority from underrepresented groups. Moreover, to strengthen **disciplinary sustainability**, the project involves peer-assisted learning (Topping, 2005) activities through two cross-training workshops where students (STEM students from the university and Non-STEM students from the community college) learn skills from the discipline they are unfamiliar with while honing their skillset with relative strength.

In the rest of the paper, we give a brief overview of the literature to contextualize the contribution of this work. We will then provide the institutional, program, and course context, followed by a description of the pedagogical design around project-based learning and its implementation and the data collected. We will share findings from the study and conclude with reflections and discussions of the specific contribution of this pilot to the research and practice in project-based learning for sustainable data science education, as well as the implications and lessons learned from this pilot project for future research and practices.

LITERATURE BACKGROUND

Digital Storytelling, Data Storytelling, and Digital Data Storytelling

Digital Storytelling is a process where individuals, regardless of video editing experience, craft personal video narratives that emphasize the creator's voice. Digital stories often last one to five minutes and combine images, video clips, music, text, and voiceovers. Digital storytelling fosters higher-order thinking skills, develops digital literacy, amplifies one's creative voice, and helps students to develop their professional identity. The storytelling journey starts with an open-ended prompt, leading to idea selection, script creation (250-500 words), and video production. Crucial to this process are Story Circles (Lambert, 2018), spaces for deep listening, feedback, and co-creation (Liguori, 2020). During each Story Circle, storytellers learn more about their narrative and audience expectations and, ideally, continue to leave with a set of editing plans until they complete and publish their story.

Data Storytelling is about effectively communicating data-driven insights (Casola, 2020) and leveraging them for social change (Bhargava, 2017). It merges data analysis, visualization, and narrative to enhance comprehension, spark action, and promote collaboration (Kosara & Mackinlay, 2013). It goes beyond mere visualization and emphasizes clear rhetorical functions like persuasion and explanation. Starting with data

insights generated from the data science workflow, it involves refining these insights into coherent stories. This approach mirrors disciplines like journalism or filming, where raw materials are transformed into stories in various formats.

Digital data storytelling is an emerging concept that integrates the data storytelling process of generating data stories and the creative process of digital storytelling to culminate into data stories presented as short videos. Perhaps one of the most popular digital data stories is late Hans Rosling's 4-minute video that tells the data story of the development trajectory of 200 countries in 200 years (BBC, 2010). Digital data stories expand digital stories' focus on personal stories of qualitative and ethnographic nature to stories that are told in the form of data stories, often supported by quantitative analysis. While data stories can assume various formats, ranging from a single static visualization to a series of presentation slides to interactive webpages, digital data stories adopt a special presentation format rendered in video format.

Teaching Cross-disciplinary Communication Competency in Data Science

Despite the recognized importance of communication skills, the research on effective pedagogical strategy and tactics is sparse other than a few lines of work to explore teaching practices for data-driven written communication, for example, through a course (Nolan & Stoudt, 2021), workshop (Hildreth et al., 2022) or embedded Python Notebook (Willis et al., 2020). One of the contributions of this research is to explore a pedagogical approach that integrates communication skills training with data storytelling project-based learning where students work with an authentic task of creating public digital data stories by analyzing a real-world dataset. This setup is augmented with peer-assisted learning in a cross-training format that motivates students to reinforce their data analytical skills through teaching non-STEM majors while learning new storytelling strategies from students with strength in communication.

Teaching Social Responsibility in Data Science

Though the modern computational and mathematical tools from data science are powerful, sustainable data science education programs should foreground teaching students how to use the tool wisely by maximizing the positive societal impact while reducing negative consequences arising from issues such as algorithmic bias, privacy, and security (Kearns & Roth, 2019; O'Neil, 2017). This goal can be realized through two complementary strategies. The first strategy involves encouraging students to explore problems with societal impact, for example, those links to the United Nations Sustainable Development Goals (United Nations, 2015), as demonstrated by current research and development work in the field of AI for social good (Tomašev et al., 2020) or Data Science for Social Good (Ghani, 2018). The second strategy explores how to teach students to practice data science in a socially responsible manner. There is a growing body of literature that explores pedagogical approaches to the study of ethics in data

science and computing (Lewis & Stoyanovich, 2021; McDonald et al., 2022); some of the other work empowers students from under-represented groups to work on projects addressing concerns in their community (Fisler, 2021; Ryoo et al., 2021). By encouraging students from minority-serving institutions to explore real-world datasets within the framework of human flourishing, this project offers students opportunities to explore societal issues through data-driven, hands-on exploration. This work adds to the limited but growing body of work in incorporating social responsibility into data science in higher education, such as through volunteering work (Monroe-White et al., 2023) or service learning (Farahi & Stroud, 2018).

