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**DOI**

[10.1080/03043797.2018.1442417](https://doi.org/10.1080/03043797.2018.1442417)

**Publication date**

2018

**Document Version**

Final published version

**Published in**

European Journal of Engineering Education (online)

**Citation (APA)**

Klaassen, R. (2018). Interdisciplinary education: a case study. *European Journal of Engineering Education (online)*. <https://doi.org/10.1080/03043797.2018.1442417>

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# Interdisciplinary education: a case study

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## ABSTRACT

Today, interdisciplinary education is a hot topic. Gaining an insight into the nature of interdisciplinary education may help when making design decisions for interdisciplinary education. In this study, we argue that, derived from interdisciplinary research, the choice of problem, the level of interaction between different disciplines and constructive alignment are variables to consider when designing interdisciplinary education. Several models of analysis have been used in two descriptive case studies to gain insight into the design parameters for interdisciplinary education. In this study, we AIM to describe (a) the level and nature of integration, (b) the problem definitions as a guiding principle for constructive alignment for (c) the design and execution of interdisciplinary/transdisciplinary education.

## ARTICLE HISTORY

Received 19 January 2017  
Accepted 13 February 2018

## KEYWORDS

Interdisciplinary education;  
engineering education

## Introduction

Universities today are based on disciplinary approaches and programmes, albeit a greater shift to interdisciplinary teamwork has taken place over the last 20 years (Evers et al. 2015; Nature 2015). This shift is apparent on websites of many innovation and integrated research institutes where interdisciplinary research is automatically a part of the research agenda. Interdisciplinary trends also surface in publication data, where more than one-third of the references in scientific papers are towards other disciplines (Ledford 2015). Despite the developments of interdisciplinary research, innovation hubs and interdisciplinary teamwork, the spin-off from interdisciplinary ways of working trickle down very slowly in academic education. Might this be due to a lack of information on what interdisciplinary research and education specifically mean? What can we learn from interdisciplinary research, if applied to educational design? How can interdisciplinary education, in particular, be conducted in the best possible way?

Traditionally, engineering innovations, amongst other driving forces, came about in the seventeenth century in experimental craft labs. As craft guilds had to evolve due to technological innovation, becoming organisations that could answer more complicated societal problems, labs came into existence. In these labs, craftsman experimented with new ways of developing technology driven products and improvements of production techniques by means of open dialogic conversations. As several craftsmen with different expertise came together in the labs, interdisciplinary exchange came naturally into the cooperative endeavour (Sennett 2013).

In the twenty-first century, co-creation and knowledge generation for complex problems is again in the front row of innovative development (NAS). Amongst others modern day professional networks, living labs and maker spaces replace these guilds, in which open dialogic exchange is equally necessary to generate new solutions. Interdisciplinary and transdisciplinary are integral

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parts of the technological innovation cycles and they bridge the gap between research, industry and education (Ehlen 2015).

### **Reasons for interdisciplinary education**

Present day disciplinary learning very much focuses on the assessment and learning of methods with a predetermined outcome and on the predetermined methods that should be practiced, emanating from the disciplinary boundedness. Here, boundedness depends on the social and epistemological status of a field of study and its interrelatedness with the market it might serve. Indeed, engineering education has been this way for a very long time. Yet, Mazur (2013, 2015) argues that modern engineering education should be a reflection of the professional world in general and engineering in particular. In this professional world most of the parameters, apart from a toolbox with available methods to solve a problem, are unknown. Creating an interdisciplinary situation in an almost natural way, when complex engineering problems are addressed.

This professional approach can, for example, be described as follows: A Client and a Professional ‘designer/engineer’ meet at a mutual agreed location *where* a client asks for a result (outcome) and the professional establishes *what* is exactly needed (problem definition and the elements situation at play to solve the problem). The professional then goes back to his office and establishes *which* patterns of relations are available in the elements of the situation and *which* methods and approaches are available to realise an outcome (*how*). Finally, the professional will decide *whom* and what sources (disciplines, persons/information etc.) should be involved to solve this complex problem.

elements of a situation – problem definition  
 patterns of relations – how’s –  
 type of input needed.  
 Outcome

Mazur shows that this where, what, which, whom format should be reflected in the way we teach and assess student learning such that students, and especially engineering students, learn to deal with divergent and ambiguous answers.

The Mazur approach allows for iterative loops in learning, similar to technological innovation in a crafts lab and thus it allows for the integration of diverse disciplinary knowledge bases to resolve a problem. Generally, we are talking about complex, real-world problems which then get addressed in pedagogical formats such as problem-based learning formats, case studies, field-work, discovery or inquiry learning.

Another driver for interdisciplinary learning is defined in social science, where it is pointed out (Gantogtokh and Quinlan 2017) that the opportunity for learning is at the boundary of disciplinary, cultural and social groups. At these boundaries, a ‘third space’ is created, in which the meeting of different perspectives (amongst others) triggers co-construction of learning (Akkerman and Bakker 2011; Almasi 2016). Akkerman argues that this third space stimulates critical thinking, helps to develop new knowledge, teaches students to be open to different perspectives and much more.<sup>1</sup> The choice of problem-type is an essential element for the realisation of this third space. The third space is often realised in overarching thematic areas such as sustainability, entrepreneurship, big data etc. where different disciplines meet to create joint solutions, products or explanations of the world (Lam, Walker, and Hills 2014). This suggests a high level of breadth and complexity in the problem to be addressed is needed to realise the third space.

The extent to which different disciplinary sources become synthesised is often one measure of success for interdisciplinary research, next to other metrics like the realisation of new innovative technology, new scenarios and active knowledge construction. Pedagogical approaches which challenge students to demonstrate interdisciplinary understanding by integrating multiple sources of knowledge, methods and perspectives, from two or more disciplines to realise a problem solution or a learning outcome, are still relatively limited (Repko 2007; Repko, Szostak, and Buchberger 2013). So, if these concerns of Mazur and the advocates of third space learning are taken into

consideration, what can we learn from interdisciplinary research approaches to design interdisciplinary education?

