Design Products in European Studies & Planning Design Process in Eindhoven University of Technology (TU/e)

CHAPTER 3

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3.1. Introduction

In some European countries, "science education begins as an integrated subject area that is intended to foster children's curiosity about their environment, providing them with basic knowledge about the world and giving them the tools with which they can investigate further" to increase students' motivation to study science (European Commission, 2011, p. 60). For example, in primary and lower secondary education science classes, teaching is often organized into broad integrated themes, "Living things respond to the environment" (Belgium -German-speaking Community), "Diversity of living beings" (Spain) or "Life and living beings" (Turkey) (Science Education in Europe: National Policies, Practices, and Research, 2011, p. 60).

According to the Framework for K-12 Science Education (NRC, 2012), a vision of what science and engineering learning should look like at the K-12 level was presented as the integration of three dimensions of scientific knowledge: science and engineering practices, disciplinary core ideas, and crosscutting concepts. However, making connections or coherence between disciplines is often not easy for teachers in practice, especially when teachers are educated as subject teachers in the teacher education programs instead of teaching subjects in an integrative way. To bridge and connect three dimensions of scientific knowledge with pedagogy, Delen et al. (2020) proposed a new pedagogical framework for pre-service teachers, called Design-based Pedagogical Content Knowledge (DPCK). "The DPCK places design products at the center of the learning environments as a way to connect PCK and teacher practices in an integrated way" (Delen et al., 2020, p. 4). In the context of the DPCK, the design products not only refer to the final outcomes of the design process (often defined in Engineering Education) but also refer to the creation of the learning environment around the design products that enables interdisciplinary learning. By creating design products, students can deepen interdisciplinary knowledge, enhance a sense of ownership and efficacy, and demonstrate explicitly what they have learned through the whole design process (Fortus & Krajicik, 2015; Krajcik & Delen, 2017). For example, there is a craft course on "smart textiles" in Finland's pre-service primary teacher education program. The craft course is designed to familiarize student teachers with many aspects of crafts (textile, design, and technology), inquirybased design, and an interdisciplinary teaching style that may be employed in a primary school setting (Karppinen et al., 2019). Students working in teams need to integrate crafts, physics, drama, and ICT (information communication technology) to complete the design task. A headgear with Bluetooth earphones, a child's belt with a signal to move after a lengthy period of immobility and a sports shirt with a heart-rate monitor were among the designs made by students. "By completing such an interdisciplinary design task, student teachers developed a new way to think and organize interdisciplinary teaching, positively changed their attitudes towards interdisciplinary teaching; and discovered new ideas and found the courage to implement the teaching of cross-over disciplines" (Karppinen et al., 2019, p.69). In the literature search, we looked at how design challenges and products have been used in the educational field, based on the importance of engineering design as a way to integrate STEM for K-12 and pre-service teachers.

3.2. Methods: Searching Design Products in European Studies

We searched Web of Science for the keywords "design challenge OR design product OR design problem," refined by Educational Research or educational, scientific disciplines, and refined by selecting European countries, yielding 34 articles. Unfortunately, two full-texts of these thirty-four articles could not be found. One study was conducted in South Africa, and another study was conducted in Saudi Arabia, so it was decided to remove these two articles from our list because we mainly focus on studies conducted in European countries. In total, our review database included 30 full-texts of articles. These 30 articles have been reviewed by researchers from the Technology University of Eindhoven (TU/e), the Netherlands, and Usak University, Turkey together. While reading the full texts of the articles, we particularly extracted five important data sources in an Excel table, including "country, participant group, design challenge, design product, and design process". The report of the review results was divided into two sections: the first section of the design challenge was presented by Dokuz Eylul University in Chapter 2, and the second section of the literature review emphasized the design products is presented by TU/e.

3.3. Findings: Examples from European Literature

In our search (N = 30), there were 26 design products presented in these original articles. To provide an overview of what these 26 design products look like, we categorized them into six types of design products based on the final appearance of the design products. These six types of design products consist of design report, physical artifact, model building, schematic design, digital design, and a final category called "other", which means we could not combine them into the other five types of design products. Table 3.1 presents an overview of the design products from the reviewed articles.

Table 3.1. An Overview of Design Products (DP) From the Review Articles

Type of Design Products (DP)	Names of DP From Articles	Time to Complete DP	Interdisciplinarity	Study Area/Course	Study
Design report (N=8)	A conceptual design report	8 weeks	Yes (Engineering students from different fields)	Engineering	Esparragoza et al. (2015)
	An array of straight rectangular fins of the uniform cross-section for the rectifier diode heat dissipation. (Team report)	7 weeks	No	Electronic Engineering	Montero & Gonzalez (2009)
	An alternative sequencing method	Not mentioned	Not mentioned	E-learning	Karampiperis & Sampson (2005)
	A performance design report	14 weeks	No	Architecture	Özkan Yazgan & Akalın (2019)
	Conceptual design: A hydraulic front brake handle for motorcycles	One semester	Yes (Different subjects that belong to different areas of knowledge are involved)	Industrial Engineering	Santolaya et al. (2018)
	Windfall collector design report	45 minutes	No	Engineering	Winkelmann & Hacker (2011)
	A report analyzing high drop-out rate problems in distance education centers and developing an	9 weeks	No	Instructional design	Sancar-Tokmak & Dogusoy (2020)

	instructional model including possible solutions.				
	Design of child play areas	75 minutes	No	Architecture	De Vries & De Jong (1999)
Physical artifact (N=1)	Clothing for prematurely born babies	15 weeks	No	Textile Science	Seitamaa-Hakkarainen et al. (2001)
Model building (N=5)	A pasta bridge	Not mentioned	Not mentioned	Engineering	Rueda & Gilchrist (2011)
	Scale models at 1/20th the size of seating units	6 weeks	No	Architecture	Duzenli et al. (2017)
	Constructing a simulation environment to test the model without the system	Not mentioned	Not mentioned	Mechanical Engineering & Electrical Engineering	Puente et al. (2014)
	Schematic diagrams, sketches, and physical models (design projects) of Landscape architects design the environment (Ali Özbilen Residence)	16 weeks	No	Landscape architecture	Alpak et al. (2018)
	Assembling a set of spaces coded with letters according to a set of rules; assembling a house where the spaces were now named after rooms in a typical home	Not mentioned	Not mentioned	Architecture	Erkan Yazici (2013)

