PATHWAYS TO SUSTAINABILITY IN HIGHER ENGINEERING EDUCATION: A CONSTRUCTIVELY ALIGNED CHANGE IN FRAMEWORK

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ABSTRACT

This study explores pathways to integrate sustainability**Z** into engineering education at technical universities, focusing on traditionally non-engaged departments. The study seeks to identify strategies for institutional change through educational innovation by using Eindhoven University of Technology (TU/e) as case study. Findings offer practical frameworks to align curricula with sustainability ambitions and prepare engineers to address grand societal challenges.

KEYWORDS

Sustainability in Engineering Education, Education Innovation, Change agency, Grand Societal Challenges in Education, Standards: 1-3, 7, 11.

INTRODUCTION

Grand societal challenges, including climate change, biodiversity loss, and rising social inequalities, are exerting significant pressure on our present and future (Rockström et al., 2009; Pickering & Persson, 2020). Addressing these challenges demands a fundamental transformation in how we manage and interact with our ecosystem (Bennett et al., 2019). While technological advancement has played a crucial role in mitigating some of these pressing issues, it alone is insufficient. For technology to be truly effective, it must be integrated with societal innovation and development, creating a holistic approach that aligns human progress with environmental and social sustainability.

Higher education institutions, in particular technical universities, play a crucial role in this transformation. Technical universities not only contribute to technological development but also shape mindsets, values and attitudes of future leaders and professionals (Grek & Ozga, 2010). Around the globe, technical universities are recognizing this necessity, with Sustainability Offices expanding and diverse solutions emerging to incorporate sustainability into education. The risk is, however, that Higher Education Institutions might be adapting to the rapidly changing world too slowly. Barry and McGeown (2023) argue that most Global North universities fail to keep pace with environmental and social shifts, and are lodged in traditional ways of transmitting knowledge which perpetuates a societal system driven by economic growth and techno-fix solutions – technological responses that address societal problems without fostering systemic change.

Scholars, including Koresky and Wieczorek (2024) and Giesenbauer and Müllerchrist (2020), have sketched the scenario of a “transformative university” as an institute that enable students to become agents of change and prepares them to tackle the complex challenges we are facing as a society and where Sustainability constitutes the main rationale around which education takes place. Multiple shifts are necessary to meet this ambition, namely: (1) a shift from solving well-defined and narrow-in-scope problems, to addressing grand societal challenges; (2) from teacher-centered education to learner-centered education, where students and teachers learn from each other and co-create solutions; (3) from mono-disciplinary learning to transdisciplinary learning, where learners co-create solutions with the outside world and other disciplines. Koretsky and Wieczorek (2024) tailored this approach to technical universities, arguing that for universities of technology to become “transformative” there should also be more emphasis on the inclusion of qualitative methods (next to the highly dominant quantitative methods), focus on post-positivist and constructivist epistemologies (next to the highly dominant positivist paradigm), inclusion of social sciences in parts of the curriculum and the integration of different economic schools of thought (next to highly dominant growth-oriented paradigm). Likewise, Rosén and Leifler (2024) elaborated in their research why this transformation is particularly relevant for *engineering education*, observing the “significant gaps between current engineering capability and the needs to meet societal challenges […].” He developed recommendations based on the CDIO Standards according to engineering education philosophy and aims, curriculum development, engineering projects and workspaces, teaching and learning methods, faculty development, assessment and evaluation. The authors reflected on what the implications would be within two engineering programs (Electrical Engineering and Civil Engineering) within their respective universities – KTH Royal Institute of Technology, Denmark, and Linköping University, Sweden.

Universities, such as Eindhoven University of Technology (TU/e), have committed to acknowledging the changing world and preparing its students to address the grand societal challenges urgently requiring action (TU/e Strategy, 2018). These institutions have adopted *guiding principles* to steer their actions, operations, research and education toward this overarching mission. TU/e, as a representative case study, emphasizes in its Educational Vision the goal of training the "Engineer for the Future" (Educational Vision TU/e, 2021; TU/e Strategy 2030, 2018). "Engineers for the future" are defined as T- or TT-shaped, and who are able to combine one or two disciplines with the skills to address "real-world challenges" in both science and technology. The "engineers for the future" are also "responsible", meaning they are able to recognize the impact of technology and the disruption that comes with it "toward a future that works for all of us" (TU/e Strategy 2030, 2018).