In the following paragraphs, it will be argued that the measure of integration, the choice of problem definition and the choice for designing the learning environment based on inductive or design abductive approaches, provides insight into the design of interdisciplinary learning environments.

## Interdisciplinary research

### *A definition*

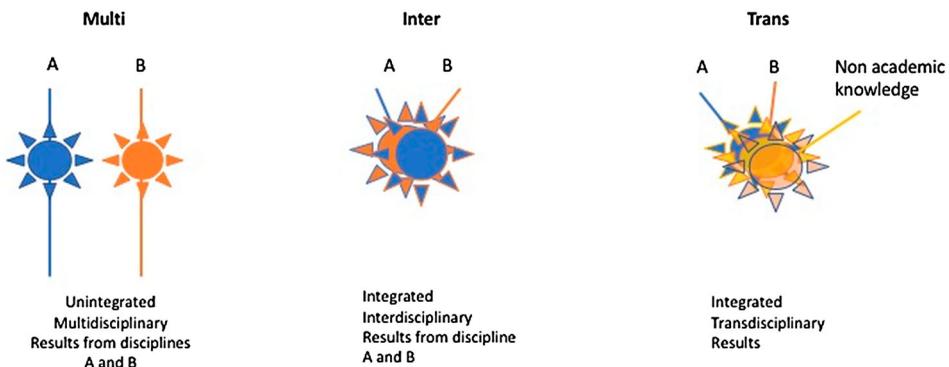
Interdisciplinary research can be defined first and foremost as a team or an individual expert (scientist or otherwise), who integrates methods, knowledge and skills, theories, perspectives and different disciplinary knowledge bodies, to realise innovative solutions and knowledge advancement in uncharted problem areas (Castán Broto, Gislason, and Ehlers 2009; Lam, Walker, and Hills 2014; Menken and Kestra 2016). De Jonge Akademie (Evers et al. 2015) even argues a change in scholarly identity takes place as a result of the integrated approach in interdisciplinary research. Where the 'new' scholarly identity becomes a symbiosis of disciplinary questions, methods and outcomes. Key characteristics in these definitions of interdisciplinary research are (1) the integration of a number of disciplinary elements also called the bridging and symbioses between different disciplines, (2) the possible implicit collaboration engrained in this interdisciplinary activity, (3) the art of identifying new problems and (4) the realisation of novel solutions and knowledge across different disciplines. In the following discussion, we will address these key characteristics.

### *Levels of integration and collaboration*

The Amsterdam Institute for Interdisciplinary Research defines a gradual scale in which multidisciplinary, interdisciplinary and transdisciplinary are defined as the degree of integration of different knowledge sources (Figure 1).

In multidisciplinary research studies, each discipline contributes a piece of the puzzle. However, this is not integrated during the research process or even in the final outcomes. The result is a parallel vision on a particular problem from different disciplinary perspectives. Interdisciplinary ways of working truly integrate ways of working and solutions at each step during the process of realising a solution. Transdisciplinary research involves, beyond the knowledge of professional experts and

..... disciplinary research approaches:  
levels of integration levels Menken & Kestra 2016



**Figure 1.** Levels of integration (Menken and Kestra 2016).

scientists, a layman's knowledge to come to new innovative solutions. It is often characterised by complex stakeholder involvement. In [Figure 1](#), we find a visual explanation of this Integration continuum (Menken and Keestra 2016). Boix Mansilla, Miller, and Gardner (2000, 219) further define the integrated understanding as;

The capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement – such as explaining a phenomenon, solving a problem, or creating a product – in ways that would have been impossible or unlikely through single disciplinary means. (Spelt et al. 2009)

Therefore, a pre-condition is the nature of the problem, that is, being addressed in education and this becomes the vehicle for organising education.

### ***The interdisciplinary research problem***

The nature of a typical interdisciplinary research problem (Lam, Walker, and Hills 2014), which in academia requires an interdisciplinary research approach, tends to be:

- Problems originating from the real world
- Problems driven by complexity
- Problems (of a more fundamental nature) concerned with new knowledge and solutions beyond or at the edge of traditional disciplines.
- Problems which are in urgent need of a solution not yet known

Menken and Keestra (2016) show that interdisciplinarity happens in the 'what', i.e. in the conceptual framing of what a problem is, giving it meaning beyond one discipline, with new definitions and new words.

Should interdisciplinary education also be approached from an interdisciplinary research problem perspective? Should we design interdisciplinary education around problems that require integration of different disciplinary perspectives, of (un)known (complex) problem areas?

### ***Induction as method for programme design***

Repko and Welch (2005), based at the Interdisciplinary Studies Program for the School of Urban and Public Affairs at the University of Texas at Arlington, devised a nine-step plan for educators to use when designing interdisciplinary learning. These steps involve careful planning of interdisciplinary learning and provide a guideline for the realisation of integration of two or more disciplines in an educational context. It is an inductive method where the elements of a situation are known (in this case the elements of each discipline to be integrated are known). The outcome of the interaction between those elements is also known – a certain format for interdisciplinary education. However, in this method, the pattern of relationships and how to realise a model for interdisciplinary learning, is yet to be discovered.

The hypothesis using the Repko approach is that 'if the elements of the inductive model are used a strong integration of different disciplines has taken place' and interdisciplinarity in the educational programme is realised. Or in normal language 'if different elements from the discipline, such as theory, methodology, problem solving strategies and results are integrated, according to the Repko model, a strong integration has taken place resulting in an interdisciplinary learning programme (and its outcomes)'.