Project-based Learning in Data Science Education

It is common to incorporate projects in data science education as projects allow students to apply theoretical knowledge and skills to the application (Farahi & Stroud, 2018) while engaging students in authentic problem-solving. Some variation of PBL in data science involves experiential learning with real clients (G. I. Allen, 2021) or service learning that engages a community partner (Farahi & Stroud, 2018). However, a limited amount of work on PBL explicitly incorporates communication goals. One exception is the work reported by (Donoghue et al., 2021), which elaborates on a student-centered project with a communication and storytelling component comprised of lectures on data communication and a written report as a deliverable. Students were evaluated on their “effectiveness of written communication, clarity in their story, and careful design of their visualizations.” Our project takes a step further by introducing digital storytelling as the data story delivery format while integrating peer-assisted learning (Topping, 2005) on topics of societal concern. Digital storytelling expands data storytelling’s common delivery medium of written sources into video format, making data stories accessible to a wider audience.

Project-based Learning and Digital Storytelling in STEM Education

Digital storytelling, despite its adoption as an educational tool as early as in the 1990s (Wu & Chen, 2020), has not received much attention in STEM education in high education, and its intersection with Project-based Learning (PBL) is even more limited. A recent survey on Educational Digital Storytelling revealed that of the 57 studies analyzed, merely nine were centered around STEM disciplines, with just four being conducted within higher education contexts, while the remaining focused on primary and secondary school subjects like science, physics, computing, and technology. Among the four studies situated in higher education, two were designed as individual assignments aimed at enhancing digital literacy (Chan et al., 2017) and fostering intercultural awareness (P. M. Ribeiro, 2016) rather than focusing on a project-based learning objective. (Rambe & Mlambo, 2014) introduced the concept of a digital storytelling community platform called "Knowledge Audio Repository," where graduate students

can externalize their personal knowledge and reflect on their research process using the Digital Storytelling format. The study by (Brace et al., 2015) was only one of the few instances where digital storytelling was integrated into a project-based learning framework. The research involved 47 college students working on group-based projects around food systems, with a digital storytelling output intended to disseminate health messages to the public. The aim was to encourage healthier food systems and stimulate a shift in food production practices.

As noted in (Wu & Chen, 2020), the use of Digital Storytelling in STEM education has not been fully exploited, and there is a lack of educational projects that articulate learning objectives with a reconstructive orientation - the process of reconstructing the meaning of a given concept. They further advocated using Digital Storytelling to probe climate change issues through critical evaluations of "facts, views, and underlying assumptions" and "relating issues to personal contexts." This perspective aligns with our intent to incorporate Digital Data Storytelling with a focus on sustainability, thereby endorsing a reconstructive approach to STEM inquiries.

INSTITUTION AND COURSE CONTEXT

Institution Context Institution A is a minority-serving public university on the east coast of the United States with a student population of over 10,000, with more than half of the students from minority backgrounds. This institution hosts over 100 degrees and programs, and over 85% of the class with less than 50 students. Institution A is also one of the major destinations for transfer students from 2-year community colleges in this area. About a third to a half of newly enrolled students are transfer students. Institution B is a community college with campuses less than 40 miles away from institution A. Institution B is a minority-majority with a Hispanic Serving Institution (HSI) designation with 43,000 students from 155 countries; about two-thirds of the student population belongs to minority groups. It is worth noting that A is a key transfer-receiving institution for B, and B is a key transfer-sending institution for A.

Course Context The pilot was conducted as part of the introductory data science course in the Spring semester of 2022. Modeled after the Data 8 course from UC Berkeley (Adhikari et al., 2021), it requires no prior programming experience and only high school Algebra 1. The course teaches data science using a custom python package similar to Pandas. Institution A's adaptation centered on Digital Data Storytelling (DDST). This provided cross-disciplinary project-based learning opportunities, focusing on real-world sustainability-related datasets. Data science students and DST interns exchanged expertise, ranging from coding and data visualization to narrative creation and video editing, respectively. The class has 25 students, with over 90% from minority groups,

over 40% community college transfers, 30% first-generation college students, and 30% females. While most were from STEM backgrounds, including information systems and computer science, some from fields like psychology, sociology, and public health.

COMPLEMENTARY PROGRAM MODEL

The course served as a host site for an inter institutional collaboration in digital storytelling. Institutions A and B have broad and deep inter-institutional partnerships fostered by the rich and varied collaborations of faculty and staff over time. The digital storytelling collaboration is a powerful exemplar of the value of that partnership for both communities. First piloted in the Fall of 2019, institution B's Digital Storytelling Internship is a two-tiered student leadership opportunity offered through the Humanities Center. During their first semester, Level One interns learn about digital storytelling, create their own digital stories, and develop expertise in the storytelling process. They support faculty and students engaged in digital story projects through office hours or classroom attendance. If they choose to continue, Level Two interns leverage their newly-gained skills and expertise and take on leadership roles in special projects hosted by key partner institutions, including institution A, the internship's most active and robust collaborator. In the past three years, institution A's faculty and staff across nine departments and units have hosted 19 unique interns, with four returning for an additional semester.