Education at Eindhoven University of Technology is structured around nine departments. Previous research (Roefs, 2024; Rijsdijk et al., 2024) suggests that the vision outlined above resonates greatly with three out of nine departments. The input, collected amongst students and teachers, (Roefs, 2024; Rijsdijk et al., 2024) propounds that some research and education areas are more "suitable" to appeal to this visionary approach of Sustainability implementation and Grand Societal Challenges orientation rather than others. Students and teachers fail to see the connection between their degree program and Sustainability, or identify other important barriers that hinder this implementation. Other barriers involve lack of professional knowledge, skills or attitude to teach about Sustainability or lack of time to properly integrate the topic within the seven weeks of time that most courses within TU/e are allocated.

Problem definition and research objective

While universities increasingly acknowledge their evolving role in society and their potential to empower students as agents of change to tackle current and future sustainability challenges (Scholz, 2020; TU/e Strategy, 2018), a gap persists between these ambitious mission statements and the practical actions implemented in education. Within our university, TU/e, some departments overlook how their work connects to Sustainability or simply lack the tools to integrate it in their educational activity (Roefs, 2024).

Especially within the engineering discipline, all subjects have a direct relation with Sustainability, in this research I aim to provide educators with guidance, and a layered approach to Sustainability integration in engineering education, prioritizing departments that have less affiliation with Sustainability. The outcomes outline actionable changes in the Constructive Alignment (CA) framework, further explained in the theoretical section of this paper.

Research Questions

This paper seeks to answer the following main research question:

What pathways can educators within department of technical universities that traditionally do not engage with Sustainability undertake to incorporate it effectively into their educational program?

The following three sub-questions will help guide the response to the main research question:

1. How is the current engineering education organized?
2. What are the pathways to sustainability integration within an educational context?
3. How can the implementation of Sustainability be operationalized in practice?

METHODS AND RESEARCH DESIGN

This research adopts a **constructivist** worldview, a prevalent approach in qualitative research. Constructivism is used in instances of theory generation, considers social and historical construction, and is grounded on the ontological discourse accepting the coexistence of multiple realities (Cresswell, 1994). While the framework of this research is constructivist, it is anticipated that interviewees might approach reality from a postpositivist perspective. However, as outlines in Table X, these interviews will be analyzed though a constructivist lens to match the methodological approach of this research. In order to cater to the constructivist approach, case study is adopted as a methodology as it enables to focus on contextual understanding as well as the gathering of rich detailed data (Creswell & Poth, 2018). Semi-structured interviews also cater to the constructivist worldview adopted in this research as their outcome provides space for interpretation of findings, and leads to a form of analysis, through coding, that allows the identification of patterns.

TU/e as a case study

We employed a case study methodology, selecting Eindhoven University of Technology (TU/e) as the focal institution. The primary reason for this selection is TU/e's strong emphasis on educational innovation, exemplified by initiatives such as TU/e innovation Space, the center of expertise for Challenge-Based Learning, and its focus on entrepreneurial education. These initiatives align closely with the objectives of this study, providing a rich context for exploring education innovation toward sustainability.

In addition, the researcher's role as a Sustainable Education Development Officer at TU/e greatly facilitates the study. This position has enabled the development of a robust network of teachers and support staff over the past year, offering access to key stakeholders and data sources.

To further validate the findings, we plan to present these at June 2025's CDIO international conference, engaging with an international academic audience to gather diverse feedback and assess the broader applicability of the conclusions.

Action research

Action research is a participatory and iterative methodology employed in this study due to its focus on educational settings, and its features linked to engagement, participation and collaboration (Kemmis & McTaggart, 2000; Coghlan & Brannick, 2014).