Schematic design (N=6)	Airport runway design	9 hours	No	Civil Engineering	Pasandín & Pérez (2020)
	Layouts for a functional kitchen located in a campervan	8 weeks	No	Engineering	Bourgeois-Bougrine et al. (2017)
	Water distribution network design	Not mentioned	Not mentioned	Environmental Engineering	Demir et al. (2017)
	Manual sketch of a barbecue grill	Not limited in hours and 2 hours on average	Not mentioned	Engineering	Winkelmann & Hacker (2010)
	Sketch design of orange squeezer by hands	1 hour	No	Engineering	Carmona Marques (2017)
	An adjustable wheel mount for wind tunnel	3 weeks	No	Engineering	Hill et al. (1998)
Digital design (N=5)	A digital game design	8 lessons (8x40 minutes)	Yes (Science, Technology, Engineering, & Mathematics)	K-12	Hacıoğlu & Dönmez Usta (2020)
	An online tool that could support the co-construction of community knowledge about learning design.	Not mentioned	No	K-12	Laurillard et al. (2018)
	A "stand-alone" website; a game on a well-known smartphone or tablet target platform; anything from wearable or mobile	5 weeks	No	Design-oriented undergraduate Informatics program	Wärnestål (2016)

	health monitor technology, a social media website designed to improve social and mental health, to novel IT enhancements for medical professionals; a complex ecosystem of services, possibly on several platforms, with effects that need to be strategic and long-term.				
	Two online CSCL tools: the fourth version of the Future Learning Environment (Fle4), a web-based software program for collaborative knowledge building; Square1, a collection of learning devices designed for collaborative learning at school	Not mentioned	Not mentioned	K-12	Leinonen & Gazulla (2014)
	Electronic portfolio	Not mentioned	Not mentioned	Teacher education	Spendlove & Hopper (2006)
Other (N=1)	Math problem (slope of curve) solution	23 to 50 minutes	No	K-12	Bos et al. (2020)

A visual representation of the design products is given below (Figure 3.1).

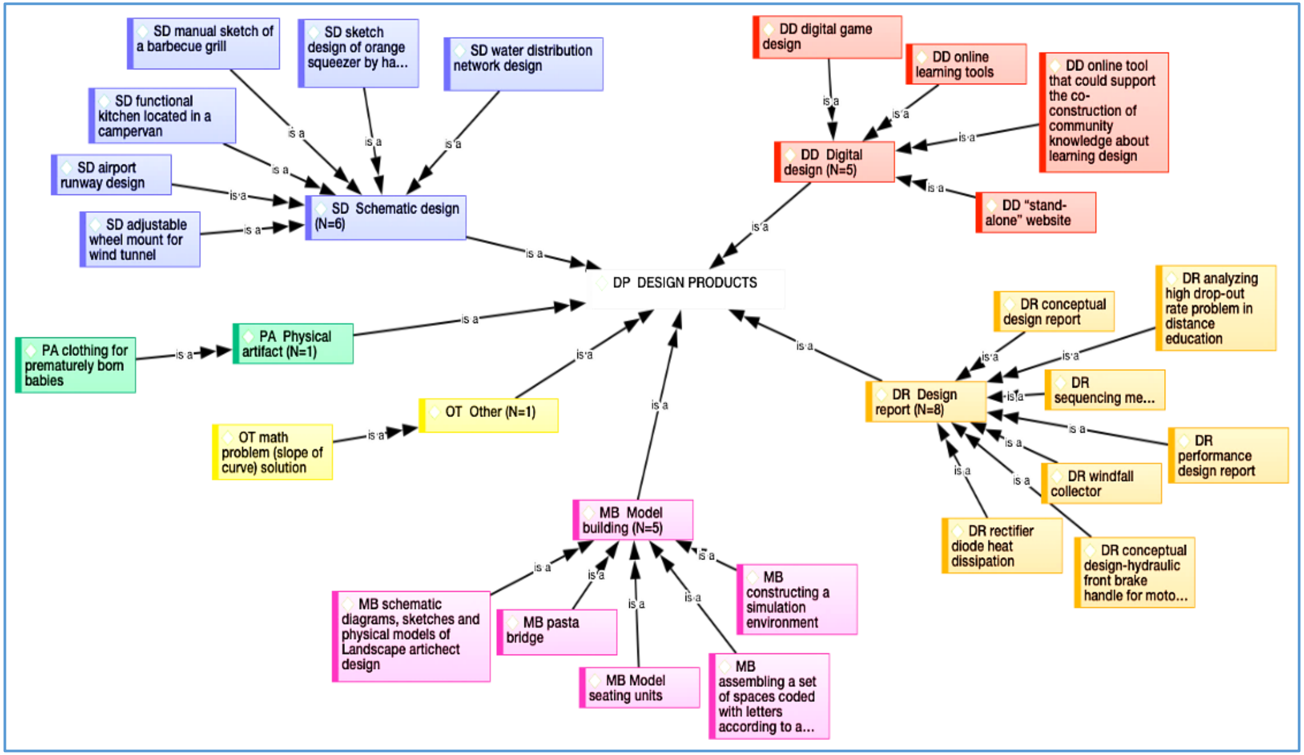

Figure 3.1. Visual Representation of the Design Products

In the following section, examples from original studies are used to illustrate these six different types of design products.

3.3.1. Type 1 - Design Report

A design report refers to the final presentation of the design products in the form of a written report, such as a design proposal and a solution report. Eight studies were found that represent this type of design product. For example, engineering students from different nationalities work as a team across eight weeks to produce a conceptual design report as a group deliverable (Esparragoza et al., 2015). In the design report, students need to write about developing a machine to produce and pack tropical dried fruits with four requirements in mind: capable of processing one ton per day; low cost of manufacturing, operation, and service; system to be manufactured in Latin America; operation and maintenance to be carried out by a cooperative in Colombia. To complete the conceptual design, students need interdisciplinary thinking and collaboration with customers, designers, and engineers in practice.

Taking another article as an example, Sancar-Tokmak and Dogusoy (2020) mentioned an instructional design activity for instructional technology students. Students were given a 9-week period to analyze the reasons for the high drop-out rate of distance education and, based on the reasons, design a solution using an instructional design model. In the end, five student groups used the Analysis-Design-Development-Implementation-Evaluation (ADDIE) model, while one group used the Attention-Relevance-Confidence-Satisfaction (ARCS) model to define their solutions.

Among eight design reports, only two of them focus on teaching-learning practices. These studies presented 'an alternative sequencing method for e-learning' (Karampiperis & Sampson, 2005) and 'instructional model for distance education to prevent high drop-out rates' (Sancar-Tokmak & Dogusoy, 2020).

