Research and Education – Education in the context of research and practice

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The collaboration between civil engineering and spatial design disciplines specifically encompasses significant challenges, primarily due to differences in vocabulary, starting with the definition of 'design' itself. In the broadest sense, design is described as a method to find common ground in cases where the measures, problems, and goals are still undefined (Van de Ven et al., 2009). However, most civil engineers are trained to use a linear and optimisation approach to solve problems, while most spatial designers adopt a more explorative, research-by-design approach. Each field employs different paradigms and rationales for problem-solving.

Moreover, Webber and Rittel (1973) argue that engineers are typically used to deal with 'tame' problems, whereas spatial designers frequently address 'wicked' problems. This discrepancy leads to a gap between striving for the most optimal 'efficient' solution for a problem and seeking the best 'contextual' solution within the open societal systems without clearly defined boundary conditions. Webber and Rittel (1973) note that this shift, marking the end of the era of efficiency, began at the end of the 1970s when the urban context was reintroduced.

A similar transformation has occurred in engineering education. Since the 1980s, engineering education has generally been dominated by research-focused faculty (Crawley et al., 2007). This shift has encouraged students to focus on deeper, fundamental knowledge, with less emphasis on application or group work skills. Moreover, the introduction of the computer brought unprecedented calculation capacity that allowed for theoretical system behaviour and exploratory scenario analysis. However, before this shift, engineering education had been dominated by practitioners, not researchers, who placed greater emphasis on project work and learning by doing – testing – in practice. In recent decades, industry leaders in engineering have appreciated the depth of knowledge in modern engineering graduates but have lamented the lack of balanced group skills for a multidisciplinary working environment (Lang et al., 1999). Mills and Treagust (2003) reviewed a range of project-based, interdisciplinary engineering programmes and concluded that while students from traditional engineering programmes possess good fundamental knowledge, they require additional on-the-job training and experience to be productive in practical project settings. Conversely, students from undergraduate programmes with a heavy emphasis on interdisciplinary work often struggle with engineering fundamentals and thus have difficulties with core engineering tasks. Lee (2011) makes a distinction between problem-seeking and problem-solving design. Voorendt (2017) distinguishes spatial design (problem-seeking) from engineering design (problem-seeking), see P 41, Figure 9.

Education in the field of spatial design, including architecture, urban design, and landscape architecture, is creative-design oriented, aiming to balance stakeholders' interests in urban projects at all scales. This educational approach is inherently interdisciplinary, involving a variety of disciplines and fields of expertise. Unlike engineering, this field is characterised by an epistemic culture that builds on diverse scientific fields such as engineering, sociology, economics, history, and natural sciences. A diverse epistemic culture implies diverse scientific fields, each characterised by its own methods, instruments, and tools of inquiry, as well as its own way of reasoning and establishing evidence (Knorr Cetina, 1999). However, designers often operated under the hypothesis that technological knowledge could realise any design they created. Thus, it can be observed that engineering has been removed from this epistemic culture (Hooimeijer, 2014). However, the contemporary demands of climate change necessitate the re-integration of engineering within the spatial design process to plan and build resilient cities of the future.

The review by Mills and Treagust (2003) suggests that intradisciplinary education is essential at the outset of undergraduate engineering studies to establish a foundation of practical knowledge. They argue that interdisciplinary education becomes advantageous when applied in upper undergraduate or graduate curricula. Traditionally, the Dutch and European university systems offered a 5-year programme culminating in the degree of Ingenieur (Dutch for engineer). However, following the Bologna process (European Commission, 2019), this structure has been divided into a 3-year bachelor's (BSc) programme and a 2-year master's (MSc) programme. At Delft University of Technology (TU Delft), the first year of the engineering master's programme comprises in-depth courses within each student's chosen discipline, which are more focused than the broad engineering curriculum of the bachelor's programme. Interdisciplinary education is incorporated in project-oriented courses and the minor at the bachelor's level and in the second year of the master's programme, which consists of project work and thesis research. This section discusses various forms of interdisciplinary education executed at TU Delft, including Challenge-Based education, the minor (bachelor), MSc Studio (Faculty of Architecture and the Built Environment), and Delta Futures Lab, an interfaculty laboratory at the MSc level.

Challenge-Based Education

Originally conceived by Apple Inc. as part of a pilot study on student motivation and curiosity, challenge-based learning first entered higher education in 2008 through the 'Classroom of Tomorrow – Today' project. This initiative aimed to identify skills, knowledge, and ideas crucial for thriving in the increasingly technological society of the 21st century. Many of today's significant challenges are categorised as 'wicked problems' due to their complex and interconnected nature. For instance, the energy transition intersects with climate change, public policy, engineering, housing, social welfare, health, psychology, and even conflict.