### ***Design abduction as method for programme design***

Kees Dorst (2013) uses a different model based on what he calls 'design abduction', in which only the outcome (interdisciplinary education) is known. To deal with a situation where the elements are unknown and the pattern of relationship is unknown, the design abduction method of framing is

**Table 1.** The Repko model and the Dorst model.

Repko, Szostak, and Buchberger (2013) inductive	Dorst (2013) design abduction
1. <i>DEFINE</i> warrant interdisciplinary education	<i>ARCHEOLOGY (HISTORY)</i> historical investigation of problem
2. <i>PRESENT</i> rationale for interdisciplinary education	<i>PARADOX</i> framing the problem definition
3. <i>IDENTIFY</i> relevant disciplines	<i>CONTEXT</i> identify research context
4. <i>CONDUCT</i> . Literary review	
5. <i>DEVELOP</i> which values/assumptions are being made in each field	<i>FIELD EXPLORATION</i> field review
6. <i>STUDY</i> – Relate it to the problem definition	
7. <i>DIFFERENCE/SIMILARITIES</i> Recognise patterns	<i>THEMES</i> Recognise themes
8. <i>CREATE</i> Develop a Frame for interdisciplinary problems (learning)	<i>FRAMES</i> Develop a Frame for interdisciplinary design problems (learning)
9. <i>COMBINE</i> Integrate frames	
10.	<i>FUTURES</i> Explore possible futures with integrated frame
11.	<i>TRANSFORMATIONS</i> which transformations are realised in practice
12.	<i>INTEGRATION</i> what can we learn from these changes and use in the future

used to realise the desired outcome. When framing interdisciplinary education, we explore an imposed pattern of relationships ‘as if it were true’, and this will lead to the desired outcome and help to design the elements to create a solution, which are based on that pattern. For example, Dorst used framing to create a model of integration between academic design and experimental research. Note that this latter model seems to be similar to the approach Mazur proposed for modern engineering education. The problem definition in a design abduction approach should emerge from the framing activity. The outcome of learning therefore cannot be predetermined, but is realised both at the programme/course design level and the students’ learning in a programme. The hypothesis is that the level of integration, in courses where the design abduction approach is used, depends on the adequate framing of the problem by the students and the adequate facilitation of the students by the teacher to realise this objective (Table 1).

Two models with STEPS to take for the creation of interdisciplinary education/design assignments from the models of Dorst and Repko.

## Case studies

Based on the characteristics of interdisciplinary research, we have identified two learning situations at our Technical University at programme level. They can be described as interdisciplinary education for Clinical Technology and transdisciplinary education for Urbanism. The cases have been identified in a scientific engineering field and a design engineering field for maximum diversity. After the description in the paragraphs below a summary is included in Table 2, in accordance with the 3TU Framework for the analysis of Interdisciplinary learning.

The reasons why each programme is as it is, is rooted in the problem definitions, the constructive alignment and the manner of integration of different disciplinary knowledge areas. We will argue that; the educational methods are aligned with the way each programme positions itself with respect to (1) the problem, (2) the level of integration (3) the design of the study programme via inductive or abductive approach.

In this study, we AIM to explore the level and nature of integration and the choice of problem definitions as guiding principles for the design and execution of a constructive alignment interdisciplinary/transdisciplinary education. Finally, we hypothesise that the design of the programme is guided by the dominant research approach (inductive vs design abductive) in the disciplines and consequently leads to different educational programmes.

It should be noted that both programmes are not necessarily focused on the participation of students with different disciplinary backgrounds. The focus is rather at programme level and aims to realise interdisciplinary learning outcomes for the purpose of being able to do one’s job in the future.

**Table 2.** Comparison Matrix according to the 3TU Framework.

	Clinical technology	Urbanism
	Bachelor Programme Multi to Interdisciplinary	Master Programme Inter to Transdisciplinary
<i>Coordination process</i>		
Curriculum	Thematically organised with integrative assignment	R&D studio with multi-actor approach key to analysis and design results
Vision	Foundational knowledge first, integration of knowledge by student's own doing	Students learn to integrate student's knowledge in each step they take
Support	Role models from the field Staff is monodisciplinary	Multi-actor feedback, facilitators used to work transdisciplinary
<i>Primary process</i>		
Goals	Prepare for work field	Prepare for work field
	Learn to empathise and come to Relevant technological solutions. Create a new mono-discipline eventually	Contextual understanding through different disciplines and actors
Blooms' taxonomy	Foundational level knowledge acquisition to application	Higher order thinking skills, application, integration and synthesis
Process	More Linear, analytic	Iterative
Assessment	Classical assessment from Contributing disciplines. Converging to technological optimisation in context	Multi-actor assessment and feedback, no right answers
Teacher skills	UTQ qualified	Preferably all skilled in facilitating and guiding multi-actor research, open personality, societal engagement
Student skills	Thorough foundational knowledge and the ability to apply this in new knowledge area's	Open, strong personality, self-awareness, communicative skills, agile learning new things, context leadership and facilitation skills

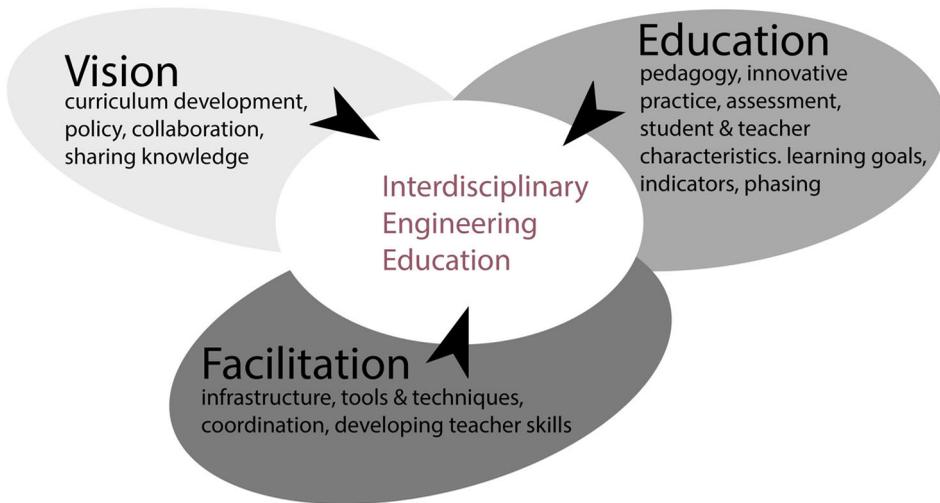
### Data analysis

The method used a cross-sectional case study of a primarily qualitative and interpretative nature. Case study design (Yin) is used to investigate the perception of predetermined parameters. A cross-sectional approach is taken by data gathering through interviews and a number of additional documents have been used to triangulate these same parameters.