Preliminary data collection

Semi-structured interviews

During the academic year 2023-2024, 25 semi-structured interviews were conducted with teachers at TU/e from six different departments. These interviews have been carried out following an analysis of elective courses offered at TU/e and their description on Osiris (platformed used at TU/e to elaborate on the course offer). The 25 interviews have been used as source of data in Roefs' Master's thesis (2024), yet they also provided in-depth insight on the general orientation of different departments toward sustainability integration and transformative educational practices.

Student survey

In addition to the semi-structured interviews, 108 responses across all nine departments of TU/e were collected by bachelors and masters students (Rijsdijk, 2024). The inquiry was collectively designed and distributed between TU/e's GO Green Office and TU/e Sustainability Office. Respondents were surveyed on their perception of the relationship between their study program and sustainability. They were also asked about the inclusion of transformative education practices in their learning, which involve alternative pedagogical techniques designed to facilitate systemic thinking, the acquisition of a plurality of worldviews, and a sustainable rationale (Roefs, 2024). Similarly to the teacher interviews, these responses were also used to assess the positioning of different departments concerning transformative educational practices and sustainability integration.

Focus Group Sessions

Within the same academic year, three departments within TU/e (innovation Space, Sustainability Office and Academy for Learning and Teaching) collaborated to organize three sessions attended by education developers, teacher supporters and educators. The sessions covered: (1) best practices of sustainability integration at TU/e; (2) barriers and promises of implementing sustainability in education; (3) promotion of sustainable partnerships in transdisciplinary education practices to provide a broad understanding of complex societal challenges. These sessions provided a broad understanding of the current state at TU/e and allowed data collection through a randomized data collection strategy.

Planned data collection

In addition to the data collected prior to this submission, we plan to conduct additional interviews with specific target groups within the university. While the first round of field study assessed transformative and sustainable practices across departments, the next round of semi-structured interviews will focus on departments traditionally disengaged from Sustainability practices. Interviews will take place with teachers and students and program directors.

Observations will continue throughout the study. The role of the researcher within TU/e, meetings, provides opportunities to collect additional input during meetings, co-creation sessions, and informal exchanges with colleagues.

Sampling Strategy

Interviews with teachers, responses from the students and the analysis of the courses offered university-wide, enabled us to map the degree to which different departments of TU/e are open to the integration of Sustainability in education, as well as alternative pedagogies that would enable a more integrated approach to Sustainability. Out of nine departments at TU/e, only three departments showed convincing evidence on the degree of current implementation of Sustainability practices in education, these departments being Industrial Engineering & Innovation Sciences, the Built Environment and Industrial Design. The departments of Applied Physics, Mathematics & Computer Sciences, Biomedical Engineering, Chemistry & Chemical Engineering, and Biomedical Engineering, on the other hand, showed some examples of innovative practices in education, yet still neglect the relation between their study program and Sustainability.

Teachers and education developers within the latter group constitute the target group of this study, as the traditionally-non-engaged departments referred to in the main question.

Mapping faculty members (students and teachers) across different departments revealed varied levels of engagement with Sustainability and educational innovation. This mapping exercise will be elaborated upon in the final paper.

Table 1: Summary of data collection and data analysis.

Problem	***Research question***	***Data (what?)***	***Source (who?/where from?)***	***Analysis (how?)***
The way that current engineering education is defined in non-engaged departments is unexplored, and might not mirror universities' missions statements of preparing future engineers of addressing grand societal challenges.	**How is current engineering education of non-engaged departments characterized?**	Mapping of the current institutional logic of TU/e.	Semi-structured interviews (Teachers, Students, Education Directors, Education Board)	In-vivo coding (Atlas.ti) Find patterns, similarities and differences within interview transcripts
It is unexplored in research how pathways of institutional change translate to an educational context, and whether this theory resonates with teachers and education developers involved in education design.	**What are the pathways to sustainability integration within an educational context?**	Pathways (way of achieving a determined result – sustainability in education)	Transition studies literature, educational science literature. Validation workshop.	Analysis of input collected through literature and validation workshop.
Educators of non-engaged departments fail to see what the implementation of Sustainability in Education practically implies as there seems to be little to no guidance.	**How can the implementation of Sustainability be operationalized in practice?**	Immediate actions on the constructive alignment framework.	Workshop/working group session with education designers and policy advisors. International validation workshop.	Thematic analysis of the input provided during the working group or workshop.