At institution A, faculty members across various disciplines host an intern to support a digital storytelling assignment or project in one of their classes. Through online and/or in-person class visits, the intern explains the story process, facilitates story circles, teaches video editing, and supports emerging stories and storytellers. One of the most distinctive and important aspects of this experience is that these community college interns serve as experts in university classrooms. As the interns provide important expertise for their host classes, they also gain opportunities to explore institution A as a potential transfer institution. They have special status as visiting students on campus with access to institution A's physical and virtual resources. They concurrently enroll in a practicum through the Center in which they reflect on their developing practices as storytellers and leaders. In these sessions, they also network with faculty and staff while they learn about important resources for transfer students, unique disciplinary opportunities, and significant campus commitments.

This program model provided another important perspective on teaching and learning, as well as interdisciplinary learning. This brief reflection below, written by the interns, illustrated the significant implications of using this model to complement communication goals in the data science class.

In this applied experience, the cross-training experience offered opportunities for us as story interns to gain and deepen skills by enacting the roles of student and teacher. As inexperienced novices, we learned the basics of coding, while as emerging experts, we taught the basics of digital storytelling. For the coding session, we learned how to perform simple warm-up tasks using the Python programming language, such as getting the program to say “Hello [Name], how are you today?” as well as fixing tables that mirrored a restaurant order. For the storytelling session, we led the students through the story process using story prompts, Story Circles, and a digital story platform (WeVideo). For example, during the Story Circle, we opened with this prompt: “What were some of the first encounters with the special people in your life?” In a subsequent Story Circle activity, one learner recalled a story of a dear friend they made when they first came to the U.S. Another shared a memory from middle school when they met one of their current best friends. Not only did this activity allow the data science students to practice their storytelling skills, it was an opportunity to recall memories and share personal stories in a safe space. Throughout the session, we strove to ensure that we tapped into various learning styles and prioritized the development of visual, written, and hands-on components.

We also gained useful insights and perspectives during the cross-training experience. While the Python tasks wouldn’t be particularly taxing for those who are familiar with code, as digital storytellers with minimal STEM field crossover, we needed great assistance from the data science students, who very willingly walked us through each activity. The coding session helped us see in action just how meticulous the act can be, where even the slightest mistake of missing a comma or apostrophe would result in an error. In some ways, the meticulous parts of coding are similar to how detailed the editing portion of digital stories can be. While audiences may not recognize small errors in audio recording or be aware of the tightness of cuts between shots, these are elements that content creators are constantly mindful of, just as programmers are to coding. Before this experience, we would have been unlikely to see these shared dimensions or to be mindful of the ways we can effectively communicate messages across a variety of mediums regardless of the field of expertise.

Crossing traditional disciplinary boundaries opens up new possibilities for collaboration and communication. Now, just about a year later, we recognize the ways the experience helped us see how much we value interdisciplinary learning in our academic and professional settings. Collaborative learning environments like the cross-training session not only allowed us to share our perspectives as students involved in the world of humanities but also the time to listen to those who are versed in STEM. Overall, much of what we experienced with the cross-training sessions went beyond what we were a part of in the virtual classroom. This type of unified environment is something that we cherish

in our learning environments and recognize as incredibly resourceful in real-life situations. When those who work in the sciences do essential research, the humanities can bring inspirational ways to present such research or offer creative outlets to spread the main takeaways of the research, offering more collaborative solutions.

These reflections offered a nuanced perspective on the ways that the course and the program model worked together to broaden the impact of the experience beyond the students enrolled in the class.

RESEARCH QUESTIONS

RQ1: What are data science students’ learning experience and outcomes from this transdisciplinary and sustainability-aware PBL pilots?

RQ2: What are the implications and lessons learned for implementing transdisciplinary and sustainability-aware PBL in data science education?

LEARNING DESIGN FOR DIGITAL DATA STORYTELLING PROJECTS

Course Overview

Table 1 shows the course's weekly schedule and how DDST PBL activities fit with course units that run for 14 weeks. The course covers data wrangling and visualization, followed by statistical reasoning and basic computing. By mid-term, students use these skills for projects, mirroring real-world data science processes. Unlike UC Berkeley's Data 8, our course emphasizes student-driven dataset selection and offers sustained inquiry, leading to concrete data stories. In addition to those defined PBL features, the project was augmented with a peer-assisted learning component through collaboration with two DST community college interns who participated in two cross-training workshops (Table 2) and provided ongoing consultation to project teams.

