# Handbook of Research on Creative Problem-Solving Skill Development in Higher Education

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# Chapter 14
# Design Thinking in Higher Education:
## How Students become Dedicated Creative Problem Solvers

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## ABSTRACT

*This chapter introduces design thinking as an educational approach to enhance creative problem-solving skills. It is a problem-based learning paradigm that builds on three pillars: A creative problem solving process, creative work-spaces and collaboration in multi-perspective teams. This chapter discusses central elements of design thinking education and contrasts the approach to conventional education as well as other problem-based learning paradigms. In particular, design thinking classes harness a unique "look and feel" and "verve" to help students acquire and experience creative mastery. Furthermore, the chapter overviews empirical studies on design thinking education. Four studies are described in more detail: Experiments on the three pillars of design thinking and one case study where a university class curriculum has been changed to a design thinking paradigm. Finally, the chapter provides resources for readers who want to learn more about design thinking education.*

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## INTRODUCTION

Many countries recognize a need for curricula changes to enhance skills that used to be neglected in school and university education (Noweski et al., 2012; Rasfeld, 2015; Wagner, 2010). One central concern is to help students become dedicated creative problem solvers. In addition, students need to acquire co-operation skills to collaborate in interdisciplinary teams. Many pressing problems today cannot be solved on the basis of specialized knowledge from one single discipline alone.

Design thinking has been identified as a promising approach to help students become creative problem solvers and socially competent team-workers. The approach was pioneered in fields like architecture and mechanical engineering. Originally, it was used to develop innovative products or services that would not only benefit companies financially but also helped to tackle pressing societal problems, like high crime rates or poor health (Brown, 2009; Asquith, Dorst, Kaldor, & Watson, 2013). However, the approach soon turned out to be useful far beyond classical design disciplines. Researchers and practitioners have become interested in design thinking as a means to build up *creative confidence*, *creative agency* and *creative mastery* (Jobst et al., 2012; Kelley & Kelley, 2013; Rauth, Köppen, Jobst, & Meinel, 2010; Royalty, Oishi, & Roth, 2012, 2014). An increasing number of universities opened up design thinking institutes to help students acquire creative problem-solving and collaboration skills that are hardly encouraged by traditional schooling. Great numbers of applicants indicate a substantial interest of students in such unconventional trainings. The quick expansion of the Hasso Plattner Institut (HPI) School of Design Thinking at the University of Potsdam in Germany is a good example. It started off in 2007 with 40 students from 30 different disciplines. Due to strongly increasing numbers of applicants from all around the globe, in 2015 the institute trains 120 students per semester, who currently stem from 20 different nations and have been trained in 70 different disciplines. Students dedicate 2 days of the week to their design thinking training, either for one semester or for a whole year. At the same time they continue their conventional university education on the remaining 3 days of the week.

Regularly, in design thinking classes, students seem to develop a passion for their work that is rarely observable in conventional schooling. Many students quickly develop autonomy and even creative mastery in solving problems. At the same time, design thinking classes teach few things explicitly. Rather, the classes use and teach a work culture of joy, collaboration, action, wild experimentation and rapid learning out in the field. Design thinking impacts the mindset of students more than building explicit knowledge.

This chapter provides a short introduction to design thinking education. The first part introduces design thinking as one approach to *problem-based learning*, which has quite unique features. The second part discusses empirical studies that investigate the mechanisms and effects of design thinking education, focusing in particular on the development of creative problem solving skills among students. The third part provides resources for readers who wish to learn more about the subject.

## FUNDAMENTALS OF DESIGN THINKING EDUCATION

Design thinking is an example of what the community calls "problem-based learning" (Barrows, 1996; Carleton & Leifer, 2009; Schmidt, 1983). Students work in teams on open-ended problems. They decide quite autonomously how to move their projects forwards. Formal lectures are rare and short. Teachers do not claim "authority of knowledge" (Zhou & Valero, 2016, p. 134). Rather, they act as facilitators.

At the same time, the approach is unique in several regards. In design thinking projects, students work on "design challenges" provided by serious project partners. In the past, global companies or non-profit organizations like SAP, JetBlue, Fraport, Volkswagen, Siemens, Special Olympics or Germany's Federal Ministry of Education and Research have been project partners in design thinking education. Typically, a team of 3 to 6 students works on each challenge. They can be asked to "redesign security processes at airports", to "help mentally challenged persons move autonomously in a city" or, very generally, to "redesign workplace experiences". At first, design thinking teams create their own unique outlook on the challenge and identify the precise problem they want to tackle. Later on, they head for a thrilling, creative solution.