The interviews were semi-open (audio-recorded and then transcribed) and were realised in accordance with the framework on interdisciplinary learning developed by a consortium of the three Technical Universities (Twente, Eindhoven and Delft) in the Netherlands (Van den Beemt et al. [forthcoming](#); Baalen and Boon 2015).<sup>2</sup> The transcriptions and interpretations for the 3TU Framework have been validated – each interview interpretation has been reviewed by a peer of the other institution. (Note that no interrater reliability coefficient was established as mutual agreement was reached on the interpretation of transcribed data.) The framework and interview questions were established on the basis of a literature review of 90 articles on interdisciplinary learning in engineering education and on the basis of data collection of six cases across the three technical universities in the Netherlands<sup>3</sup> (Figure 2).

The interview questions focused on (1) the participant's interpretation of the curricular approach used and the intention of the interdisciplinarity (vision) (2) the educational pedagogy/activities by which the interdisciplinarity was realised and (3) the facilitation available to realise interdisciplinary education. The documents were used for the contextual description of the cases, equally along the lines of this 3TU framework.

The case study descriptions in this paper are from one university and re-use the results gathered for the 3TU study. On top of the jointly used framework, which primarily focuses on constructive alignment, the same data are re-analysed with the Repko/Dorst framework and the key criteria used in interdisciplinary research integration, problem choice and the (research) approach to the design of education by the author.



**Figure 2.** 3TU – centre for engineering education – framework (Van den Beemt and van de Ven 2016).

The information is not meant to be exhaustive. The study is rather meant to come to some useful insights for the design of interdisciplinary engineering education. A full overview of the number of interviews and documents used can be found in the annex.

## Case descriptions

In the following paragraphs, the 3TU framework (as in the methods section) is used to explore the bachelor programme of Clinical Technology and 2 master courses in Urbanism. The Clinical Technology case has been chosen as it takes a more science and technology type of approach and Urbanism has been chosen as it is a more design-oriented engineering programme. Both deal with complex and real-life issues, which are indicative of interdisciplinary learning.

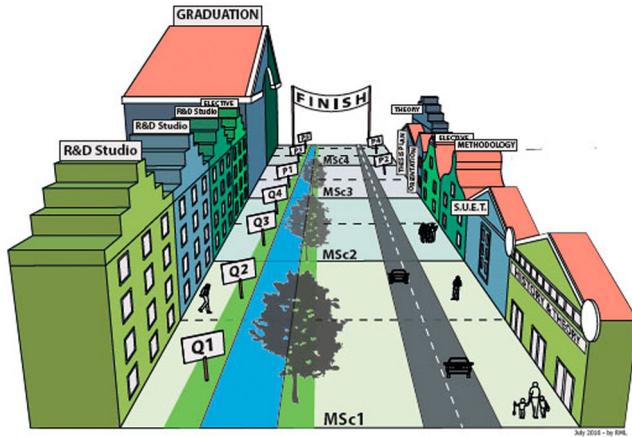
### *Clinical technology*

The Clinical Technology Bachelor programme entails an inter-university bachelor programme,<sup>4</sup> realising the integration of two different fields of disciplinary science, technology and medicine. The clinical technologist will work at the crossroads of these two existing professions. They will need both technological and medical knowledge as well as the medical skills to meet and diagnose patients (in cooperation with a medical specialist) and the ability to design technological solutions for medical problems. On their website, the programme is advertised (2016) as multidisciplinary. However, the original intention when the programme started was for it to be interdisciplinary.

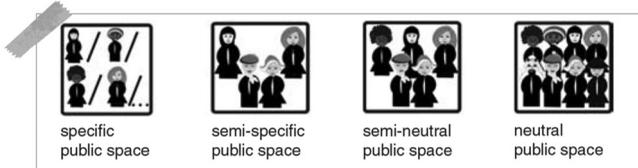
### *Urbanism*

The two-year Master Urbanism is embedded as a masters programme in the Architecture department at the University. Within this programme, the focus is on two research and development (R&D) studio courses in the first and the second quarter of the first academic year. The first quarter R&D studio Q1 is Analysis and Design of Urban Form and the second quarter R&D studio Q2 is Socio-spatial processes in the city (Figure 3).

The studio courses involve legal, political, social-psychological/cultural knowledge of public/non-public space and economic and environmental impact. The master programme Urbanism is, by



**Figure 3.** Yearbook programme overview Urbanism 2015/2016.



**Figure 4.** M.G.A.D.Harteveld (2015), presentation Liveability & Public Space in Happy Cities.

definition, a programme focused on multi-actor/stakeholder engagement and activities with different experts who are involved in the contextual problem definition of spatial design (Figure 4).

These stakeholders and expertise areas such as health professionals, environmental psychologists, but also legal building regulations experts and technologists, are involved in the spatial design. Local non-expert participation is equally key to the creation of an adequate spatial design. This makes urbanism a more transdisciplinary study as defined in terms of the Institute of Interdisciplinary Studies definition (school for interdisciplinary studies at the University of Amsterdam).

**Results constructive alignment**

**Learning outcomes**

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*“framing integration skills and activities in a different way”*

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**Clinical technology**

Aims to realise the learning outcomes by offering a thematic programme consisting of integrated building blocks representing both disciplinary fields, for example, Systems biology and mathematics, the digestive system and thermodynamics. In the first year, students explore the healthy body organs and systems, in the second year the sick body and in the third year the practical application of medical/technological design and research are tackled in on the job training and research projects. During the entire study period, the students also receive academic, clinical and professional skills training. The whole programme requires horizontal and vertical integration from staff and students.

Vertical integration (perspectives and applications) from two disciplinary fields. Horizontal integration in lines of advancement and cohesion in which the clinical technology line specifically contributes to the realisation of a medical/technical research question and results. For the design of classroom materials, a medical and technical coordinator has been appointed. They match and preferably integrate materials from different perspectives. The students are asked to realise an integrative assignment at the end of each module.