Week #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Course Content	Overview	Table Operations			Data Visualization			Probability	Statistical Inference				Review	
Project Based Learning	Project Timeline	Interest Survey		Topic Selection			Curious Qs		Weekly Update				Presentation	
	Cross-Training Workshop				Workshop #1				Workshop #2					
	Interns Activity	Meet and Greet	Workshop Planning		Workshop Participation	Workshop Planning		Workshop Participation	Consulting/Giving Feedback to Project Teams					

Table 1. The overall course schedule and the alignment of Digital Data Storytelling PBL Activity with the course content.

	Week No.	Data Science Students' Role	Digital Storytelling Interns' Role
Workshop #1	Week 5	Teach DST interns Table Functions	Teach DS students story construction process
Workshop #2	Week 9	Teach DST interns data visualization	Teach DS students digital story implementation techniques

Table 2. The specifics of the two cross-training workshops with data science students (DS students) and community college Digital Storytelling interns (DST interns).

Interest Survey: The project started with an interest survey in week 2 when students were asked to watch a video on human flourishing published by the Templeton Foundation³, reflect on what living a good life looks like and share thoughts on how to use data-driven technology to improve human flourishing. In addition, students identify areas of interest relevant to the empirical evidence of human flourishing (VanderWeele, 2017).

Topic Selection: In week 4, students were asked to finalize their topic selection and teaming. Students were given a list of public data sources which include websites such as kaggle.com and government websites hosting datasets. To encourage students to look into sustainability issues, we also listed climate-related datasets themed around global warming, polar region ice melting, sea-level change, natural disaster, etc.

Curious Questions: After allowing students to take a few weeks to explore potential data sources and zones in the dataset to work on, we asked them to pose a few curious questions based on background reading or some initial understanding of the dataset. Those questions may guide their deeper exploration in the coming weeks. We also offered a mental health data set and an option to design a quantified-self project in which they would collect and analyze their own data.

Please refer to Appendix for a summary of students' responses to the interest survey, topic selection, and curious questions.

Weekly update and feedback: After the mid-term, students were asked to submit a weekly update each with a few data insights they gleaned from analysis, presented in table summaries or plots. Students also need to provide a narrative to tell the stories of the data. The instructor, teaching assistants, and DST interns were asked to provide feedback on those weekly updates. During the next iteration, students were expected to revise their narrative in accordance with their feedback. To compose a complete data story, students must select relevant story slices or data insights to organize it into a logical

sequence and weave it into a compelling and coherent story. This process happens organically later in the process.

Final deliverable: The project culminates in a set of digital data story elements, which includes a set of story slices (in the format of presentation slides) and written scripts of the story narrative. For extra credits, students could produce a digital data story using the video editing tool WeVideo.

Engaging DST interns in Students' Digital Data Storytelling Projects

Both interns are non-STEM majors (communication and business, respectively), and neither has previous experience with data science. Their background brings a fresh perspective to data science students, who are typically STEM students who are trained to mainly think in terms of numbers, abstraction, and computing, often with little exposure to qualitative thinking, narrative, and communication through mediums such as storytelling. As such, interns are well-positioned to serve not only as experts who could coach and provide feedback for students but also as "sounding boards" for students to try out new materials and strategies.

The interns were introduced to the class early in the semester and interacted with faculty and students through the virtual platforms Discord, an online instant messaging and virtual meeting platform. Since over 40% of the students in the data science class are transfer students from community colleges, they helped to build a sense of community for the interns as they explored prospective transfer institutions.

Cross-training workshop

We conducted two cross-training workshops in weeks 5 and 9, respectively, as illustrated in Table 2. The objective of the cross-training workshop is for data science students and DST interns to share their relative strengths in data science and digital storytelling and discover the common ground between Digital Storytelling (deeply rooted in the humanities and social sciences) and Data Science (commonly perceived as the STEM discipline).

The workshop was conducted over Zoom; each session lasted three hours. In each 3-hour session, half of the time, data science students taught their newly learned skills to interns, and half of the time, interns taught data science students digital storytelling skills. The specific topic during the cross-training is outlined in Table 2. This design is motivated by the learning-by-teaching (Chase et al., 2009) empirical evidence by providing opportunities for data science students to teach non-STEM students. We hypothesize this experience will improve their learning and sharpen their cross-disciplinary communication skills when they are challenged to explain technical details to non-technical audiences.