Design thinking work culture builds upon three pillars. They are called the "3 Ps", standing for process, place and people (HPI School of Design Thinking, 2015).

**Process:** Among the few things that design thinking students learn explicitly, a process of creative problem solving plays a prominent role. The process exists in several versions. A current one reads: (1) Empathize, (2) Define View, (3) Ideate, (4) Test Prototypes, (5) Bring Home. In each phase, the team can choose among many methods that have been adapted from different disciplines.

**Place:** To support creative team-work, design thinking locations are carefully designed. The space is variable and can be adapted to the needs of each project. Tables, couches and shelves are placed on wheels, such that they can be moved around easily (Figure 1). Walls and many other surfaces are used to visualize thoughts. Craft material helps teams create tangible, sometimes "toy-like" prototypes.

**People:** Design thinking embraces a culture of "radical collaboration" and of "collaboration at eye-level". Design thinkers work in teams. Multidisciplinarity is very welcome, both in student teams and the teaching staff. Hierarchical differences are evened out as much as possible. Teachers act as facilitators; they help students reflect on their work process by spotting difficulties or opportunities and by providing new impulses when energy is wavering.

To convey an idea of a design thinking project, the task of redesigning airport security processes shall serve as an example. Given this challenge, a design thinking team will first try to *empathize* with

*Figure 1. A creative space at the HPI Potsdam. Tables and couches are placed on wheels. The small number of volumes in the "D-Library" suggests that books are there to inspire. They do not compile the whole knowledge of the world that is worth knowing. Students are supposed to go out and learn about the world first-hand, not by reading books.*

people who are involved. The team can use methods such as interviews, behaviour observations, video documentation or personal experiences to understand the needs of different stakeholders. When *defining a point of view*, the team might decide to focus on passengers – not on police officers, cleaners, pilots or other people affected by airport security processes. The team will also identify a need. Maybe they note that passengers would prefer to sit down while waiting for the security check. Furthermore, a striking discrepancy can yield an insight to build on: at first, passengers spend a lot of time waiting, doing nothing. However, once they have reached the security check, from one moment to the next they hectically engage in action, sorting electronic equipment, liquids and other belongings into different baskets. In the phase of *ideation*, the design thinking team will try to come up with as many different ideas as possible to solve the identified problem. They will pick one or two options and *test prototypes* with real users. For instance, the team can design a "security trolley" shaped like a chair on wheels. The trolley has multiple compartments such that passengers can sort their different belongings into boxes already while waiting in the line. Once done, passengers can sit on their trolley and wait for the security check in a comfortable position. Finally, in the *Bring Home* phase, the idea is passed over to someone who can make it real, someone who can build security trolleys for airports. (This example is based on a design thinking project at the D-School in Potsdam.)

Next to the 3 Ps—Process, Place and People—design thinking education is characterized by other features that seem particularly important for its positive outcomes.

**Safety:** Design thinking is taught and practiced in safe environments (d.school, 2012a). That means, first, students can move around freely and concentrate on work tasks without having to worry that someone might steal their jackets, backpacks or electronic devices. Second, coaches and teachers ensure that their courses are safe places for students to experiment, to try wild ideas and in particular safe places to fail. Students are invited to try 100 very diverse ideas, see 99 fail, derive important new insights and filter down to one outrageously good idea.

**Verve:** Design thinking is an energizing and often joyful process, or mode of working. Coaches and teachers pay close attention to the energy level and mood of students. Warm up games or "improv activities" (d.school, 2014) help create the specific mood that is considered helpful in each stage of the process. Often times, music plays in the background. Different music samples have been compiled for different stages of the process (d.school, 2012b), once again stimulating specific moods. Time constraints are used as a productive stressor to forestall unconstructive discussions and get people going. Furthermore, the architecture (Doorley & Witthoft, 2012), the equipment (d.school, 2011) and model behaviours of experienced design thinkers (d.school, 2012a) help create a playful and joyful atmosphere. The intent is not simply to make people feel good. Positive affect has been shown to positively correlate with creativity (Amabile et al., 2005). Cultivating fun, not fear is a necessary support. Finally, the community celebrates their work process. Often times, there are presentations "on stage" with constructive feedback sessions and applause from the audience.