One validation workshop will be held with experts in the international context during the CDIO conference taking place at Monash University in June 2025.

The table below summarizes key data collection and data analysis moments taking place throughout the research endeavor.

THEORY

To address the question we combine transition studies, new institutional theory, and educational insights as this relation permits us to study change within education institution, and to determine implementational insights in practice within a degree program.

Regimes

Regimes are dominant and highly institutionalized socio-technical structures that undergo constant negotiation (Fuenfschilling & Truffer, 2014; Fuenfshilling & Binz, 2018). Actors (parties within the socio-technical structure), technology (the infrastructure alongside which the actors operate) and institutions (rules of the game), constitute the basis of any regime (van Summeren et al, 2023).

In our case, the Higher Education system can be defined as a regime since it is built around the interplay between actors, institutions and infrastructure. Within the Higher Education system, actors include teachers, students, academic and non-academic staff and the education and research partners. Higher Education Institutions' technology is represented by the infrastructure that enables learning and education, namely university campuses, classrooms, online platforms and other learning ecosystems. Lastly, higher education institutions are characterized by the rules of the game that legitimize education. At present, education is built around Intended Learning Objectives (ILO's) for the educational path, and a series of Learning Activities (LA's) that facilitate the process of learning. These ultimately culminate in Assessment (A) which provides to acquire study points or standardized European Credit Transfers (ECTs). The cumulative sum of these allows students to earn degrees or diplomas, currently the only recognized proof of education completion.

New Institutional Theory

To transition from the old regime to the new desired regime, where Sustainability is implemented within education, *Institutional Work* is needed. Lawrence et al. (2011) identify practices to create, maintain and disrupt institutions. Integrating Sustainability in education involves institutional work to change the old regime and transform it into a new one. As Lawrence et al. (2011) suggest, multiple *pathways* exist to facilitate this transition: (1) *Maintaining* is part of institutional work, does not imply any transition, yet reinforces the idea that maintaining institutions requires institutional work likewise. As a matter of fact, Trank and Washington (2009) identify actions of valorizing and demonizing, mythologizing, and embedding and routinizing as processes to maintain an institution, which are required once the change is adopted. (2) *Creating* implies the creation of new space to facilitate new regimes to exist. Lawrence and Suddaby (2006) emphasize the importance of specific actions in institutional work to create new regimes. These include advocating, defining, and vesting. Advocating involves actively mobilizing political and social support to push forward new institutional structures. This includes lobbying for curriculum changes or persuading key stakeholders to adopt sustainability principles in educational frameworks. Defining entails establishing clear rules, norms, and boundaries that give the new institution its identity and purpose, such as creating frameworks for sustainability-focused programs or criteria for courses. Vesting refers to granting legitimacy and authority to the emerging institution, such as formalizing new sustainability guidelines within accreditation standards or establishing governance structures to support these changes. While maintaining is a crucial avenue to support existing institutions that need to be endured, and creating offers a launchpad to pilot new intentions aimed at facilitating sustainability transitions, this paper focuses on the (3) disrupting pathway. Disruption involves revising and altering the old system. This alteration results in three distinct avenues ranging in levels of less to more radical. Sterling (2004) identifies the following three practices: (a) accommodation, where Sustainability is seen as a "gloss" or as an "add-on" (Lönngren et al., 2022). Small changes are made within a curriculum to "free space" to accommodate Sustainability integration, for instance, in the form of a guest lecture; (b) *reformation*, which implies more significant changes, aimed at dismantling current educational practices, but without altering the entire regime, thus the interplay between actors, technology and institutions; (c) *transformation*: a complete reimagining of education's purpose, incorporating systemic changes. Researchers such as O'Sullivan (1999), Giesenbauer and Müller-Christ (2020), and Rodríguez Aboytes and Barth (2020) have explored transformative education, its goals, and the practical implications of such a shift.