Having been taught the disciplinary concepts of the medical field and the technological field, students are supposed to relate important concepts, the meaning for the profession of clinical technology and the applicability thereof. Being able to independently linking across different disciplinary fields helps them to better remember and interpret relevant knowledge and use it in practice. (7)

So it is argued in the 'pedagogical vision' document of the clinical technology bachelor. Clinical Technology Experts (13) are role models demonstrating thought, language and attitude of both disciplinary fields, that they relate to one another. Spending a lot of time with experts, whom have already realised this integrative approach, is key for the integrative learning of both disciplines. (Note that these experts are few, if non-existent, at the education staff level. The first students still have to finish at this institution and hopefully, in the future, will be involved as experts in the programme). The clinical technology programme focuses on problems concerned with new fundamental knowledge and on solutions beyond traditional disciplines to realise answers for real-world issues that can presently be answered due to technological revolutions that have not been available in earlier decades.

The Urbanism studio's<sup>5</sup> learning outcomes focus on:

The urbanism track draws on the Dutch tradition of combining urban design, landscape architecture and spatial planning. Students learn to integrate social, cultural, economic and political perspectives with the natural and technical conditions of the site in order to design and plan for more sustainable development.

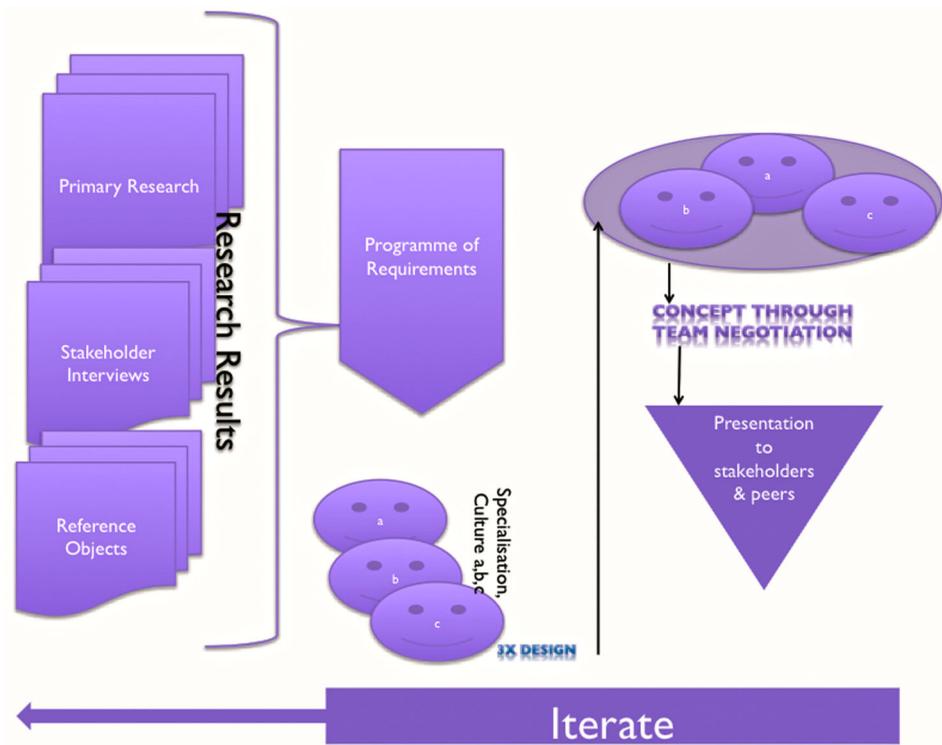
The inter-transdisciplinarity is shaped at different levels of the programme:

Not only the multi-actor setting of the often complex – real life spatial problems are at the heart of the programme, but the student body is equally diverse range from architecture, social geography to designer, policy specialist or anyone who acquires a place at the table and is able to deliver a relevant and serious contribution to the outcome. Additionally, students come from a variety of cultural backgrounds having specific lenses through which they frame the urban design problems. If we generalise in cultural terms; Scandinavians and Chinese are very good at planning and regulating governance issues, whereas Italians tend to be better at architecture. So, each person, discipline, and culture brings different perspectives to the table and creates added value in their own way.

This diversity, in addition to the multi-actor setting, also requires teachers who have experience with research in a multi-actor setting and education and who are able to work in a team of guest-speakers (experts from different fields), clients (community council members), laymen (local participation of inhabitants of a particular urban space), and diverse student and teacher bodies.

Urbanism can be seen as a hybrid discipline in which we continually bring together different specialisms (ideally across engineering faculties and involving humanoria), developing a joint new language to create and voice new insights, thus creating new disciplines with each new integrated problem solution.

A pre-condition for operating in this arena is to be open to other disciplines, perspectives and people, to have a strong sense of self (know your strengths and weaknesses) and self-awareness as a tool, to be able to function in a constructive and professional way. Personal development is therefore a core element embedded in the educational activities. Other student skills pertain to communicative, facilitating and leadership competences needed to shape the collaborative work that must be realised. Broad societal interests, creative skills, being able to quickly acquire enough knowledge of new fields to make relevant use of the information, and curiosity to discover and explore are much-needed skills to make working together a success (courtesy Maurice Hartevelde/Marco Lub; interview results) (Figure 5).



**Figure 5.** Designed from the interview results of Marco Lub.

Each urban design studio process can be characterised as an iteration of (1) the primary research process in which different disciplinary fields are studied, (2) the use of reference objects to create a common frame of reference in a team and (3) conducting stakeholder interviews to explore the context and information needed to come to a result. This integrated information, results in (4) a programme of requirements and wishes. Successively, (5) each individual team member with different cultural and educational background, thinks of possible concepts (this is the solution space) and first presents it to the sub-team. (6) The team renegotiates what the integrated concept should be. (7) The team chooses a final concept, (8) seeks stakeholder feedback and reiterates as many times as needed or possible within a given time constraint. (The deliverable can be an individual result or a team result and is presented to stakeholders at the end of the course) (courtesy M. Lub).

### ***Teaching methods and assessment***

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*"foundational versus explorative learning"*

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### ***Clinical technology***

The teaching methods are aligned to the learning goals and assessed on the basis of clinical technological competencies according to the Pedagogical Vision document of the Clinical Technology programme. Teaching methods consist of activating lectures with theoretical knowledge and embedded

case studies, practicals (labwork) to acquire medical and technical skills, patient–practitioners role-play and diagnostic investigation.