**Sense:** The whole setup of design thinking projects lets students experience how important and sensible their work is: they tackle crucial real-life problems, in face-to-face exchanges with affected persons ("users"), on behalf of actual project partners who can make visions real. Furthermore (as in other settings of *problem-based learning*), students are invited and challenged to find the path that makes most sense to them in handling wicked problems (von Thienen, Meinel, & Nicolai, 2014). There is no predefined problem for teams to work on. Rather, teams explore a diffuse problem domain from different perspectives. They reframe the problem according to team preferences. "Point of

view madlibs" (d.school, 2010a) support the specification of thrilling project directives. Teams also decide for themselves, which ideas they prototype and test, when to move from one process phase to another and how to use the space they work in.

**Culture:** Design thinking is much more than a teaching method. It is a whole culture that promotes specific ways of working, of thinking and of dealing with one another. Already, the architecture and room equipment is a manifestation of design thinking culture. Large panels on the walls convey design thinking mottos and help newcomers arrive at "the world of design thinking". These panels display inspirational mottos like; "encourage wild ideas", "defer judgement", "bias to action", "embrace experimentation". Playful prototypes such as Lego models and plenty of craft materials reveal that – as design thinkers – students will work with their hands, are free to play and try things out. Furthermore, design thinkers are generally well connected. Pools of talented people form around design thinking schools; they are united by a design thinking mindset of co-operation despite their diverse professional backgrounds.

**Different "Look and Feel":** Design thinking classes have a unique *look and feel*. The setting and atmosphere is unlike that of other university classes. Indeed, the authors of this chapter hold that such a different *look and feel* is an essential ingredient of design thinking education. After all, design thinking has been developed to yield skills, work practices and cultural values that students fail to develop in traditional education. Therefore, design thinking classes need to communicate that a different manner of working is valued here.

## DIFFERENCES TO OTHER APPROACHES TO PROBLEM-BASED LEARNING AND TO CONVENTIONAL EDUCATION

This chapter introduces design thinking as an example of *problem-based learning*. At the same time, design thinking is called "unique". The authors of this chapter hold that the specific *look and feel* of design thinking classes is an important distinguishing parameter.

To explain this idea in more analytical terms, a dialogue examined by Mehan (1979, cf. Sinclair & Coulthard, 1975) shall be re-analysed and elaborated. He contrasts two scenarios that help to pinpoint the difference between (1) conventional education, (2) many other approaches to *problem-based learning* and (3) design thinking.

**Conventional Education:** Here is an example of traditional education. At school, the following dialogue might take place.

Speaker A: What time is it, Denise?
Speaker B: 2:30.
Speaker A: Very good, Denise.

This dialogue illustrates the *look and feel* of traditional education. It suggests an idle effort on behalf of the student. Her answer does not solve any problem out there in the world, apart from educational purposes. She merely allows the teacher to evaluate her level of knowledge and proficiency.

**Problem-Based Learning:** The following dialogue is very similar and yet conveys a different scenario.
Speaker A: What time is it, Denise?

Speaker B: 2:30.
Speaker A: Thank you, Denise.

This dialogue is more likely to occur outside of school. Denise may have the gratifying experience of helping someone out. Speaker A lacks knowledge (regarding time) that Denise can provide. However, Denise will not credit herself with having said something so remarkable that all experts in the field are stunned, because they never heard such a great answer before.

Many approaches to *problem-based learning* create a scenario of this second type. In the ideal case, students are not only confronted with fictitious problems, but with real-life persons who introduce real-life challenges. For instance, a patient comes in and reports symptoms. When students successfully produce an adequate diagnosis and treatment, they might be likely to experience *task-specific mastery.* They solve a real-life problem and hear an honest "thank you" in the end.

**Design Thinking:** In the case of design thinking, problem-based learning is not only used to enhance problem-solving skills, but also to enhance creative skills.

When Denise is asked for the time, and when medical students are asked for a diagnosis in *problem-based learning*, the task they work on typically does not start a design thinking project. In both cases, no excessively unique solution is requested. Rather, different persons working on the same challenge (e.g., different medical experts) might all come to similar solutions (the same diagnosis).

In design thinking, project partners pose vital, open-ended questions regarding pressing problems of the day that affect many people. "How might we…?" Over weeks or even months students work to provide a thrilling reply. Then, project partners react. Their reaction is used as an unofficial metric for the success of a design thinking project. If project partners react like Speaker A in the dialogue above, saying "thank you", the project is basically considered a failure. The answer design thinkers work for is a deeply moved "WOW!" (cf. Leifer, 2012, 2013). In a similar vein, Liedtka & Ogilvie (2011) relabel stages of the design thinking process; explicitly, one stage is guided by the headline "what wow's" (p. 31).