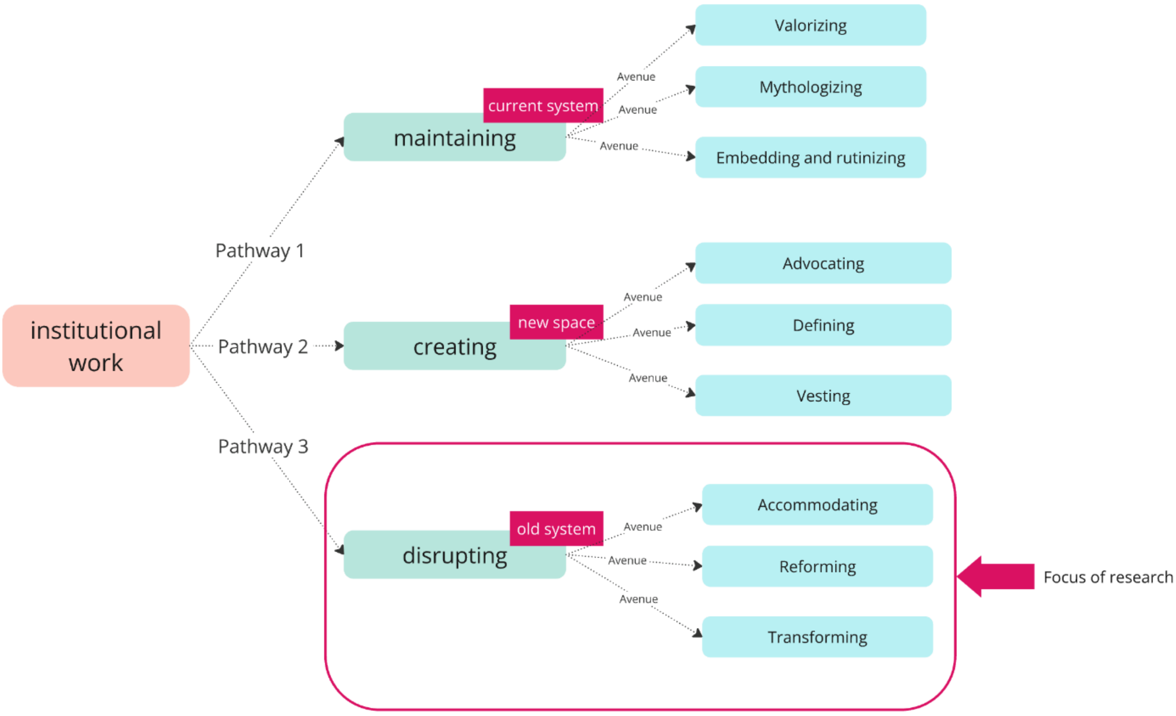

Figure 11: Theoretical background of research

The Constructive Alignment Framework

In his work, Biggs (1996) brings together literature on constructivism and instructional design. Constructivism is a family of theories that explain how individuals create meaning focusing on the learner's perspective. Biggs synthesized these two bodies of literature by identifying the way that best works for learners to make meaning – namely, by following a design that constantly seeks alignment within its main components, defined as the Intended Learning Outcomes (ILOs), Learning Activities (LAs) and Assessment (A). This framework is commonly recognized as the Constructive Alignment (CA) framework. As Loughlin, Lygo-Baker and Lindberg-Sand (2020) revised the framework, they noted that it has remained relevant over time, and that the current education system is still largely administered around this framework. Despite its longevity, literature does not challenge its validity. This consistency explains why it is used as a foundation for this research.

Analytical framework

In this paper we combine the insights of regimes, institutional theory and Constructive Alignment to develop a comprehensive analytical framework. Figure X shows that is necessary to perform institutional work in order to transition from an old regime to a new regime where Sustainability is fully embedded in the education of traditionally non-engaged departments. The figure also shows that multiple pathways are, in fact, possible in order to reach the desired state.