3.3.2. Type 2 - Physical Artifact

Physical artifact refers to the final design products that are presented in the form of actual artifacts, which could be directly used in practice. In the reviewed articles, only one research paper was found to represent this type of design product: in a Finnish context (Seitamaa-Hakkarainen et al., 2001), students (working *collaboratively in groups*) were asked to design and produce functionally and aesthetically delightful clothes for prematurely born babies. The students were given 15 weeks to complete the design. The design products were tested in an authentic hospital environment to provide feedback about the functional aspects of the prototypes being designed. At the end of the project, about 200 pieces of clothes were manufactured for the hospital.

3.3.3. Type 3 - Model Building

Model building refers to the final design products that are presented in the form of physical visual models. Different from physical artifact, the models could not directly be used in practice. Five articles were found to represent this type of design product. For example, 30 Turkish landscape architecture students collaborated to create a 1/20th scale physical model of a piece of equipment for a sitting activity. Students were given complete freedom to choose their materials, allowing them to choose the best material for the envisaged form and conduct trials in order to identify the best technique for the material's nature by creating harmony between the material and the form (Alpak et al., 2018).

3.3.4. Type 4 - Schematic Design

Schematic design refers to the final design products are presented in the form of graphic sketches of the products. Six articles were found to represent this type of design product. For example, 27 French engineering students were given an 8-week period to design individually six layouts for a functional kitchen located in a campervan. These students produced a total of 162 layouts of a campervan kitchen. The most creative students came up with different concepts (e.g. remote cooking using smarthpne, ecological kitchen) of kitchen that differ from a classic kitchen to allow new experiences for the user (Bourgeois-Bougrine et al., 2017). Taking another two articles as an example, engineering students were given three weeks to prepare a scheme design of an adjustable wheel mount for a wind tunnel (Hill et al., 1998). Engineering students were given one hour to develop a sketch to produce a device for making orange juice by hand, working as a team (Carmona Marques, 2017).

3.3.5. Type 5 - Digital Design

Digital design means the final design products are presented in a digital form, such as online teaching/learning support tools and digital games. Five articles were found under this type of design product, and three design products were completed in the K-12 education context. For example, 20 Turkish fifth-grade students were asked to use the Scratch program to create a computer game product in 8 lessons (8x40 minutes), with the guidance of the teacher. To be able to create digital games, students need an interdisciplinary perspective of science, technology, engineering, and mathematics (Hacıoğlu & Dönmez Usta, 2020). Besides, a digital design tool (the Learning Designer) has been developed to support teachers in sharing "instructional products" by developing the teacher-as-designer. In this way, teachers' development and representation of learning designs can be shared online and adapted by other teachers (Laurillard et al., 2018). Similarly, Leinonen and Gazulla (2014) described two online learning tools developed to support online collaborative learning. One developed tool is called Fle4 (Future Learning Environment 4), a knowledge-building tool that can be used in conjunction with a blog service. Fle4 gives network views of the dialogue that may be zoomed in and out. This should aid learners in keeping track of the numerous activities in the knowledge-building discourse as well as organizing notes by importance. The other tool is called Square1, a prototype that consists of several learning devices designed for collaborative learning at school. Although there is one article particularly referring to the design products completed in the teacher education context, its main focus is on trainee students' use of "electric portfolios". Spendlove and Hopper (2006) documented those 12 trainee teachers engaged in a reflective and creative process through the use of an "electronic portfolio". The electronic portfolio offered a portable container for their ideas, which enabled them to map their progress more clearly as they went through several filtering stages.

3.3.6. Type 6 - Other Type of Design Products

There is one design product that we could not combine into any of the above types of design products. It is called the "math problem (slope of the curve) solution". 44 groups of three students in sixth grade in 9 or 10 Dutch classrooms were given about 60-90 minutes to work on a math design task, i.e., designing a slide or ski jump with one straight part and one bended part, and at the end, students came up with different solution strategies (Bos et al., 2020).

After summarizing the design products from the literature review, we provided below a summary that presents how these design products are connected. As shown in Figure 3.2, although design products are displayed in different formats, such as sketches and design reports, these different design products can be connected to trigger students' critical thinking and deep learning.

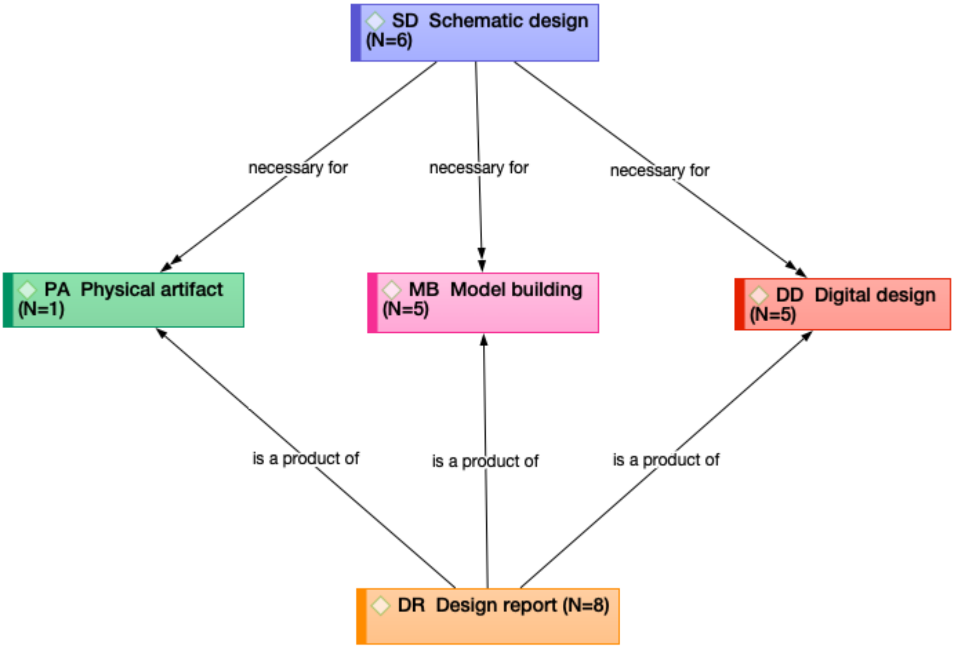

Figure 3.2. Connection of the Design Products

Given that there is a missing role for design challenges and design products in teacher education programs, we offered local examples from our teacher education programs where we used many engineering design elements at the Eindhoven School of Education (ESoE) TU/e. In the following section, we first introduced an interdisciplinary teacher education course called *Designing STEM Education* to align with the critical thinking dimensions, followed by an illustration of two design examples of student teachers from this course. We chose to analyze the local teacher education course with critical thinking dimensions to make a connection with the next chapter, which will be elaborated on in the next chapter. More importantly, one of the rationales behind design challenges and design products is to cultivate students' critical thinking skills.