METHODOLOGY: DATA COLLECTION AND ANALYSIS

The study was approved by Institution A's Institutional Research Board. Students' demographic information was collected as part of the pre-course survey. In addition, we also collected students' survey responses at the beginning of the project. Students' work products, including weekly updates and final products, were collected. We conducted semi-structured interviews with three data science students who participated in cross-training sessions. The main objective of the interviews was to gain deep insights into students' learning experiences both as "teachers" to DST interns as well as students learning digital storytelling techniques from DST interns. All interviews were recorded with the consent of the participants and later transcribed verbatim for analysis. The interview protocol consisted of open-ended questions relevant to the research questions.

The qualitative data, including students' responses to open-ended survey questions, interview transcripts were analyzed using thematic analysis, following the six-phase guide in (Braun & Clarke, 2006). This process involved familiarizing ourselves with the data, generating initial codes, searching for themes among codes relevant to research questions, reviewing themes, defining and naming themes, and producing the findings. Excel spreadsheets were utilized to facilitate the organization and analysis of the data.

FINDINGS

In this section, we summarize the findings pertaining to RQ1 on data science students' learning experience and outcomes from this transdisciplinary and sustainability-aware PBL pilot.

Data Science Students' Learning from the two Cross-training Sessions with DST interns

As Teachers of Data Science

Several themes emerged from analyzing the interview transcripts with three data science students.

The positive effect of the teaching experience.

Though with different prior knowledge and various teaching experiences, all students agree that the teaching experience via cross-training provided them with opportunities to sharpen their skills, absorb materials better, "cement understanding," and improve their self-efficacy by teaching others.

We noted two possible pathways leading to enhanced learning which resonates with the literature on learning-by-teaching or protege effects (Chase et al., 2009).

Pathway #1: Motivated to learn deeply to teach effectively.

As commented by Student A3,

“I honestly felt an immense pressure to really know my stuff because I am expected to teach others and sound like I know what I am doing. So naturally, I studied harder and took additional measures such as writing myself a script, creating a cheat sheet, and annotating my personal copy of my exercise question with supplementary information for myself. I did so much to create a safety net for myself, and it paid off because it helped cement my understanding and made me prepared.” - Student A3

Likewise, being expected to be the master of the teaching topic motivated them to “absorb materials differently” (A1). For student A2, however, who comes with little teaching background and prior knowledge, the group-coaching format with multiple “teachers” in the break-out room is helpful as they could support each other.

Pathway #2: The real urge to communicate well about something they know.

A secondary pathway is the desire to communicate well about something they know. All students realize that learning alone is one thing, but the bar is much higher if they need to get the idea across. This could be even more challenging if the “students” are from different disciplines. Despite little formal training, students were able to develop their strategies and tactics to tackle this challenge.

For example, A2 uses the strategy of envisioning teaching a younger sibling, as he remarks,

“I tried my best to simplify code and the (main) point of the module, and I tried thinking of ways that I could show it to maybe my younger siblings for example. That’s mostly my approach, I just wanted to make it accessible and easily understandable.” - Student A2

A3’s strategy is a “piecemeal approach of breaking down steps and explaining how they work together to manipulate data.” A2 also mentions teaching allows him to develop empathetic thinking. As he noted,

“... So when you’re learning for somebody else, you have to think about what type of, I guess, perspective that the other person has in terms of what you’re learning.” - Student A2

Likewise, A3 mentions that he strives to “make it cohesive to not just myself, but also someone without similar experience as me.” This desire to be cohesive may trigger decisions about how to organize knowledge and structure learning (e.g., active learning), thus improving outcomes. Interestingly, students also reflected that in preparing lessons, they need to be ready to improvise and deal with unexpected questions or think on their

feet. However, some students expressed needing to work out more problems to prepare themselves better.

As Learners of Digital Storytelling

Takeaways from being trained in storytelling concepts and techniques.

Student A2 participated in the Story Circle breakout session led by one of the interns. Reflecting on his experience, he feels more confident in his ability to convey data through a data storytelling format, though being a first-timer participant, he felt it was fast-paced and challenging:

“...it got me to think about preparing information to share and the best way to articulate it in a way that is easy to understand and descriptive. .. it was pretty quick, I would say, in terms of the pacing. Because I’m not sure about how the timing worked, but we were taught what digital data storytelling is like, and then we moved into a prompt, and we shared with our groups what we prepared for the prompt. It was pretty (fast-paced) – like we didn’t necessarily have time to write anything down or anything,” - Student A2

Students A1 and A3, who participated in the WeVideo demo session, appreciated the interns’ well-planned, well-taught tutorial session and the excellent organization of the hand-out that helped to “connect the dots” so that they could use the tools to convey quantitative information. Overall, they feel the DST principle and techniques learned are “valuable addition to the knowledge base.”