In response, higher education institutions, originally organised by discipline, have made concerted efforts to prepare students to tackle these challenges within their professional fields. At TU Delft, there are specific courses dedicated to integrated approaches and working in multidisciplinary teams. For example, the minor (bachelor) in Integrated Infrastructure Design, supported by DIMI, involves students from various disciplines collaborating on challenges posed by the municipality of Rotterdam. Similarly, the Joint Interdisciplinary Project, a centrally organised master's course at TU Delft, has students in multidisciplinary teams working for clients to achieve interdisciplinary results.

To facilitate this type of education, more flexible or combinable courses are required in the curriculum to better adapt to the uncertainties and complexities of today's world. The term 'challenge-based learning' or 'challenge-based education' is often used for educational initiatives that utilise challenges as a means to an end—to produce better-prepared graduates – or view solving these challenges as the goal itself. While different institutions may apply their specific labels for challenge-based education (CBE), certain foundational elements are consistent across the method. Primarily, CBE aims to enhance student engagement by demonstrating the relevance of their discipline to ongoing real-world problems. Its emphasis on authentic challenges and self-directed learning aligns with experiential learning, although challenge-based learning does not necessarily involve first-hand experiences for students.

As mentioned earlier, the wicked nature of 21st-century challenges necessitates a multidisciplinary and collaborative approach. Consequently, CBE is often understood as rooted in problem-based and project-based learning, encouraging students to ideate, analyse, and design together, drawing on their diverse perspectives and experiences. The open-ended nature of these problems increases the likelihood of uncertain outcomes, which can complicate assessment in ways not seen in problem-based or project-based learning but also positively affects student agency and creativity.

The execution and conceptualisation of CBE vary across institutions. Some create 'similar to reality' cases or recycle challenges to minimise the uncertainty of outcomes. Malmqvist, Kohn Rådberg, and Lundqvist (2015) proposed the following definition: "Challenge-based learning takes place through the identification, analysis, and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, involves different stakeholder perspectives, and aims to find a collaboratively developed solution, which is environmentally, socially, and economically sustainable."

Most recently, Malmqvist, Kohn Rådberg, and Lundqvist (2015), along with Beemt, Bots, and van de Watering (2022), introduced a conceptualisation that distinguishes CBE from other modes of learning, noting that CBE engages students through the direct involvement of stakeholders – a feature absent in traditional problem-based learning but integral to the DIMI approach. Moreover, CBE requires students to consider both the problem and the solution. In assessments, process and product will therefore need to be balanced. This philosophy aligns with the concept of the T-shaped professional, who must not only master fundamental knowledge and skills but also contextualise that knowledge and skills in both real-world applications and their broader relevance (Hertogh, 2013).

Minor 'Integrated Infrastructure Design' BSc Education

DIMI has focused on design research as a scientific approach, and this knowledge is integrated into education through the Integrated Infrastructure Design minor. Students from various design and engineering disciplines work together for a semester on design cases addressing concrete infrastructure challenges. Collaboration with municipalities like Delft and Rotterdam, as well as the Province of South Holland, are vital, as these issues, still in an exploratory phase, are not yet ready to be presented to engineering firms but are well-suited for study-through-design research.

Initially, students learn the fundamentals: the analytical and design skills and the perspectives of different disciplines. "Urban planning, landscape design, architecture, civil engineering, and technical public administration: we bring together all these perspectives in the various courses."

The minor begins with a comprehensive introduction to various objects of integrated transport and water infrastructures, exploring their historical development and environmental context. It introduces a wide range of design perspectives and approaches to familiarise students with analytical and problem-solving methods and techniques. As part of this course, students are required to write an essay from a theoretical standpoint about an infrastructure and how it presents an integral challenge.

The core of the minor is the design course, which includes in-depth design exercises for bridges, flyovers, underpasses, and route design across different scales and levels of complexity. This course stimulates and develops students' design, collaboration, and presentation skills through multidisciplinary teamwork in a studio setting.

Other courses delve into present and future mobility and flood protection issues, design challenges for transport and water infrastructures within the context of contemporary urban and landscape conditions, infrastructure planning and governance, and the intricacies of (infra-)structures from a reverse-engineering perspective.