3.4. An Interdisciplinary Teacher Education Course - "Designing STEM Education"

3.4.1. An Analysis of the Interdisciplinary Teacher Education Course Using Critical Thinking Dimensions[1]

This section provides a brief overview of our master's program in Science Education and Communication at ESoE to help you understand our teacher education program structures. Afterward, you will expect to read our analysis of the interdisciplinary course structures *Designing STEM Education* connected with the critical thinking dimensions from a teacher educator perspective. In this way, we offered a local case of how to integrate critical thinking into the design process from a teacher educator's perspective.

The Master's program in Science Education and Communication prepares science teacher candidates for upper secondary education. This program lasts two years, and it contains five specializations: Physics, Chemistry, Mathematics, Computer Science, and the combination of Nature, Life, and Technology (NLT) with Research & Design. The program is preceded by a subject-specific bachelor's degree in the direction of students' chosen specialization (e.g. physics, chemistry, etc.). Students will then study the pedagogy of the chosen subject (e.g., physics pedagogy), educational science, design STEM education, deepen their subject knowledge, and complete internships in secondary schools (https://www.tue.nl/en/our-university/departments/eindhoven-school-of-education/).

The interdisciplinary course "Designing STEM Education" is an obligatory course for all student teachers within the STEM domain (chemistry, physics, mathematics, computer science, and Research & Design). It consists of two parts. Part one is preparatory to part two, in which students work in multidisciplinary teams on curriculum design projects for schools and other educational contexts. Below, we analyzed the course structure of "Designing STEM Education" connected with the CT dimensions from the perspective of the teacher educator.

The explicit explanations of critical thinking (CT) dimensions can be found in Chapter 4, and here we offer a summary of the CT dimensions to analyze our interdisciplinary course structure. These CT dimensions need more attention when we create a learning environment for implementing design challenges and products in teacher education programs. They include *learning goals*, *CT approach*, *instructional design approach*, *type of task*, *duration*, *multiple perspectives*, *critical voice*, *evidence-based reasoning, and interdisciplinary thinking*, *decision-making*, *meta-reflection on knowledge and CT skills*, *discerning between information and opinions*, *peer negotiation*, *uncertainty*, *students' role*, and *teachers' support*. It is worthy of mentioning that critical thinking is just one of our interdisciplinary course objectives, and those CT dimensions are sometimes integrated implicitly into the course.

Learning Goals & Planning Design

- To recognize the developments in STEM education
- To be able to apply knowledge of design-based pedagogy to an educational design for an external client.

- To be able to explain design choices and perform an evaluation (implicit CT)

Design-Based Pedagogy Approach

Challenge-based learning (CBL): The design requires student teachers to generate a product to solve an educational real-world related problem that is requested by a client (such as schools and non-profit educational organizations). By using CBL, student teachers are expected to be active learners, and they can integrate their STEM subject content knowledge and educational knowledge to design an educational product.

Type of Task

Schools and other educational organizations request authentic and relevant tasks. For example, one of our clients is called Engineers Without Borders (EWB). It is a non-profit organization that aims to promote, teach, and implement sustainable technical solutions in developing countries to enhance the local quality of life. Taking another example, our client can also be a high school who wishes to establish challenge-based group projects for their students.

Duration

The design project is a semester course, and it lasts 20 weeks from kick-off to the final presentation of the design products.

Multiple Perspectives (MP)

Every design project involves multiple parties: A client (often schools and educational organizations or even sometimes companies), student teachers who are the designers, and relevant professionals at universities to offer professional feedback. To be able to design an excellent educational product, student teachers need to communicate and collaborate with different relevant parties.

Besides, student teachers work as a team to design an educational product, and these student teachers come from different subject backgrounds. Thus, each student teacher team also involves diverse perspectives.

Critical Voice (CV)

Our course "Designing STEM Education" creates a learning environment that triggers a critical voice. For example, our project task is designed to involve multiple parties, clients, designers (student teachers), and other relevant professionals. To design a product that satisfies the needs of different parties, student teachers need strong communication skills that trigger critical voices within the student teacher team but also with their clients and professionals.

Besides, to inspire student teachers' critical voices, we offered the Van Den Akker (2003) curriculum spider web (see Figure 3.3) to guide student teachers to critically think about the rationale behind their curriculum or workshop design.

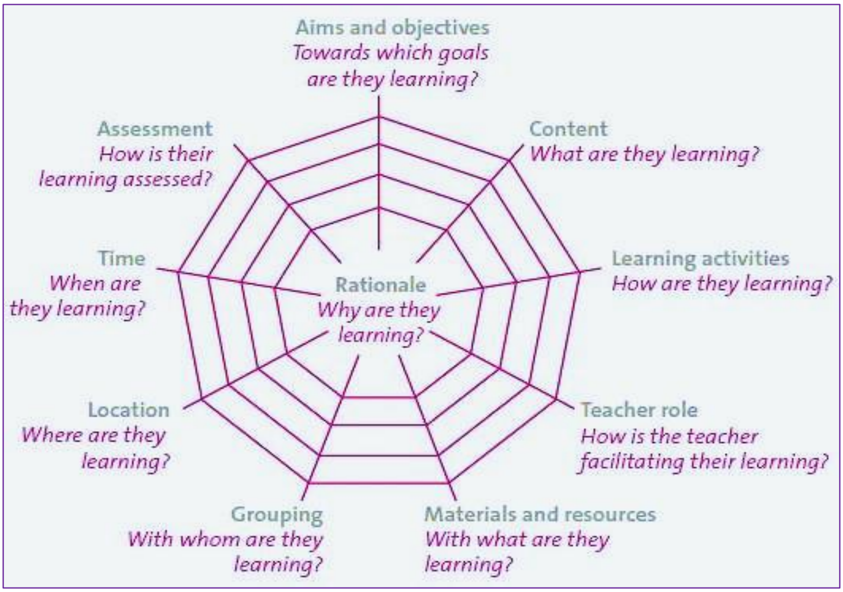

Figure 3.3. Curricular Spider Web (Van den Akker, 2003)

Evidence-Based Reasoning

In this course, *Designing STEM Education*, three core elements are required in the final design report (part of the design product). These three elements are (a) analysis, (b) design choices, (c) evaluation of the design choices. The element of analysis typically includes the analysis of the request of the clients, source materials, target group analysis (who will use these design products), background knowledge of the intended design product, and the rationale behind the design. The results of the analysis provide evidence for the next step in the design process. During the design process, student teachers need to pay specific attention to the rationale, namely the reasoning behind the design choices. In this way, the student teacher team needs to write down their decision-making as well as the reasons that support their decision-making. The final step is the evaluation of the design choices. In this step, student teachers assess their design choices by using four evaluation criteria for their design choices: *relevance*, *consistency*, *usability, and effectiveness,* presented later in this chapter. Using these four dimensions to assess the designed curriculum materials, student teachers can reflect on their design and have some recommendations for their re-design.