Assessment formats predominantly are tests for lectures-based modules, pass/fail assignments for lab work and possibly an integrative assignment. In the university programme of clinical technology, specialists provide part of the training, each course has two coordinators of each discipline whom it is assumed will match study material to the course programme. Test matrices based on the aspired competencies, to validly and reliably test the learning outcomes guide the test design. The assessment is graded via the 8\_eye principle for multidisciplinary content, i.e. each test question is checked by a colleague, with two colleagues from each discipline, thus meaning one needs 8 eyes for quality assurance. Assessment used in the skills-lab/technical labs are based on pass or fail grades as the feedback on learning is felt to be more essential in these situations. In the most optimal situation, students are asked to realise an integrative assignment at the end of each module, which is graded separately by each respective disciplinary specialist.

The assumption that students will independently be able to integrate information from different disciplinary sources seem fallacious as in previous research it is demonstrated that this does not necessarily or automatically happens (Beers 2005). Or even worse, at the intersection of two (disciplinary) worlds each may attempt to impose their perspective on the other, by coercion or by convincing the other or by silencing and marginalising the other (Star and Griesemer 1989). This may result in social sub-worlds in which students belong more to one or more to the other.

A very serious attempt is made in which students in the journal clubs integrate the two disciplinary knowledge sets, to build integrated frameworks of clinical technology solutions. This method of working has to evolve over time as we are still in the early phases of the existence of the programme. (Alons)

Teaching staff should minimally be aware of the differences between disciplinary/interdisciplinarity and as Richter and Paretto (2009, 40) point out:

faculty need to create specific interventions for interdisciplinary classrooms and contexts to assist students in overcoming barriers of disciplinary egocentrism.

Starting as early as possible for lifelong learning seems to be one of the keys to successful interdisciplinary education and work. Once ingrained in a certain discipline it will be hard to lower the disciplinary egocentrism. Questioning students specifically on how their discipline might contribute to solving the problem and which theories or modes can support that claim may help students gain insight into the strength/weaknesses of the disciplinary background and gain the self-awareness to come up with better results (Wachter 2012).

### **Urbanism**

The more integrative and transdisciplinary approach to the acquisition of design and planning of spatial area's and space in general is aligned with the teaching methods is described below. In both studio Q1 and studio Q2 a real-life case study is tackled. In Q1 this is realised in a team and in Q2 on an individual basis (Figure 6).

In both cases, the deliverables are presentations, posters, models and a booklet containing a diagnosis of the studied space and a vision showing the long-term development. These are shown, discussed with feedback and assessed by all the stakeholders to thus determine the final grade. Note that we talk about visualised materials such as drawings and; or maps with appropriate explanation. These include an explanation as how different disciplinary knowledge is integrated to realise a qualitative 'good' design matching the identified problem. The assessment thus more or less realises a 'design crit'. A design crit is a situation in which the quality of the work is assessed by peers and professionals (academic or other, according to particular criteria valid in the field).

<p>Q1. In this project three different medium sized Dutch towns are selected, as cases and each student will choose one of them. In the analysis and in the construction of the vision, the student will make drawings, sketches, collages and models. The student learns to structure the relation between analysis, diagnosis, vision and interventions, and to use different methods to relate multiple scales and layers. The studio tutor, the co-students and the representatives of the different towns give feedback on the work and progress.</p>	<p>Q2. This studio works from a presumed reciprocal relation between empirical and experimental methods. It gathers data in an empirical way by means of observations in reality, while design strategies and proposals have to be considered as theoretical propositions to be evaluated. Analyses of the design case are made to define the design strategy. Through designing and describing, your vision is translated into concepts conditioning socio-spatial change, and allowing continuity. The experiments are elaborated into detailed and materialised urban designs. The experiments are elaborated into detailed and materialised urban designs</p>
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Figure 6. Yearbook Urbanism programme 2015/2016.

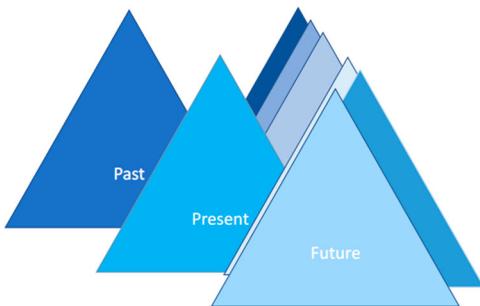
## Results analysis

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*“Problem definitions guide the process of integrating knowledge”*

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The three analysis indicators we discussed, in the beginning, were integration, problem definition and method of programme creation.



If we reverse engineer or analyse the two cases against the inductive method of Repko for curriculum design and the design abductive method of Dorst, we find a rationale for programme design and a difference in the level of integration and of the choice for problem definition. Each number can be considered a level of analysis. Bringing us from the present to a realised past and allowing us to predict possible future patterns (Table 3).