In design thinking education, this is the kind of conversation that is expected over time; and it is often observed in practice.

Speaker A: How might we…?
Speaker B: We could…
Speaker A: WOW!

Such a dialogue suggests the *look and feel* of design thinking. Students experience themselves as contributing something extraordinary, something surprising and thrilling no one has thought of before. By themselves, they have found a solution for a pressing problem out there in the world. Users and project partners embrace this new solution with great excitement. Students can be "flashed" by their own capacity to understand and solve a fundamental problem of the world. When a design thinking project succeeds, students experience *creative mastery*.

## THE LOOK AND FEEL OF CLASSES: CUING STUDENTS INTO DIFFERENT SCENARIOS

Why does design thinking have a unique *look and feel* that is so different from traditional education? Next to the specific questions that start a design challenge ("How might we…?"), other factors seem essential too. The architecture is carefully designed to differ from conventional seminar rooms. Furthermore, the design thinking process suggests a scenario where the protagonists are "explorers" or "inventors" rather than "students", both because of its vocabulary and the scheduled activities.

By contrast, there are other process models in *problem-based learning* that do enforce quite traditional student roles. For instance, Schmidt (1983) suggests a seven-step process:

**Step 1:** *Clarify terms and concepts not readily comprehensible.*
**Step 2:** *Define the problem.*
**Step 3:** *Analyse the problem.*
**Step 4:** *Draw a systematic inventory of the explanations inferred from step 3.*
**Step 5:** *Formulate learning objectives.*
**Step 6:** *Collect additional information outside the group.*
**Step 7:** *Synthesize and test the newly acquired information. ( Schmidt, 1983 , p. 13)*

In step five, the term "learning objectives" is immediately reminiscent of a traditional school scenario. Participants are asked to learn something, even though they are allowed to formulate learning goals for themselves. By contrast, in design thinking classes, participants are not prompted to achieve learning goals, but to solve problems. Learning (from empathizing with users, testing prototypes etc.) figures as a highly effective means along the way to achieve great solutions.

Furthermore, a lot of Schmidt's vocabulary suggests a traditional scientific paradigm. Students work on *terms* and *concepts*; they *systematize* and make *inferences*. Such a process suggests the *look and feel* of serious science rather than "an epic voyage" and "unexpected discoveries". The process model of design thinking is very different in that regard: (1) Empathize, (2) Define View, (3) Ideate, (4) Test Prototypes, (5) Bring Home. In design thinking, students empathize; they don't theorize. Design thinkers turn to people. Schmidt's students turn to the "dictionary" (Schmidt, 1983, p. 13). Then, design thinkers choose a view point. Once again, this task is a cue not for traditional "serious" science but rather for storytelling. For instance, the story of a war can be told from the viewpoint of a king, a poor child, a warrior etc. Schmidt's students, by contrast, do not choose viewpoints but "hypotheses" (ibid.). Design thinkers ideate wildly, tapping their creativity. Schmidt's students tap "prior knowledge" (ibid.). Design thinkers build prototypes, which they test with real users. Schmidt's students consult the "literature" (p. 14) to evaluate and substantiate ideas. This comparison is not meant to suggest that one approach be better than the other. It simply illustrates that the two approaches are reminiscent of quite different scenarios. They have a different *look and feel*. Project work according to Schmidt's model resembles traditional education much more than design thinking project work.

## IMPACT OF DESIGN THINKING EDUCATION ON STUDENTS

Generally, what effects do design thinking classes have on students? First of all, it is a striking observation that students regularly report profound impacts on their whole lives (cf. Plattner, Meinel, & Weinberg, 2009; Meinel, Weinberg, & Krohn, 2015). Students voice severe changes of their self-image, private habits, work-styles and career preferences. Thus, once again there seems to be a sharp contrast to many other classes, which students take and quickly forget about afterwards.

Royalty et al. (2012) explore what learning outcomes alumni attribute to their design thinking training – sometimes years after graduation. The authors report survey findings from alumni (N=175) who graduated between 2005 and 2011 at Stanford University, and results from in-depth follow-up interviews (N=16). They find that "alumni apply a range of design thinking methods and dispositions in their professional lives, particularly related to creative confidence, comfort with risk and failure, and building creative environments" (p. 95). The majority of alumni state they still use what they have learned in their design thinking education on a weekly basis. All alumni attribute some level of confidence in their creative abilities to their time at the d.school, where they learned and practiced design thinking.