Students’ Digital Data Stories Product

While all student team deliverables met the minimum requirements of a slide deck of a collection of selected data insights and story scripts, three project teams followed through to create a digital story video. Please refer to Appendix for two examples of digital data stories, one on *World Happiness* and another on *Industrialization, Carbon Emissions, and Climate Change*. In both of the videos, students were able to present compelling and coherent stories backed by data analytics. Following a narrative arc, the stories began with an exposition of the issues and followed up with analysis, concluding with calls to action. Moreover, the application of digital storytelling techniques shared by interns, such as the usage of stock videos, seemed to be quite effective.

Students benefited from the ongoing support from interns; for example, on one occasion, the interns were asked to review a student’s script draft for their video regarding climate change. While the team had a very strong base in delivering the essential facts regarding the issue, the interns’ edits helped to establish a more urgent tone to emphasize the need to address climate change. This is where the artistic choices in digital storytelling complemented and enhanced the data analytics content. While it is important to share

critical information regarding a topic, presenting it compellingly maintains the audience's attention and has a better chance of achieving communication goals.

Students' End-of-course Reflections

Toward the end of the course, students were asked to reflect on takeaways from the courses. Among the 18 submitted reflections, 14 (78%) explicitly mentioned the data storytelling project. Five students believed those skills learned through the projects could be readily applied to support, for example, the sense-making of the data they will encounter in real life. As mentioned by one student, “before (the project), I would just skim over graphs, but now I would stop and try to understand what is being said in the data.” Yet another student speaks to the authenticity of the task by explaining that “the project had us break down datasets and get to apply code and do it the way data scientists do.” Four students saw the immediate value of those skills to their future job. One of the students gave a vivid example of how he could use data storytelling skills to communicate effectively with his co-workers to help to improve their performance. Six students expressed positive sentiment toward the project experience using words such as “enjoy” and “like,” and some are especially proud of the digital data stories they were able to make, as this required them to “break out of the comfort zone” of their discipline. It is worth mentioning that two of the students explicitly mentioned the value of this project in raising awareness of societal issues such as climate change and human well-being.

DISCUSSION

In this paper, we report a novel project-based learning Digital Data Storytelling pilot in an undergraduate introductory data science course. This pilot is built upon a cross-disciplinary and inter-institutional partnership between a university and community college serving diverse student populations. This pilot was designed to explore sustainability from three perspectives: *domain sustainability* (by tasking students with exploring real-world datasets with sustainability themes such as climate change or well-being), *disciplinary sustainability* (through the authentic task of creating public data stories as the result of multidisciplinary collaboration), and *educational sustainability* (by engaging students from a diverse background using an asset-based peer-assisted learning approach through cross-training sessions where data science students and Digital Storytelling interns learn from and teach each other the skills with relative strength). In this section, we summarize the implications and lessons learned for implementing transdisciplinary and sustainability-aware PBL in data science education.

Promises of Sustainability-Aware PBL Learning Design in Data Science Education

Featuring authentic tasks with clear communication goals and social impact, and exploration of peer-assisted learning through cross-training, this project adds to the

limited data science PBL literature in teaching cross-disciplinary communication competency and social responsibility. In particular, the peer-assisted learning format we explored involves students outside the course with different disciplinary majors. This setup presents an authentic communication scenario challenging data science students to hone their cross-disciplinary communication skills, which frequently arise in real-world contexts and are highly valued by employers (Halwani et al., 2021). From the reflections of the cross-training participants, it is evident that the students benefit from being a teacher of their domain when their newly acquired knowledge and skills are reinforced through the protege effect (Duran, 2017). Moreover, they develop the capacity to empathize with learners, which lays the foundation for effective communication across disciplines. Students also seem to benefit from increased self-efficacy in their domain. By presenting students with the opportunity to learn skills out of their comfort zone, we note that students appreciate the challenges and potential values of working with students from different disciplines. Though with only limited evidence, we observe that some students connect with the sustainability themes embedded in the data analysis task, leading to increased awareness about societal issues like climate change and human well-being. Future work could benefit from a more principled approach to measure students' learning outcomes in areas of sustainability competency.

Significance of an Inter-institutional Transdisciplinary Program Model

Our pilot is built on a mature collaborative inter-institutional transdisciplinary program model, which provides important infrastructure for enriching data science students' learning experience via the communication expertise brought by DST interns. Crossing disciplinary boundaries requires concerted efforts, and developing an effective inter-institutional collaboration like ours could take years. For institutes that do not yet have such infrastructure, small initiatives can make a difference. Inviting colleagues from other disciplines (e.g. communication, social science or humanity) to give guest lectures in data science classes, or organizing campus-wide hackathon events to encourage students to form multidisciplinary teams, could open avenues for future interdisciplinary collaboration.