**Table 3.** Clinical technology/Urbanism; frameworks Repko – Dorst.

Repko (2007) and Repko, Szostak, and Buchberger (2013) inductive		Clinical technology	Urbanism	Dorst (2013) design abduction
1.	<i>DEFINE</i> warrant interdisciplinary education	The reason to warrant interdisciplinary education is that patient care can be improved by using new technologies in a responsible way	The reason here to warrant interdisciplinary education is that one cannot solve spatial problems without becoming fully aware of the entire (historical) context of a particular space and the multi-actor interests taking place in that space	<i>ARCHEOLOGY (HISTORY)</i> historical investigation of problem
2.	<i>PRESENT</i> rationale for interdisciplinary education	Yet one cannot design technological solutions without having relevant foundational knowledge of the biological systems of humans and their needs in terms of treating disease and the technological options to do so	The rationale for interdisciplinary learning is that problem definitions tend to be in a real-life environment and of a complex nature. The elements or variables of the situation are unknown. The very questions need to be explored and defined	<i>PARADOX</i> framing the problem definition
3.	<i>IDENTIFY</i> relevant disciplines	'the problems' are at the boundaries of disciplines. This knowledge is not available at our own institution, but at present needs to be jointly developed with different bio-medical disciplines	Depending on the problem space, governance, law, psychology, health or any other discipline is involved to tackle the identified spatial problem. The relevance of the input is determined by the proposed output	<i>CONTEXT</i> identify research context
4.	<i>CONDUCT</i> Literary review	The disciplines that can be identified for integration are medical biology and technical systems knowledge (material science).		
5.	<i>DEVELOP</i> which values/ assumptions are being made in each field	To make the relevant literature accessible, specialists from each field are flown in to teach the relevant theories, methods of research and design within their disciplinary field to students. The teachers share their disciplinary values and assumptions.	Interdisciplinary teachers are appointed and specialists flown in to share expertise, facilitate and coach students. Values and assumptions emerge from the 'third space', which are tested in the field. In the confrontation of different perspectives a learning space is found by students to create new theories, outcomes and design solutions	<i>FIELD EXPLORATION</i> field review
6.	<i>STUDY-</i> Relate it to the problem definition	Students relate the fundamental disciplinary knowledge to problem definitions given to them	Students define their own problem within the constrictions of the given case (spatial area)	
7.	<i>DIFFERENCES/SIMILARITIES</i>	Students identify patterns of differences and similarities and they construct new patterns or solutions	Successively, students create an integrated framework for solving their problem, under the guidance of teachers with interdisciplinary expertise	<i>THEMES</i> create patterns
8.	<i>CREATE</i> Develop a framework for interdisciplinary problems (learning)	A framework for integration is not yet available and integration is not fully realised yet at this moment	Students integrate all the relevant knowledge into a framework. This will help them to come up with a relevant design for the problem they have defined. Students are assessed on their ability to realise the result	<i>FRAMES</i> Develop a framework for interdisciplinary design problems (learning)
9.	<i>COMBINE</i> Integrate frame	Stimulated through integrative assignments, not realised yet		
10.			During the assessment, possible futures are presented with integrated frames. These are judged by experts and stakeholders and determine the relevance of the integrated framework and its solutions	<i>FUTURES</i> Explore possible futures with integrated frame
11.		XX	XX	<i>TRANSFORMATIONS</i> which transformations are realised in practice
12.		XX	XX	<i>INTEGRATION</i> what can we learn from these changes and might we use them in the future

## Comparison matrix

### Challenges

Challenges in *Clinical technology* has realised Step 1–7 in the model of Repko for curriculum set up. The steps are recognisable in the pedagogical vision document and in the programme set up. Step 8 ‘Create’ and Step 9 ‘Integrate’ have not yet been realised in the educational context. As the educational coordinator Allons states in an interview:

matching the language of both disciplines is a continuous point of attention, we are still in the starting phase of multidisciplinary integration. One could say that once we have realised the integration Clinical Technology will become a new mono-discipline again as it has realised a full integration of both domains and is able to build on a new disciplinary domain with its own register, cases and profession. For that purpose, a real professional association of clinical technologists is being founded. Once our students have worked in the field and contribute as experts to our education programme this newly integrated and then a new mono-disciplinary approach will have been realised. For now, we use continuous informal evaluation moments with students and teacher to optimally integrate and guard the quality of the educational programme.

Additionally, one should not forget that on top of the disciplinary education we also work across institutional cultures of the consortium in which the programme is embedded.<sup>6</sup>

Challenges in the *Urbanism* education programme seem to be primarily in the logistics and in the guidance for effective cooperation of interdisciplinary teams in the creation of design solutions, which are grounded in different scientific disciplines. Urbanism follows the framing approach of Dorst in which patterns will help define the elements that are designed by students for a desired outcome. Students learn to define a problem, facilitate stakeholder involvement and determine their path towards an acceptable result. The teacher is there to guide them through the process of integration. A final obstacle is linking the design results back to a theoretical model of interdisciplinary input, to derive new generic knowledge/identify innovations/and novel scenario's. According to Dorst (2013), this last step is often omitted in educational design programmes (Figure 7).

In the light of this discussion, we might argue that too little focus on the integrated model has occurred in the case of clinical technology at the educational level. In the case of Urbanism, too little emphasis is placed on scientific rigour and looping back to scientific knowledge development, where a presentation of solution scenarios of a design is the final assessment point.

The crucial part in design education seems to be in the final steps, with the creation of an integrated framework involving more than one discipline for renewed understanding of a problem, which is then tested in practice, and learned from for future similar problems. Dorst (2013) has described this process in an elegant model for academic design education.

- *A problem is defined.*
- *The creation of an integrated model is realised based on thorough exploration of scientific knowledge in different disciplinary fields.*
- *Design and/or experimental interventions are implemented and reflected upon on the basis of the integrated model in an iterative way.*
- *Successively, a reflection on the traditional theory takes place in different disciplines and newly developed theory.*

This iteration of process of research integration into a model, designing interventions, testing the model and reflecting upon the results, generates new academic knowledge, new scenarios and innovations. (Dorst, 2013)

**Figure 7.** Dorst (2013).

## Discussion of future patterns

A number of interesting phenomena can be observed (Table 4), relevant for inter/transdisciplinary learning in higher education in the cases discussed, that might be applicable to other educational programmes. There seem to be different kinds of disciplinarity. In higher education, we see the merger of different existing disciplines to become a new specialism drawing on both, moving from mono- to multi- to inter- and back to monodisciplinary studies with their own newly formed foundational theory, methods and approaches. These tend to focus on problems at the boundary of one discipline, which does not have an answer and another one that does. This seems to be a typical example of the way new engineering disciplines have emerged in the last few decades (Ramachandran 2010). The knowledge creation is foundational and breeds new specialists needed in a particular era and area. The educational model closely follows the traditional models, which follow monodisciplinarity and with success. The way such a programme is built is an inductive approach to science, in which integration to realise interdisciplinarity is a top-down activity.

Contrary to this approach are the fields which deal with complex, real-world problems that cannot be solved without multiple stakeholder involvement and thus will in general need an inter- or transdisciplinary approach like the one used in the Urbanism case. Students are challenged to create 'products/services, etc.', by identifying patterns and realising a problem definition that fits the desired outcome of the many parties involved.