Indeed, building up creative confidence has become a central and official goal of design thinking education (Kelley & Kelley, 2013). Someone who does not believe in his or her creative abilities will rarely give them a try. Creative confidence is a major prerequisite for creativity.

Design thinking classes seem quite successful in fostering creative confidence. A design thinking teacher reports in a qualitative interview: "If I ask students at the beginning of a term: Who of you is creative? Almost nobody raises his/her hand, except some design or art students. When I ask them at the end of the first year, almost everybody says: I'm!" (Rauth et al., 2010).

Royalty and Roth (2016) analyse the effect of design thinking education on creative confidence with a quantitative approach. They compare three groups of students: (1) Students who take a design thinking class (N=31), (2) students who apply for the design thinking class but are not enrolled (N=51) and students who take a product design class at Stanford University that also addresses issues of creativity and innovation, but uses a more traditional educational model (N=31). All students answer questionnaires before the classes start and after they end. The authors find that only design thinking affects *creative confidence* positively. In both control conditions, the student's creative confidence does not change significantly over time.

Another focus of research has been to illuminate neuro-cognitive effects of design thinking education.

Bott et al. (2014) report that design thinking training enhances goal-directed attention and information processing. Saggar et al. (2015) find high performance in a creativity task to be correlated with an increased activity of the cerebellum. This is surprising, given that the cerebellum is traditionally thought to facilitate bodily movements and not (creative) thinking. By contrast, an increased activity of the prefrontal cortex – traditionally associated with conscious thinking – does not predict good creative performance. Quite to the contrary, the prefrontal cortex is active when subjects find a creativity task difficult and don't perform so well. In sum, the authors suggest that conscious monitoring and volitional control might actually be adverse to creativity. As Saggar puts it: "The more you think about it, the more you mess it up" (Stanford Medicine, 2015).

The findings of neuro-cognitive studies seem to support a general philosophy of design thinking: Bias to action. Don't discuss, judge and make plans upfront. Try things out immediately, learn and iterate quickly. Dow and Klemmer (2011) test this strategy in a behaviour experiment and contribute further evidence for its effectiveness. Participants (N=28) are asked to build a vessel from everyday materials

in 25 minutes. The vessel shall protect a raw egg from crushing while it is dropped from increasing heights. Task performance is measured in terms of the highest height at which an egg survives the fall. In the experimental condition, participants receive a full carton of eggs. They are encouraged to test their vessel prototypes at minutes 5, 10, 15 and 25. Participants of the control condition only receive one egg altogether. In the end, the average drop height that eggs survive is almost twice as high in the experimental condition as it is in the control condition. Thus, biasing to action and iterating designs seems a very successful strategy. At the same time, the authors report interview findings that illuminate challenges of design thinking education. Several participants from the experimental condition say they felt uncomfortable "having to iterate too early and too frequently" (p. 125). After all, a vessel prototype at minute five is likely to be unfinished and there was little time to think it through. Thus, it seems all the more important that design thinking classes do not only teach a successful work strategy. There needs to be a safe environment and a cheerleading community to help students test "unfinished work", see it tank and learn from "failures".

The overall package of design thinking education at the d.schools in Stanford or Potsdam seems quite effective in that regard. Energetically, students embrace a work routine even though it often requires them to abandon their "comfort zones". Plattner (2009) uses an unconventional metric to assess this effect. As he describes the start of Potsdam's D-School he notes:

*Already after a short period of time people had so much fun that we almost had troubles paying the electricity bill because the light would never go out at the HPI School of Design Thinking. I was there several times in the evenings; there was light in the workrooms! What do they do there? They work at night. It's so much fun to sit on a red couch and work on the solution of a problem. (Plattner, 2009, p. 21, authors' translation)*

In what follows, empirical tests of design thinking education shall be discussed in more detail. Special attention is paid to the three "pillars" of design thinking: Process, place and people. In a fourth section, a case study is described where an existing course curriculum has been changed to incorporate design thinking elements.

## How Students Become Happy Problem Solvers: A High-School Experiment on Different Teaching Approaches

Noweski et al. (2012) test the effects of design thinking education in an experiment with 116 high school students. The study takes place on 3 subsequent days in a German Gymnasium with all students of the tenth grade (four classes of students; participants aged 15 and 16).

Students are randomly assigned to the experimental or control condition, yet making sure that gender and classes are dispersed as equally as possible. In many respects, the experimental and the control condition are designed to be alike:

**Problem-Based Learning, Teamwork, Project-Based Learning:** Students work in teams of 4 or 5 members. They work on a project, or more precisely a design challenge. This challenge is identical for all teams: Come up with ideas how teachers could profit from the students' knowledge of digital media.