Lesson Learned for Teaching Cross-disciplinary Data-driven Communication

Despite the awareness of its benefit, teaching cross-disciplinary data-driven communication is a relatively new area and can be challenging. This pilot study explored possible formats and collected an initial set of evidence to demonstrate its potential values. However, we identified several areas for future improvement from both teaching practice and research perspectives. Firstly, though it was planned for storytelling interns to provide feedback to data science students while they craft the stories, in reality, only a small number of the teams could take advantage of these resources. It is likely due to the short timeline of the project. Most teams spend most of their time wrestling with data

analysis to derive insights, so they have little time to construct stories. Moreover, we realize that students may benefit from the scaffolding of the feedback-giving and seeking process, for example, by providing a list of example questions that data science students could ask interns. Secondly, though there are theoretical explorations on the narrative structure of data storytelling (Cohn, 2013), it is yet to be operationalized in teaching practices. Students from both disciplines will likely benefit from explicit discussion to draw the parallelization between the story construction in digital storytelling and data storytelling. Story circles explored in the cross-training workshop could be adapted to facilitate feedback and reflection during the data stories construction process later in the project. Thirdly, though this study captures a few students' experiences through written reflections and interviews, a more structured approach to measure more students' learning outcomes in communication competency and growth of domain knowledge will be beneficial to guide future pedagogical decisions and provide more rigorous evidence of its effectiveness and areas of needed growth.

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APPENDIX

Students' Responses to Interest Survey

We analyzed the 23 responses to the open-ended question in the interest survey “In your own words, what does living a good life look like?” Several themes emerged: The most popular concept is related to working, being productive, self-fulfillment and self-improvement, and realizing potential, coming from 48% of the respondents (n=11); followed by a related concept oriented toward meaning, purpose, and goal (39% of respondents, n=9); about 35% (n=8) of the students consider the access to basic resources and a certain level of quality of life as the hallmark for a good life. About 22% of the students believe helping and connecting with others are important factors. The other relatively infrequently mentioned concepts include mental health, subject well-being, and resilience (i.e., handling adversities)

Figure 2 summarizes students' responses to the general area of interest concerning the domains and enabling factors of human flourishing (VanderWeele, 2017).

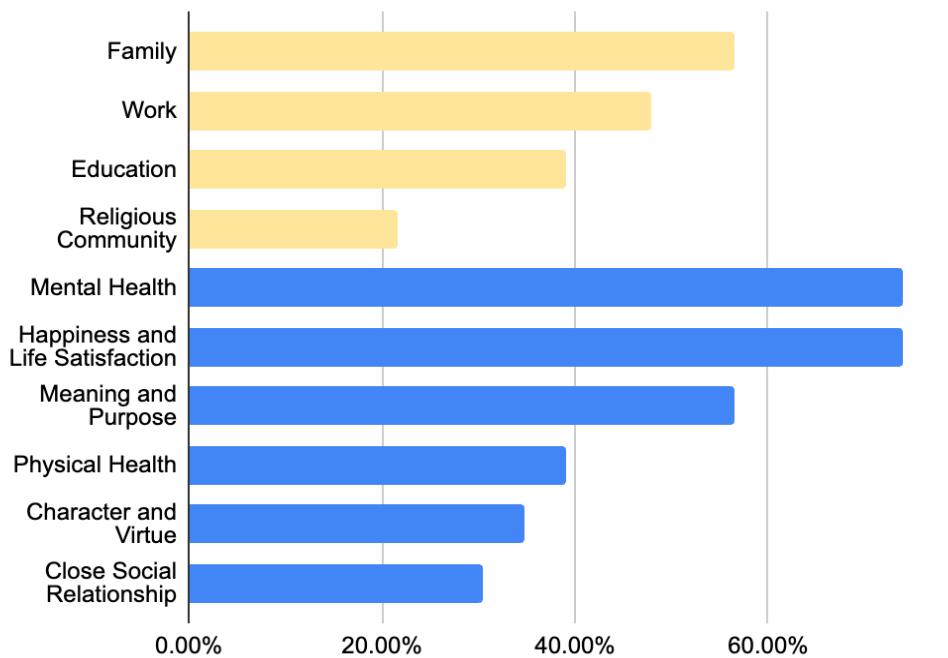


Figure 2. Summary of students' responses to one of the Interest Survey questions: Relating to the empirical evidence of human flourishing per VanderWeele 2017 paper, which of the following areas are you especially interested in exploring? Percentage of students choose a given selection item. The top four selection items (in yellow) are the four enabling factors of human flourishing, and the bottom six are the domain of human flourishing (VanderWeele, 2017).