Interdisciplinary Thinking

The course, *Designing STEM Education*, is structured in an interdisciplinary way. This course contains two types of interdisciplinary connections.

The composition of the student teacher team is one example of interdisciplinary connection. The student teachers who are enrolled in this course come from various departments, like chemistry, physics, mathematics, and engineering departments. In this course, they work together as an interdisciplinary team on an authentic task that is often requested by the client.

Another way for the student teachers to connect across disciplines is through the design of their products. For example, one of the tasks requested by the client is to design an interdisciplinary project for the school.

Student Teacher Role

Student teachers are active designers who work as a team.

Teacher Role

Teachers are coaches who offer feedback during the design process and assess the final design product.

Assessment Process

The assessment process includes: (a) student teachers' peer assessment of the teamwork collaboration process and (b) the teacher's (coach/teacher of the student team) assessment of the design products.

1. Peer assessment: To support peer assessment, four criteria are offered in the rubric for process assessment:
    - Way of participating in group discussion,
    - Translation of knowledge from lessons/syllabus/literature to project,
    - fulfilling agreements/planning, and
    - Creative input.
2. Teacher/coach assessment: The teacher/coach assesses the final product by using the rubrics to evaluate the design projects. This rubric includes four dimensions (sub-rubrics) that refer to the essential elements required in the final product - design report analysis, design choice description, evaluation, and material & presentation.

3.4.2. An Example of the Guiding Questions for Facilitating Critical Thinking From the Interdisciplinary Course Designing STEM Education

In this course, the guiding questions connected with each design process are offered to facilitate student teachers' critical thinking (see Table 3.2 below). These guiding questions are designed to facilitate student teachers' discussions within their group. The teacher or the coach scaffolds the student teachers' discussion. For example, at the beginning of the design process (from step 1 to 3), the teacher or the coach can respond to the student teachers' discussions to enhance their critical thinking. Starting from the design process step 4, the student teachers need to write down their discussion results together with their evidence in the design report. During the student teacher team collaboration, they can divide the roles, but they are all responsible for the final design report.

Table 3.2. Guiding Questions to Facilitate Student Teachers' Critical Thinking

Design Process		Guiding Questions
1. Selecting a design challenge		• What experience do you already have? • What prior knowledge that is relevant to this challenge do you have? • What is your subject background?
2. Agreements about planning and cooperation	2a. Competences in the team	• What are the competencies that are present in your team? • What is the relevant subject content? • To what extent the team members have teaching experience? • What are the competencies of the team members as a writer? • What are the collaboration competencies of the team members? • What are the planning competencies of the team members?
	2b. Division of duties	• What are the roles and tasks of each member of the team?
	2c. Communication	• How can you reach each other between meetings? • Which moments are suitable for the consultation?
	2d. Documents	Where will you store concept documents?
	2e. Relevant concepts ESCOM mindmap	• Which concepts from the ESCOM mind map from EME31 are relevant to this project? • Who will study these concepts? • When and how outcomes will be shared?
	2f. Planning	Think of: - contact with the client

		- elaboration of relevant mind map concepts - (draft) student/teacher material - feedback on concept material - concept design plan/interim presentation - execution of the test - Evaluation - presentation/design plan
3. Rights of the use of the design product (P.S. It is recommended students to have the products open access unless the client requires otherwise, we warn them to only use images that are permitted.)	3a. Rights	• What are your rights as authors of the design product? • What are the principles for reuse/reproduction? • Do you know about the use licenses that are issued by ESoE?
	3b. Publication in Wikiwijs	• Why publish the design product in Wikiwijs? • Under which license agreement to publish in Wikiwijs? • Are there rights or licenses associated with the images you used?
4. Design plan	4a. Group members	• Who are the team members? • Is this a multidisciplinary team?
	4b. Client	• Who is the client?
	4c. Analysis	*1. Wishes of the client:* • What requirements the does client set for the design, e.g. based on the curricular spider web? *2. Resources:* • Which existing educational materials may be (partly) usable in the educational materials that you are designing, or what can inspire you? *3. Target group analysis:* • What do you know about the target group for whom you will design education?

<table>
<tr><td></td><td></td><td>4. Prior knowledge:
• Which relevant prior competencies (knowledge, skills, and attitude) you expect students to already have, in two parts:
i. From (formal) education
ii. From informal education
Indicate what you base that on.
5. Relation to developments in cross-curricular education:
• How does this project relate to other developments in cross-curricular science education?
• Which relevant concepts from the ESCOM mind map can you refer to?
6. Persons and parties involved in the project:
• Which persons and parties are involved in this project?
• What are the different roles of the involved stakeholders?
• Who is involved in the design, and with whom should there be coordination within or outside the school?
• What are their interests/roles?
7. Involved students:
• Describe the considerations of whether and how to involve students in the project.</td></tr>
<tr><td></td><td>4d. Design choices</td><td>1. Challenges (curriculum issues) that this series of lessons want to focus on:
• What are the challenges that you want to address with your lesson design?
• What are the concepts from this category in the mind map (refer to at least two of the concepts)?</td></tr>
</table>

		2. Learning goals: • What are the learning goals that you want to achieve? • What are the concepts from the mind map? (Refer to at least two concepts from this category in the mind map.) • How will you determine whether the learning objectives have been achieved? • What is the relationship between learning objectives and examination programs or other relevant frameworks? • Which courses are involved? • To what extent is there integration of courses? *3. Strategy for taking the prior knowledge into account:* • How do you intend to include students' mental models on the topics in your lesson series? (Make use of both knowledge from literature and practice.) *4. Taking diversity into account:* • How do you intend to take diversity into account in your lesson series? • How do you plan to consider differences in motivation for science in your lesson series?