**Teachers in the Role of Coaches:** Twelve teachers accompany the students. Each teacher supports two student teams. There is little formal lecturing. Teachers rather help the students find their own paths as they tackle the challenges.

**Design Thinking Work Spaces:** All students receive the same equipment, which is typical of design thinking work. Each team has two moveable whiteboards, sticky notes, pens etc., a movable high table and highchairs. Thus, "standing" is inevitable for most of the time.

However, the experimental and the control condition also differ in crucial respects:

**Experimental Condition: Design Thinking:** Six of the teachers are trained design thinkers. They teach their teams a design thinking process to tackle the challenge, including specific methods for each process phase. Furthermore, these teachers are trained to monitor the students' mood and energy level. Typical design thinking interventions are launched to help the students have fun, find a thrilling problem statement and explore many possible solutions including wild ideas.

**Control Condition: Dewey-Kilpatrick Approach:** Six of the teachers use an educational approach suggested by Dewey (1916, 1931/1935) and Kilpatrick (1918). This approach is explained in a more philosophical and abstract fashion by the authors. There is no clear process model. However, teachers are supposed to play a similar role as in design thinking, facilitating the students' journey rather than dictating what was "right" or "wrong". The teachers also help the students find their own path, e.g., by letting them note down a plan before engaging in action.

While students like to work on the design challenge in both conditions, design thinking consistently yields more positive results than the Dewey-Kilpatrick approach.

- *Design thinking has more positive effects on the students' social skills.* All students fill out the *Social Competencies Inventory ISK* (Kanning, 2009) before and after the project days. In 18 out of 21 scales, students of the design thinking condition obtain higher gain scores.
- *Students rate the coach-team relationship more positively in the design thinking condition.* While teachers in both conditions are received well, design thinking teachers consistently obtain better ratings on all scales. They are described as more benevolent; the relationship is rated as more relaxed, trustful and co-operative.
- *Students appreciate the design thinking methodology more than the Dewey-Kilpatrick approach***.** While "the method used throughout the last days" is rated positively in both study conditions, design thinking – once again – receives better ratings on all scales. Students like this methodology better; they find it more practical, more effective, more fun and they are more eager to use it again.
- *All teachers believe design thinking has better effects on students.* Teachers believe "the youth" would profit both if Dewey or if design thinking projects were launched regularly at schools. However, positive effects attributed to design thinking are much larger. Students are expected to be much more motivated, engaged, independent, determined, productive, reflected and socially competent if there were more design thinking projects at schools.
- *Teachers prefer to use the design thinking approach.* All teachers would like to use the design thinking methodology at school if they had the chance. By contrast, teachers are uncertain whether they would choose to launch a Dewey/Kilpatrick project by themselves.

- *Both students and teachers have positive sentiments all the time. However, design thinking teachers feel better than Dewey teachers in the end.* On all workshop days students and teachers specify their mood on a scale from -10 (extremely negative) to + 10 (extremely positive). Mood is assessed each morning, midday and in the afternoon. Both for teachers and students, on each point of measurement and in both study conditions the average mood is positive. However, at the end of the workshop, when all teams have presented their final ideas, the mood of Dewey teachers drops to an "all-time low". By contrast, the mood of design thinking teachers reaches an "all-time high".

This experiment with high school students investigates one of three design thinking pillars: a specific work process. Obviously, the process is quite favourable. It yields additional benefits compared to a similar teaching approach, which also embraces *problem-based learning* and project-oriented teamwork.

Next to the process, design thinking rests on two other pillars: place and people. The second pillar has been tested in the following study.

## How Students Become Creative Problem Solvers, Even Against Their Own Will: A University Experiment on Different Learning Environments

Design thinking is taught in unique work spaces—rooms or buildings—that are designed to foster target-oriented and team-based creativity.

**Stimulating Creativity:** Design thinking locations include a variety of equipment which induces a mood of playfulness and experimentation. Many objects in design thinking spaces can also be found in Kindergarten. There are craft materials including colourful pens, paper, scissors and glue, Lego blocks, polystyrene beads and the like. There are even cosy corners to relax. At the same time, the equipment does not pre-determine any specific usage. For instance, there are no ready-made dollhouses that would call for playing "doll at home".