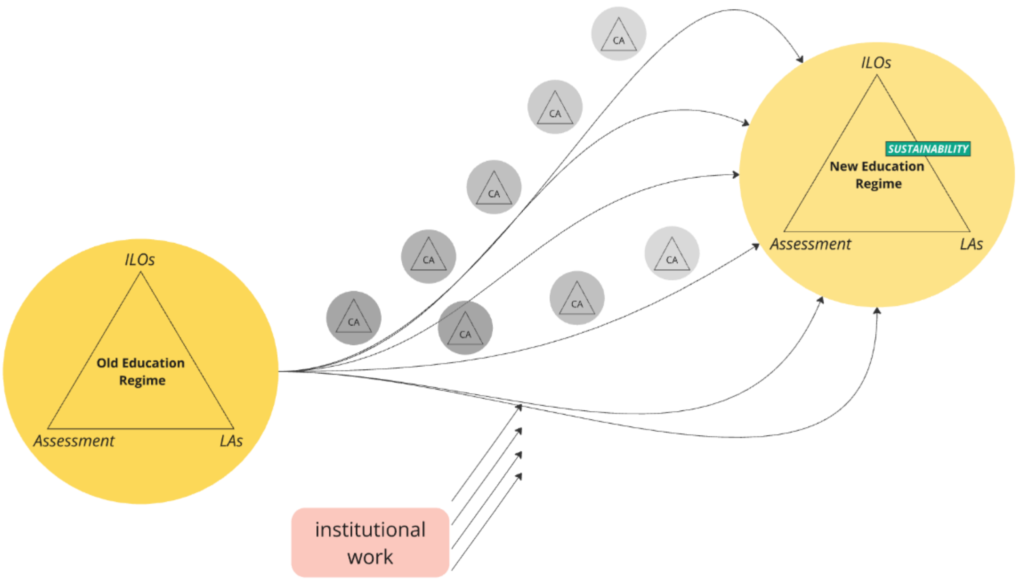

Figure 12: Theoretical framework: Institutional Work to encourage a transition from the olde education regime to the new (desired) education regime.

Next steps

Building on the findings from interviews, surveys, and focus group sessions, the next phase of this research will focus on deepening insights into departments traditionally less engaged with sustainability, identified during the preliminary steps. Additional semi-structured interviews will be conducted with educators, students, and program directors to identify specific barriers and opportunities for integrating sustainability into their curricula and how these can be mitigated by means of *institutional work*. Observational data collected during co-creation sessions and discussions with stakeholders will further enrich the analysis. To validate the proposed pathways for sustainability integration, a workshop will be conducted at the CDIO international conference, engaging an international audience of educators and policymakers. This collaborative session will refine the practical frameworks developed in this study and assess their broader applicability across technical universities. **The outcome of these activities will result in a completion of the framework proposed hereby, where different pathways of institutional work are connected to concrete changes within the Constructive Alignment framework**. Finally, the research will aim to synthesize these findings into actionable recommendations for institutional change, emphasizing strategies for aligning engineering education with sustainability goals and the addressing of grand societal challenges.

ACKNOWLEDGEMENTS

The authors received no financial support for this work. Acknowledgements for this work are extended to TU/e Sustainability Office and TU/e innovation Space for providing the tools, platforms and time to conduct this research. We also wish to express our gratitude to the master students Lotte Roefs and Meike Rijsdijk for coordinating the processes of data collection of interviews with teachers and students.

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Tommaso Mondovì is Lead Sustainable Education at Eindhoven University of Technology (TU/e). He holds a master's degree in Environment and Society Studies from Radboud University, where he completed his thesis on integrating pluralism and sustainability within Economics Education. Upon joining TU/e, Tommaso began his research trajectory with Professor Anna J. Wieczorek focusing on the intersection of transition studies and educational sciences.

Anna J. Wieczorek is Full Professor Sustainable Innovation and Transitions, co-founder of the sustainability transition field and a TU/e Sustainability Ambassador. She focuses on transforming TU/e's research, education, operations, and governance towards sustainability. With background in innovation sciences Anna contributes to innovation theory development, sustainable development and transitions. Her scientific expertise is in studying systems providing human needs such as education from a socio-technical perspective and informing practice through transdisciplinary research. Anna Wieczorek has supervised 6 PhD's and 2 postdocs. Anna received several teaching (8), research (3) and communication (1) awards. Anna co-developed and implemented a series of CBL professional trainings for entrepreneurs in sustainability transitions for Climate KIC and InnoEnergy KIC before they got traction at universities (Huijben et al., 2022).

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