		5. Choosing Pedagogy of science approach: a. Pedagogy: • Which pedagogical approach did you choose for your lesson series? (refer to a concept from the mind map.) b. Consequences for structure: • What does the chosen pedagogical approach mean for the structure of the course and its further elaboration? (Make use of the curricular spider web (http://curriculumontwerp.slo.nl/spinnenweb). *6. Deployment of ICT:* • How will you (or not) use ICT within your lesson series? (For example, use the iPAC model; see http://www.mobilelearningtoolkit.com/ipac-framework.html). *7. Activating and motivating students:* • How are learners activated and/or motivated in the education you have designed? *8. Teacher guide:* • What should a teacher know/be able to understand/be able to work with the teaching material if it is not carried out by the designers

3.4.3. Design Examples from Interdisciplinary Teacher Education Course[6]

In this section, we present two local design examples of our student teachers to help you understand how the above design-based course is implemented in a teacher education program. The first design example is from the interdisciplinary course Designing STEM Education, and the second design example is from the course subject-specific pedagogy for Research and Design.

3.4.3.1. Example 1: Design Workshop on Electrotechnics

This example was designed by the student teachers of the teacher education program at ESoE, Stefan Maubach, Hester Wolf, Janna van Rosmalen, Joris Veens, Stef Voermans (Science Education and Communication Master, ESoE) for the Designing STEM Education course.

The client who requested this design product is called EWB. EWB has a project, "Schools of the Future: Mozambique". This project aims to empower teenagers in Mozambique through technical education and entrepreneurship (Schools of the Future—Mozambique, 2019). The goals of this project are to spark interest in science and technology and to give teenagers fundamental knowledge of technical and societal development. The long-term objective is to inspire and facilitate students to undertake a higher education path in a technical area and encourage students to practice the knowledge they have obtained to improve the local community's wellbeing.

The design task is described as creating a new electronics workshop for Mozambican teenagers aged 14 to 16 (high school students), with the workshop being hands-on and accompanied by an explanation and exercises about the theory related to the hands-on part. It is also asked by EWB that the budget per student should be less than 15 euros to keep the project sustainable in the future.

The design process includes four main steps: analysis - design choices - evaluation - design product. In Step 1 - analysis, student teachers have done a thorough analysis of the design task requirements, available source materials, and local education background, including the general education system in Mozambique, the targeted students' schooling situation, as well as the students' daily life and informal education. After these initial comprehensive analyses, student teachers completed their initial workshop design rationale and structure by using the Curriculum Spiderweb (Van Den Akker, 2003).

Rationale: Inspire people to learn about technology and science, tackle community issues, and inspire them to pursue higher education.

[6] Students gave their informed consent for using their design products as examples in this Chapter.

Aims and objectives: The learning objectives will be different for each module in the workshop. The modules can be taught independently from each other, so no prior knowledge of other modules is needed to participate in a module.

Content: The lessons will be focused on electrical technology.

Learning activities include hands-on experiments, theoretical explanations, and exercises in modular workshops. Those designed learning activities align with the didactic approach - authentic education, such as learning from doing.

Students from Eduardo Mondlane University will lead the workshop for high school students. They need to guide the high school students actively throughout the whole workshop since these studies have extremely little prior knowledge.

Materials and resources: The school does not have any materials that can be used in the workshop. So, everything has to be ordered while staying within a price range of 15 euros per student.

Grouping: The students with the highest educational level and motivation for technology are chosen to participate in the workshop. These students will largely be in the age range of 14 to 16 years old, but may be older.

Location: The workshop will be given at the Săo Joaquim high school. No technical equipment can be expected from the school.

Time: The workshop will be divided into different modules, where the modules will vary in length, difficulty, and learning goals.

Assessment: The results of the workshop will not be formally assessed, but the EWB workshop executors will analyze if the learning objectives are achieved. There is a possibility of showing the results at a science fair. For example, the student teachers planned to interview the EWB workshop executors using the question such as "on a scale from 1 to 10, how relevant do you think the workshop is for Mozambican high school students?"

Based on the above thorough analysis results, student teachers continue to make explicit their design choices by integrating interdisciplinary perspectives and knowledge in Step 2.

The summary of the design choices

The challenges that will be tackled in the workshop are "motivation for Beta" and "irrelevance". This will be done by providing a practical workshop and connecting it to real-life problems and situations the students may be familiar with.

The learning objectives of the workshop are 21st-century skills, collaboration, communication, and technological literacy. The students will learn to collaborate since they will be working with other students. Their communication skills will be developed when they present the results of the workshop at the science fair. The students will learn about technology since it will be the focus of the workshop.

The content of the workshop will be centered on electronics. We will try to adhere to the Mozambican physics curriculum when deciding on the final learning goals for each module in the workshop.

Since students have little foreknowledge, the workshop will be divided into several modules. In this way, the theory can be taught at a slow pace. Also, to take into account their foreknowledge, the students are asked to do an assignment before the workshop.

To accommodate different types of students, the workshop will be practical as well as theoretical. Also, students have the possibility of discovering the possibilities of technology themselves.

The didactic approaches of "authentic education" and "concept-context education" will be used to motivate students.

Evaluation of the design choices

Step 3 included evaluations of the design choices the student teachers made in Step 2. Student teachers initially formulated the assumptions and design choices that should be evaluated. Afterward, they worked on formulating methods and tools to evaluate these assumptions and design choices.

Assumptions to be evaluated:

1. A workshop based on the reality of the students will contribute to a higher interest in technology, since they can directly see how they can use their newly retrieved knowledge and development skills in their daily lives.
2. All design choices are translated into the design.

Design choices to be evaluated:

1. We want to use a modular workshop, to discriminate by level and opportunity.
2. The workshop must first and foremost inspire students to pursue careers in technology and science, with knowledge transfer coming second.

Methods and tools to evaluate assumptions and design choices:

Each of the assumptions and design choices will be evaluated based on four criteria: relevance, consistency, usability, and effectiveness. The evaluation criteria are offered by the teacher/coach, and these evaluation methods and tools are all designed by student teachers.

Evaluation criteria 1- Relevance

Desired: The students see a link between the workshop and their reality, and thus the relevance of the workshop.

Method & Tools

The methods and tools that are used to evaluate relevance are presented in the Table 3.3 below.