The culmination of all courses is the final project, where students, as part of multidisciplinary teams in a studio setting, work on an assignment from a commissioner in practice to tackle a complex infrastructure design issue in a real-world context. Examples include the (re)design of a large bridge or a multimodal transport hub, and its integration into the urban transport system and public space. Besides designing the object and its integration, students also develop ideas for social and economic added value and financing options.

Interestingly, the minor also promotes collaboration among scientists from the various disciplines involved. In this way, education also serves as an important means of integration and facilitates networking between research groups and faculties.

Studio MSc Education

In the Faculty of Architecture and the Built Environment, the studio serves as a collaborative platform for students, where they collectively advance their design projects by collaborating on analysis, diagnosis, and executing collective or individual design tasks. Each step is complemented by additional lectures, and students engage in at least one day of contact hours per week dedicated to presentations and receiving feedback from tutors. Typically, studios are affiliated with a group of researchers; for instance, the Transitional Territories studio is connected to the Delta Urbanism Research Group. This particular studio focuses on the concept of territory as a constructed project across various scales, subjects, and media. Transitional Territories specifically explores the role of design in shaping fragile and highly dynamic landscapes at the interface of land and water, such as maritime, riverine, and delta landscapes, emphasising the inseparable relationship between nature and culture. Through interdisciplinary and situated knowledge – drawing from theory, material practice, design, and representation—the studio investigates lines of inquiry and action, building upon the Delta Urbanism research tradition while also moving beyond conventional methods and spatial concepts.

Adopting a transdisciplinary approach, the studio brings together experts from diverse fields, including landscape architecture, planning, engineering, earth sciences, humanities, and arts. This diversity enriches students' perspectives and encourages them to challenge disciplinary boundaries. Given pressing issues such as the climate crisis, biodiversity loss, resource scarcity, and the intersectionality of subjects and histories, there's a need for a fundamental shift in mindset and actions – from viewing land as a passive backdrop to recognising its active role in shaping intergenerational life.

The studio organises its work around three main modes: archive, laboratory, and atelier. Documentation, analysis, synthesis, and narrative exercises support the development of interventions that address the nature and causes of urban issues and their externalities. During the graduation year, students are guided to construct and apply a theoretical, analytical, and conceptual framework that intersects urban design, landscape architecture, and political ecology to study systemic relations leading to states of scarcity.

Critical thinking, interdisciplinary and transdisciplinary methods, and the pursuit of innovative design solutions are central to the studio's ethos. Students are encouraged to formulate their thesis topics and develop their own critical perspectives on the future trajectory of urban projects.

Delta Futures Lab

The Delta Futures lab is an inter-faculty collaboration platform that aims to integrate education, research, and practice through innovative interdisciplinary projects. The lab provides a multidisciplinary network for students who aspire to become interdisciplinary frontrunners in spatial design, engineering, and the governance of deltas. Students, societal stakeholders, and university staff collaborate within thematic working groups, projects, and courses.

The Delta Futures Lab facilitates cross-pollination between practice and university and between students and researchers from different faculties. It is an addition to the regular master's graduation programmes at TU Delft for students interested in interdisciplinary design connected to practice and research. Involving three connected faculties, i.e., Architecture and the Built Environment A+BE (Delta Urbanism group), Civil Engineering and Geosciences CEG (Water Management, Hydraulic Engineering, Geo-Engineering, Construction Management Engineering and Transport), and Technology, Policy and Management TPM (Multi-Actor Systems), the research programme offers opportunities for collaboration with students and practice. Beyond learning from the researchers and professionals, students in the Delta Futures Lab benefit from 'peer learning', where they learn from each other.

There are three models for collaboration in the lab: specific research lines, research projects and educational projects.

Research Line Model

The ongoing research line connects graduation projects from students of different masters over the years with long-term partners. Students from faculties other than A+BE do not graduate within a collective programme. The CEG faculty has graduation committees consisting of at least three tutors, with the possibility of including an external member from practice. The purpose of the lab is to bring students together around a challenge in thematic groups. They meet with supervisors from different faculties and engage in ongoing exchanges during their projects, adding an extra dimension to their graduation experience beyond the regular tutoring. This specifically targets the interdisciplinarity of the challenge as it is experienced in practice.

Research Project Model

In addition to regular and graduating students, the lab also serves as a platform where students participating in the MSc Honours Programme and Multidisciplinary Project students (CEG) collaborate on research projects. Master's students with above-average performance are eligible for a place on the TU Delft-wide Honours Programme aimed at developing talent. The Honours Programme is a challenging 20 ECTS extra-curricular programme that is largely self-designed by the students. It offers additional teaching, research, and projects related to specific themes, such as those offered by the Delta Futures Lab for the A+BE faculty students. These students have the flexibility to integrate research into their regular studies and are encouraged to exceed their disciplinary boundaries.