**Target-Oriented Work:** Design thinking equipment is very flexible. Both the prototyping-material and the overall room-setup can be used in multiple ways, creating different moods and opportunities. For instance, whiteboards on wheels can be used to create tiny team-corners where student teams work in some kind of privacy. When whiteboards are moved aside, there is a wide open space for presentations in front of large audiences. Music and light is also used to create different work settings (d.school, 2012a; Doorley & Witthoft, 2012). Thus, students and teachers automatically reflect on their next purposes and set up the space accordingly.

**Fostering Teamwork:** While design thinking spaces are very flexible, they do not support all possible modes of working. There are design thinking "anti-spaces": Locations or settings which make it particularly difficult to practice design thinking. In a study with design thinking experts from the d.school at Stanford and the D-School of Potsdam (von Thienen, Noweski, Rauth, Meinel, & Lang, 2012), the following places were named as TOP 3 design thinking anti-spaces: (1) a prison, (2) a conventional classroom/office/cubicle and (3) a library. All of them tend to isolate people, for instance, by promoting single-person quiet desk work. In terms of the architecture and room equipment, design thinking spaces carefully avoid the *look and feel* of such anti-spaces. Even if one tries, it is very difficult to find zones for concentrated one-person quiet desk work in design thinking architecture. Rather, it promotes the noise and jumble of creative teamwork.

What effects does it have when the same class is taught in different places? In a study with 16 university students (von Thienen et al., 2012), the effects of places are investigated experimentally. All students come together for a 2-day workshop to study measurement and test theory of the social sciences. At first, the participants listen to an introductory lecture on the subject. Afterwards, they receive reading material and a challenge to work on. They shall help a 16 year old girl named Anna who wants to find out (measure) how she comes across in different outfits. What suits her best, what doesn't suit her at all? Among the reading material of study participants, there are also step-by-step guides to construct measurement instruments according to several standard approaches of the social sciences. On a random basis, students are grouped into teams and sent to different work environments. Half of the students work at the d.school, the other students work in a conventional seminar room located in the same building at a different floor. After two days, all students come together again to present their approaches and results.

The participants come to the workshop to practice for exams on standard methodological procedures. Participants do not expect to be creative during the workshop. However, there is a twist in the study design. In reality, none of the step-by-step guides that is made available to the participants helps to answer Anna's question straightforwardly. All methodological procedures described in the reading material need a major adaptation to yield sensible answers in Anna's case.

At both locations, students do not notice the discrepancy between their step-by-step guides and the challenge they work on. Teams simply pick one step-by-step guide and want to follow it strictly. In the conventional seminar room, the workshop participants actually proceed that way. Thus, they calculate sense-less numbers which cannot answer Anna's question. However, the students obviously do not notice any pitfall, not even during the final presentation on the second workshop day when they report to the audience what they did and found out.

At the d.school, students have the same intention to follow one step-by-step guide strictly. However, without noticing it, they fundamentally change the approach described in their reading material. This unnoticed adaptation actually allows them to calculate sensible numbers that answer Anna's question. Only after more than one day, students at the d.school notice that there seems something wrong with their calculation. Once they become aware of the methodological changes they made on their own, they are very surprised and discuss how to move on. They decide to proceed with their newly created measurement routine first, to answer Anna's question. Afterwards, they formulate another question for Anna, which allows them to apply a standard approach of measurement and test theory in a sensible way.

Thus, even against their own will, students at the d.school are creative. They devise a new measurement routine which allows them to answer the question they work on. This creativity is actually accompanied by making good use of the d.school space. Students move around furniture to account for differing needs over time. As a matter of their free and spontaneous choice, they also use perukes and other prototyping material to act out the challenge. One student dresses up like Anna in different outfits (see Figure 2). Another student takes pictures, which are then printed out. The students assign themselves different roles (grandmother, best friend, father etc.). Everyone looks at the pictures and numerically evaluates how they like each look. Thus, students at the d.school are "closely in touch with Anna" throughout the challenge.

Students in the conventional classroom also have cameras at their disposal. However, they do not decide to act out Anna's challenge in concrete terms. They rather focus on the reading material as primary equipment over the days. Thus, there are also some hints as to why students at the d-school are creative and sense-making, while students in the conventional seminar room replicate standard measurement routines without sense and meaning.

*Figure 2. In the creative space, students act out the challenge they work on. One student pretends to be Anna and dresses up in different outfits. The other students judge her diverse looks. As the students proceed, they deviate from the step-by-step guide in their reading material and creatively develop a new measurement routine. Due to this change of methodology, the students can solve the problem they work on*

## How Students Become Welcoming Collaborative Problem Solvers

Next to the two pillars "process" and "place", there is a third design thinking pillar that seems to be the most ambivalent in terms of research findings. This pillar is named "people". It might also be called "radical collaboration" or "plurality of people". Whenever possible, design thinkers work in teams; and teams are set up to be diverse. To achieve diversity is even one selection criterion when the teaching staff sees applicants at the schools of design thinking.