Table 3.3. Method & Tools for Relevance

Method	*Tool*
Try-out or micro-evaluation with Dutch students	Survey taken by Dutch students. Question: Can you link the knowledge and practical skills retrieved from the workshop to something in your daily life?
Focus group interview with university students	Interview with university students. Question: On a scale from 1 to 10, how relevant do you think the workshop is for high Mozambican high school students?
Focus group interview with clients (EWB executors)	Interview with EWB executors. Question: On a scale of 1 to 10, how relevant do you think the workshop is for high Mozambican high school students?

Evaluation criteria 2- Consistency

Desired: The finalized product is based on all the design choices posed in the design plan.

Method & Tools: The consistency will be assessed by using the screening method. Student teachers check if the connection between the design choices posted in the design plan with their final design product-workshop is consistent.

Evaluation criteria 3- Usability

Desired: The modularity of the workshop does not affect the ability of students to follow the workshop as a whole, or the teacher to supervise the workshop. Even if students miss a module, they should be able to continue the workshop and contribute to the final module. The average level of the modules should fit the level of the class, such that all students should be able to successfully finish every module. For teachers, it should be clear how the workshop is structured by reading the teacher's manual, without any external help.

Method & Tools:

The methods and tools that are used to evaluate usability are presented in the Table 3.4 below.

Table 3.4. Method & Tools for Usability

Method	*Tool*
Try-out or micro-evaluation with Dutch students	Observation. What to observe: Do students get stuck during a module if they did not do a certain other module? How actively (1-10) do students participate during the workshop?
Try-out or micro-evaluation with Dutch students	Interview with the teacher of Dutch students Question: How high (1-10) would you rate the average involvement of your students during a normal lesson and the workshop? If some students do not participate well, do you think that this is due to the level of the workshop or due to the level/character of the student?
Focus group with university students	Interview with the University students. Question: Which section of the teacher's manual did you find most difficult to understand? Why do you think it was difficult to understand? Are there parts that are too difficult, which can lead to the workshop failing? Which percentage of the teacher's manual did you find clear to use?

Evaluation criteria 4 - Effectiveness

Desired: Students are more interested in technology and science after the workshop.

Method & Tools:

The method and tools that are used to evaluate effectiveness are presented in the Table 3.5 below.

Table 3.5. Method & Tools for Effectiveness

Method	*Tool*
Try-out or micro-evaluation with Dutch students	Survey: Ask students to rate (1-10) their interest in technology and science before and after the workshop. Let them explain why there is or is not a difference
Try-out or micro-evaluation with Dutch students	Interview with university students. Question: Do you think this workshop will increase the interest of Mozambican high school students in science and technology? (on a scale from not at all, not much, somewhat, to very much) Question: Would this workshop have made you more interested in science and technology when you were in high school?
Focus group with university students	Question: Do you think this workshop will increase the interest of Mozambican high school students in science and technology? (on a scale from not at all to very much).

Step 4 is the design product - the designed workshop is called "building an electrical car". The workshop has six modules. These six modules can be seen as six connected design products for the audience (future high school teachers and their high school students). Because the six modules were created independently, a high school student does not have to complete the first module in order to participate in the second. However, each module includes a summary of the content if a student may need some basic previous knowledge.

Module 1: Electronics, sensors, and actuators

Module 2: The electric motor

Module 3: Combining circuits

Module 4: The electric car

Module 5: Workshop time!

Module 6: Science fair

For this workshop, the students designed a student guide and a teacher's guide. The teacher’s guide (81 pages), one of the design products aimed at guiding teachers to make this workshop successful for the students. The teacher's guide started with tips and tricks for teaching (for motivating students) and was followed by six modules of the workshop. The students' guide (67 pages) consists of six modules and a 'list of common errors made when a circuit fails' in order to assist students in diagnosing and resolving problems on their own. In each module of the students' guide, it is indicated which content belongs to the theoretical part, to the practical part, and to the safety rules part. Figure 3. 4 shows an example student sheet for guiding students through the construction of their first electrical circuit as a step toward building an electrical car.

Practical: Make your first electrical circuit

In this practical you will learn how to make an electrical circuit.

Materials:

- Battery pack
- Jumper wires
- Button
- 220 Ω Resistor
- LED

What to do?

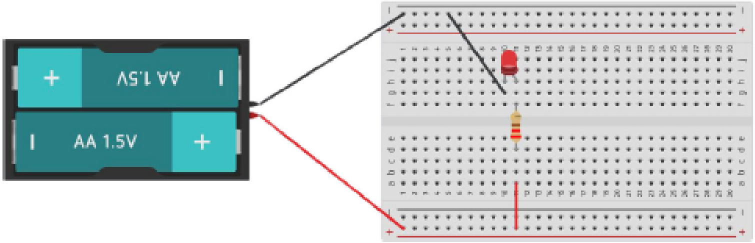

Figure 1.2. Circuit LED

Make sure you keep in mind the safety rules.

1. Put the LED somewhere in the breadboard, it does not matter where.
2. Grab the resistor and make sure it is connects the negative side/short pin of the LED to the other side of the breadboard.
3. Connect the positive side/long pin of the LED to the plus side of the breadboard.
4. Connect the resistor to the minus side of the breadboard.
5. Connect the plus side of the battery to the plus side of the breadboard you used and the minus side of the battery to the minus side of the breadboard you used.
6. If you have done everything right, your LED should be lit up.

Well done, you made your first electrical circuit!

Figure 3.4. Student Sheet 'Make Your First Electrical Circuit'

The design products and workshops are intended to be designed in an interdisciplinary way. Due to the lack of access to the curriculum of subjects in Mozambique, the integration of multiple subjects is difficult for student teachers. Also, the requested focus on electronics in combination with limited resources makes it difficult to include other subjects in the workshop. Therefore, student teachers choose to design the products- workshops mainly targeted at electronics, and integrate them into other subjects as much as possible. Student teachers choose to combine physics and mathematics, such as working with formulas. In addition, student teachers decided to design products- workshops that are independent of ICT infrastructure, because there is a shortage of multimedia and technolgical tools in schools in Mozambique.

3.4.3.2. Example 2: A Dialogue Tool for Promoting Self-Directed Learning for Students

In this design project, the student teachers Bernice d'Anjou and Nine Sellier designed a dialogue tool as a new method for feedback dialogues to promote self-directed learning. The tool is aimed at students in the Dutch secondary school subject "Research & Design (R & D)."