Students' Topic Selection

Seven students (6 teams) selected the World Happiness project; 8 students (4 teams) selected the Climate Change topic; 8 students (6 teams) opted to work on healthcare topics which included a project investigating gamer's mental health and cardiovascular disease,

as well one student worked on Quantified self project which analyzed the data collected from himself and his friends on well-being related topics using Experience-Sampling Tool Expiwell.

Students' Teaming Choices

We permit students to form teams comprising up to three members. Nine students opted to form teams of three, while the remaining students chose to work independently. Regardless of their team size, all students collaborated with DST interns via cross-training and by participating in consultation or feedback processes.

Students' Curious Questions

After students finalized the topics, they were asked to do some preliminary research on the topic and dataset based on background reading or initial exploration of the data. At this stage, the questions can be large and vague, and the motivation is to empower the students to find an angle of analysis they find interesting. For example, teams working on the World Happiness project are interested in exploring the true definition of happiness and the factors contributing to happiness (e.g., material wealth, law and regulation), the property of happiness (e.g., whether it lasts, and whether everyone has the same definition of happiness, etc.). For teams working on the climate change project, the curious questions were centered around the state of carbon emission and how industrialization might be related and how it can be explained by policy, how natural disasters and severe weather might be linked to climate change, whether the sea-level rise is linked to the current global warming trend.

Example Digital Data Stories Produced by Students

The Story of World Happiness

Link to video: <https://youtu.be/-4XQqu-BXsU>

In this story, the student walked through his analysis step by step toward the revelation of the major contributing factors to the country-level happiness score. His story unfolds by introducing the candidate factors one by one. Here, his use of stock images and videos appears quite effective. He then attracts the audience's attention by posing an intriguing question: Why do some countries like Finland and Denmark scored the highest while countries like Afghanistan slipped to the bottom? Finally, he shared his aha moments of discovery. As he reflected at the end of the video on the meaning of happiness and potential pathways to improve world happiness:

“Happiness isn't just a commodity, it's a goal, something to strive for ... from my findings, the proper steps needed will involve looking at the happiness driving factors for countries, like GDP, Social Support, Healthy Life Expectancy, and seeing to it that countries found on the lower end of the ladder positively achieve these. I feel that with this data, we can

conclude, such as I have, that will point us to the kind of solutions and decisions needed to achieve true world happiness.”

Those narratives shed light on his deepened understanding of well-being related sustainability issues through his journey of data-driven inquiry.

The Story of Industrialization, Carbon Emissions, and Climate Change

Link to video: <https://youtu.be/g8qd-iQljBY>

This story starts with a definition of carbon emission and plausible causes linked to industrialization, population growth, and resource overconsumption, which were substantiated through data analysis. The story presents insights by contrasting the amount of carbon emission from one developed and one developing country from each continent. It follows with a historical account of industrialization and its impact on carbon emissions. The story further explores data showing the disproportional burden of air pollution-related health issues from developing countries compared to developed countries. The story concludes with a statement of the consequences of global warming, accompanied by a call to action by making small individual changes:

“Global warming threatens the survival of all living things and is directly linked to the health of the human species, especially in densely populated areas. Doing things like using reusable bags, using public transport instead of individual vehicles, and turning off electronic devices while not in use are some examples of small changes that many people can accomplish. If we all make small individual changes, we can accomplish great things together to ensure the health of future generations and our one and only planet.” Those narratives illustrate students’ emerging understandings of sustainability issues related to global warming, along with actions they could personally undertake to address them.

Glossary

Story Circle

In a story circle, participants gather (either physically or virtually) to share, listen to, and give feedback on each other's stories. The primary purpose is to create a collaborative, supportive environment for developing narratives.

Curious Questions

Students pose questions out of curiosity, given some basic understanding of the domain and data set. This pedagogy move is inspired by question-driven learning (Herranen & Aksela, 2019) or problem-based learning (D. E. Allen et al., 2011), where we use those student-initiated questions to motivate students in data-driven inquiry.

Minority Serving Institution

A Minority-Serving Institution (MSI) is a term used in the United States to describe colleges and universities that enroll a high percentage of minority students. There are

several types of MSIs, each serving a particular minority group. Some examples include Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), Tribal Colleges and Universities (TCUs), Asian American and Native American Pacific Islander-Serving Institutions (AANAPISIs), or Predominantly Black Institutions (PBIs).

¹ *ESD for 2030 toolbox: Priority action areas*. UNESCO. (2020, November 12). <https://en.unesco.org/themes/education-sustainable-development/toolbox/priorities#paa>

² SDG icons are from <https://www.un.org/sustainabledevelopment/>

³ [Innovations in Human Flourishing | Stories of Impact](#)