The latter approach may be under-valued, as it requires a different mind and a partly different skills set.

- Students in the first set will need deep fundamental knowledge to solve the complex engineering problems, to be open to different sources of disciplinary information, to be respectful and to have cooperative skills. Analytical skills will most likely be emphasised here. Finally, professional skills apt for a particular context will be needed most.
- Students in the second set will need openness, self-awareness, personal development, to be able to deal with uncertainty, facilitation and leadership skills and the ability to synthesise large amounts of information into a coherent and relevant engineering solution. Although foundational skills are of importance, knowledge evolves at a quicker pace and may not need to be as fundamental as in the first situation (Table 4).

Thus, higher education institutions do need to question themselves about what type of disciplinarity fits the contextual situation and is the most beneficial for the students and the profiling of an institution. Key questions to be asked are listed in the box (Figure 8).

Its point of departure for the design of education, are the (research) questions that need to be asked, reframed either for fundamental science or for grand engineering challenges requiring issues and actions. These questions and actions should guide which (learning) methods and processes need to be used to help students deal with unknown solutions and possibly unknown problems. The questions go beyond disciplines as we know them and ask varying levels of integration in conceptual understanding of the questions addressed. Students need not only to learn fundamental engineering principles irrespective of engineering sector but they also need to learn life-centred product design skills, problem-solving skills, economic skills, autonomous learning etc. (Ramachandran 2010). Possibly, a key skill may be knowing the process of going from being a disciplinary outsider to becoming a disciplinary insider (Eriksson et al. 2014), such that the mutual understanding of crossing different disciplinary fields is more effective and results in understanding and problem-solving for interdisciplinary learning.

**Table 4.** Emerging patterns of interdisciplinary to transdisciplinary learning.

Outcome	Multi to interdisciplinary education	Inter to transdisciplinary education
Drivers in education	Bringing fundamental knowledge together for technological innovation Focus on product results	Complex, real-world problems with multiple (innovative) solutions Focus on process
Programme integration features	Themes/issues presented	Open complex environment with multiple questions emerging from students
<i>HOW (Methods)</i>		
Theory	Lectures (lit. study)	Field Research (lit study) Guest lectures
Approaches	Case Study/practice in context	Research: exploration of patterns to frame definition and design solutions
Knowledge	Foundational	Just in time learning relevant theory/experts etc.
Learned skills	Professional skills Application of knowledge in context	Research skills Facilitation skills Interview skills Openness
Assignments	Determined by teachers	Determined by students and teachers
Assessment	Evaluation by experts	Evaluation by staff and multiple stakeholders
Integration is realised at	At programme level and at the level of the student	At programme, teacher and student level
<i>WHAT</i>		
Problem definition	Meeting at the edge of disciplines for a clear purpose	Complex/real life
Approach	Problem is determined by patient diagnosis and availability of technological solutions	Problem is not predetermined as it is the process that determines the learning outcome
Inquiry process	Induction	Design abduction, for problems that cannot be solved by deduction/induction
Solutions	Based on foundational knowledge available; implementation of technical product to help patient (limited amount of possibilities)	Needs to be created by interaction with multiple stakeholders/environment. Unlimited amount of solutions
<i>WHOM</i>		
Teachers	Disciplinary experts used for teaching	Teachers disciplinary and interdisciplinary expertise, experienced facilitators
Sources	Disciplinary experts/foundational sources	Multiple disciplines, stakeholders (experts-laymen), contextual information

- What is the type of problem that is addressed?
- Which type of research/educational questions belong to that problem?
- What type of research approach is used? Inductive vs design abduction?
- What type of solutions are generated?
- What type of outcomes are driving the learning process? (and at what level?)
- What integrative features are used in the programme design?
- What types of activities are used to realise the integrative features and at what levels?
- What type of activities allow skills/knowledge development in the best possible way?
- What type of staffing is needed for this particular context?

**Figure 8.** Key questions to be asked.

## Conclusion

In conclusion, we might say that the design of multi- to transdisciplinary learning is based on the chosen problem. The problem then is central to the learning outcomes, which in turn takes care of the level of integration and the constructive alignment of a programme. The insights generated along the lines of the Repko/Dorst models may help to further test and solidify a model and/or an approach towards interdisciplinary educational design. Yet, this model, in itself, needs to be tested further and explored in terms of its robustness to chart uncovered grounds.

## Notes

1. <https://serc.carleton.edu/econ/interdisciplinary/why.html>.
2. Since June 2016 Wageningen University has joined the 3TU federation, now 4TU Federation. The framework was, however, devised in 3TU context. [www.4tu-cee.nl](http://www.4tu-cee.nl).
3. The article with the literature review and case-studies are forth-coming.
4. It concerns a cooperation between Delft University of Technology, Leiden University and Erasmus University in Rotterdam.
5. Design based education in architectural – Studio's. Historical description [http://www.edi.msstate.edu/work/pdf/history\\_studio\\_based\\_learning.pdf](http://www.edi.msstate.edu/work/pdf/history_studio_based_learning.pdf).
6. Read Delft University of Technology, Erasmus University Rotterdam, Leiden University.

## Acknowledgements

This article could not have been written without the interview contributions of P. Alons, M. Lub and M. Hartelveld. The feedback from J.van de Veen, A. Kamp en P. den Brok and the proof reading of J. Chadwick. A special thanks to all of you.

## Disclosure statement

No potential conflict of interest was reported by the author.

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## Internal documents

- Visions on education bachelor programme for clinical technology, (date not available) written by collaborating universities, TU-Delft, Department of Mechanical Engineering, Leiden University, Medical Department LUMC, Erasmus University Rotterdam, Department EMC. Document only available in Dutch
- Yearbook, MSc Urbanism Program 2016–2017, Department of Urbanism Faculty of
- Architecture
- Study-guide 2015–2016, master programme 2015–2016, Department of Urbanism Faculty of Architecture

## Interviews

Professor Maurice Harteveld interviewed in 2015  
 Track Coordinator; Marco Lub interviewed in 2015  
 Programme coordinator: Pelle Allons interviewed in 2015  
 Assessment expert; Clinical Technology