Research & Design (R & D) is a relatively new course in Dutch Secondary Education that was introduced in 2004. Secondary schools can choose to offer this course to their students at the levels of HAVO (senior general secondary education) and VWO (Pre-university education) throughout all the years (5 for HAVO and 6 for VWO). R&D is comparable to international STEM education. R & D is cross-curricular, which means it includes topics from the more classic Dutch courses, like Math, Physics, Chemistry, and Biology, in the project-based course. The course is taught by teachers from various backgrounds who serve only as coaches. Students in R & D work in groups on projects about real-world problems that are usually solved by STEM professionals. By using their methods and having intense contact with STEM professionals, students can get an impression of a career opportunity. The projects are designed to help students improve their skills. In contrast to more classic courses, which are more about developing knowledge. Students develop their competencies over time by reflecting on their projects, so that they are well prepared for STEM-oriented studies at (Applied) universities.

Students work in groups on projects about real-world problems. A project takes about 8 weeks in the first three years of R & D projects will be arranged for the students. The projects are organized by the students after these three years. This gives students ownership of their projects. The projects finish with a presentation to the class, the teacher, and the company. The project is graded on the delivered product, but also the process. Over the years, the projects get more challenging as the students develop their competencies that can be seen as 21st Century skills.

We show an example of a "dialogue tool" created by the student teachers below.The prototype for the "conversation tool" was created based on a literature review on self-directed learning, interviews with four R & D teachers, and observations of current R & D lessons at two different schools.The final design product is called the "conversation tool", aiming to build a more intensive relationship with the students during feedback conversations with the teacher (see Figure 3.5). This conversation tool consists of a board, cards for students and a teacher, feedback cards with example questions for individuals and groups, and reflection sheets. Via a physical board, chips, and feedback cards, both students and the teacher contribute to the subject of the conversation. The feedback cards consist of several questions at different levels of feedback focused on individuals where the students and teachers are introduced to a spectrum of feedback options. The outcomes of the feedback conversations can be documented on reflection sheets by the students (see Figure 3.6). In the end, how this conversation tool works in practice is visualized in Figures 3.7 & Figure 3.8.

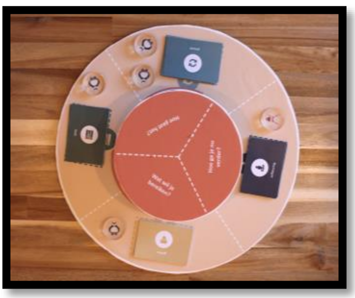

Figure 3.5. Design Product-Conversation Tool

Figure 3.6. Design Product-Reflection Sheets

Figure 3.7. Design Product

Figure 3.8. How it Works in Practice

3.5. Conclusion

Based upon our initial literature search results and our local examples, we reached the following conclusions. For starters, there is a lack of solid examples of design challenges and products at teacher education programs and K-12 levels in the European literature, which necessitates additional research. The articles about design challenges and products are highly skewed towards engineering education. We only found five articles (17% of the studies reached through the search) that included design challenges and products completed in K-12 and teacher education program contexts. Examples from the European literature primarily used digital design as the design product, but there were also other examples presenting physical artifact, model building, and schematic design. Four of the five design products from K-12 and teacher education were categorized as "digital design". However, these digital design products are online support tools that have been designed by researchers or teachers to support students' learning. In this sense, these online support design products are different from the ones in engineering education where students create design products by solving design challenges. There are good local examples of using design challenges and projects in teacher education programs, such as the ones mentioned at the Eindhoven School of Education, TU/e, in the Netherlands. This is also because there is a relatively new interdisciplinary course called Research and Design (R & D) in secondary schools in the Netherlands. Future research could focus more on collecting and analyzing these local examples. Secondly, we could only find three studies that mentioned interdisciplinarity, and hence, the integration of knowledge from different disciplines was missing in most studies. Thirdly, among those three interdisciplinary studies, the interdisciplinary characteristics are mostly visible in design challenges and design processes instead of the design products. Thus, how to make interdisciplinary characteristics more visible in design products deserves further thinking. Finally, the time spans that allow students to complete a design task efficiently vary greatly, and they should be considered in the future when preparing and planning for interdisciplinary design challenges and products in teacher education programs.

The interdisciplinary course *Designing STEM Education* and two student teachers' design project examples provided good local examples of creating a learning environment for implementing critical thinking into design challenges and design products in teacher education programs. Based on our local student teachers' design project examples, we can find some characteristics of the design challenges and design products. The design challenges are often formulated by the student teachers themselves after doing a thorough analysis of the clients' needs and doing little research about the targeted audience (who will use the design products), needs etc. What we offer student teachers as teacher educators is an open-structured real-world, relevant problem or a request. The design products our student teachers created are relevant to their professional careers, which they could implement in their classrooms when they become secondary teachers. Besides, these design products are also sent to these clients, so they can implement them in practice. Thus, student teachers are not only active designers, but also owners of design products that enhance their professional identity as educators.

CT dimensions are an integrated part of the course, *Designing STEM Education*. Although developing students' CT skills is not a separate explicit goal of the course, it is already embedded in the course activities. In our local design examples, the instructional design approach is CBL, not problem-based learning. This is because TU/e offers students CBL, which plays an important role in TU/e's education vision for 2030. The CBL, on the other hand, shares elements with the PBL, such as starting with a real-world problem and requiring teamwork. The tasks are open-ended and real-life challenges for particular clients. So, they can be applied immediately in practice and have practical implications which also promote the development of students' critical thinking during the design process. For the CT dimensions that have been listed under the design context/learning environment, such as multiple perspectives (MP), critical voice (CV), evidence-based reasoning, and interdisciplinary thinking, these dimensions are implicitly embedded in a connected way during the design process. As a teacher educator, we do offer student teachers some guides to support these CT dimensions, for example using the curriculum spiderweb (Van Den Akker, 2003) as a tool to inspire student teachers' critical thinking about the rationale behind curriculum (workshop) design. The evidence to support the design choices that the student teacher team made is an obligatory element in the final design report. This also makes the student teacher team aware of coming up with clear evidence-based reasoning after peer negotiations. For the assessment process, the CT is not yet explicitly integrated into the assessment process by providing students with evidence about their CT development according to their learning goals. This is because CT is not an independent main course goal in our teacher education program. It is not difficult to explicitly include it in the assessment process in our course in the future, since the core CT dimensions are already covered in the design process.

In this chapter, we offer a few local examples to inspire teacher educators to integrate critical thinking dimensions into design challenges and design products in practice. Chapter 4 will provide more detailed information on how to implement critical thinking dimensions in design-based pedagogy from both a theoretical and practical standpoint.

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