In the Multidisciplinary Project (MDP), teams of students from various disciplines within the Faculty of Civil Engineering and Geosciences investigate a problem posed by a client. They develop a strategy for a solution or other forms of advice. The client can be external or consist of faculty staff, and the project is organised into three phases:

- Preliminary Investigation: This involves analysing the problem to formulate a clear problem statement and objective that supports a project strategy with methods and multidisciplinary contributions.
- Design and/or Research: This phase executes the research strategy by developing design or solution alternatives.
- Round-off: This final phase involves delivering the project results to the client and supervisors.

Bringing together Honours and MDP students around the same case is an important method of 'goal-integration' that promotes interdisciplinary design, contrasting with the multidisciplinary collaboration typically seen within MDP projects. Assembling students from vastly different disciplines around a shared project goal enhances cooperation, as there is a mutual interest in understanding each other's perspectives. The goal integration approach allows students significant freedom in an MDP, though it tends to yield interdisciplinary outcomes less frequently than multidisciplinary results. A multidisciplinary project typically involves each expert contributing their discipline-specific knowledge to the project. In contrast, an interdisciplinary project, particularly one involving Honours students, takes it a step further: experts not only contribute their knowledge but also gain an understanding of methodologies from significantly different disciplines, leading to a more coherent and valued overall project outcome. This shared case adopts an interdisciplinary framework, thereby fostering a more experimental approach within the project's scope.

Educational Model

While similar to the research model, the educational model at TU Delft is more deeply integrated into regular education and unfolds during the second year of the MSc education. The university has streamlined the master's programmes across various faculties to foster collaboration. In Q4 of MSc 2, the focus is on intra-disciplinarity, promoting collaboration among students from different tracks within the same faculty. The focus shifts to interdisciplinarity in Q5 of MSc 3, encouraging collaboration between students from tracks in different faculties.

DIMI Portfolio

The DIMI portfolio has been developed with substantial support from working with students. Conversely, students have greatly benefited from the research projects executed within the frame of DIMI, as they provide context and tools for their work. Moreover, the collaboration with tutors and their research partners enriches critical thinking. This interaction forms the basis for challenge-based learning; it presents challenges not only in content or societal context but also in the format and collaboration of the research.

The Integrated Infrastructure Design minor is a tangible outcome of DIMI's ambition to focus on design research as a scientific approach and to integrate this knowledge into education. At the bachelor's level, this minor offers students their first experience addressing concrete societal challenges in infrastructure and urban development. For instance, the ***'City of the Future'*** (P 174) project involved 300 first-year civil engineering students who worked in teams of about eight to produce designs for specific sites within a larger design study. At the master's level, Research by Design projects such as 'City of the Future', ***'Highway x City'*** (P 118) and ***'Spatial Design Sarts with a Cross Section'*** (P 194) have provided a context for work in the graduation studio 'Cities of the Futures' and the MSc 2 Architecture and Urban Design elective course. Both groups consist of students from Architecture and Urban Design with Transport Infrastructure and Logistics. The exchange between professional teams in the study and the students has been particularly fruitful; students pose basic questions that require re-evaluation, and professionals demonstrate decision-making in design.

The 'Highway x City' project has also been an important catalyst for another DIMI project, 'Intelligent Subsurface', to connect the subsurface with other urban challenges, such as new mobility, through the elective course Infrastructure and Environment Design. Here, students become a catalyst for collaboration or expanding on a research approach, making it more explorative in connecting research topics. The transition from fossil-fuelled to electric mobility has significantly impacted the soils in areas targeted for urban design and infrastructure development.

The ideal education and research model was explored in projects in Japan, combining the research line (with graduation students) and project models (with MSc 3 students) in the Delta Futures Lab. Both groups consisted of students from five departments: Hydraulic

Engineering, Geo-Sciences and Engineering, Transport Infrastructure and Logistics (TIL), Urban Drainage Engineering, and Urbanism.

Fieldwork was done collaboratively, with an important component being the workshop in which the charrette and integrated design were performed with the goal of understanding the scope of interdisciplinary possibilities for the case. Subsequently, the project group developed a group output, and the graduation students continued with their individual projects. Sharing the location and the workshop meant that all were involved in each other's projects. This was a significant added value that was explored in depth during regular meetings throughout their graduation period. Presentations to each other enhanced the interdisciplinary exchange, characterised by dialogue and commitment.

students and practice learn together

Colophon

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