There are good reasons that speak in favour of team diversity. Each academic discipline provides students with a unique vocabulary, methodology and outlook on the world. Typically, students learn to tackle problems by applying ever the same analytic strategies and standard solutions. However, very often, it is the academic discipline rather than a problem by itself, which suggests unvarying solutions. After all, different academic disciplines promote different analyses and solutions. For instance, when there is a problem situation because a youngster robed an old man underneath a bridge, a psychologist might focus on the youngster's mindset while an architect notices bad lighting conditions under the bridge

that he wants to change. Thus, there is a danger of overlooking potential solutions because problems are immediately interpreted through the lenses of single academic disciplines. To avoid this pitfall, design thinking calls for an extensive exploration of *problem* and *solution space* first, before a team decides on one point of view. The final team perspective is supposed to be both thrillingly new and promising. Against this background, different academic trainings seem a resource for teams. Multidisciplinary collaboration could help teams overcome cognitive automatisms, which predetermine how a problem is framed and what kind of solution is considered.

Work reality is another issue that counts in favour of team diversity. Both in the economy as well as in science, increasingly often the specialized knowledge of one discipline does not suffice to tackle issues. Specialists with different professional backgrounds must collaborate to solve problems jointly. However, this can be difficult given the dissimilar vocabulary and methodology that people are used to.

In terms of research findings, however, it is a striking observation that team diversity does not predict better work results. Kress and Schar note: "Existing organizational behaviour research has shown that diversity on a team has mixed and frequently negative effects, particularly when outward indicators such as gender, ethnicity, age and experience measure diversity" (2012, p. 189). In light of this data, Kress and Schar consider the idea that diversity of thinking styles ("cognitive diversity") might be a better predictor for project success. They study 97 master-level engineering students in eight different countries who collaborate in teams over a period of 8 months. However, in the end the authors find "that overall cognitive diversity does not appear to correlate with overall team project performance" (p. 189).

Similar results are found in an experiment with 40 students who work on a design challenge over a week (von Thienen, Noweski, Meinel & Rauth, 2011). Half of the participants work in mono-disciplinary teams, the other half in multi-disciplinary teams. All teams face the same challenge. Their solutions are rated by four independent experts in the end. Strikingly, the solutions presented by mono-disciplinary teams obtain significantly better ratings than solutions of multidisciplinary-teams.

Next to the effect of team diversity, the experiment just described monitors a second factor. Half of the participants are trained design thinkers; the other participants are novices who have no design thinking experience. Thus, in sum the experiment covers three design thinking mono-disciplinary teams, three design thinking multi-disciplinary teams, three novice mono-disciplinary teams and three novice multi-disciplinary teams. Several measures of the study assess communication problems in the teams. Consistently across all measures and study conditions, trained design thinkers experience less communication problems than novice teams. So, there is some evidence that design thinking education has positive effects on team communication.

Reviewing empirical evidences available up to this day, the authors of this chapter hold that multidisciplinary teams cannot be considered a strategic means to achieve better or more innovative project results yet. Maybe in the future that will be the case. The community still needs to find better techniques to make use of the great potential that should lie in multidisciplinary expertise.

However, design thinking seems to have something valuable to contribute already. Given that multidisciplinary collaboration is a necessity in many economic or scientific projects, design thinking might help to reduce communication problems in mixed teams. Furthermore, there is qualitative evidence that design thinking creates a passion for collaboration that might be all the more important in diverse teams. Given that science regularly observes a "performance deficit" of mixed teams, its members might experience their collaboration as somewhat frustrating. However, unanimously, observers report that design thinking students seem to enjoy multidisciplinary collaboration rather than trip over its hardships. As one design thinking teacher reports: "In my years at the D-School, I never heard students complain that

they rather would like to work in mono-disciplinary teams. Quite to the contrary, they find it inspiring to have diverse teams" (A. Perlich, personal communication, October 12, 2015). Another teacher writes on the same issue: "In general I have seen and experienced teams with difficulties and ups and downs, but never heard anyone blaming it on the [difference of] educational background!" (M. Taheri, personal communication, October 13, 2015). Regarding the diversity of teams she also confirms: "D-schoolers seem to enjoy it" (ibid.). This perceived value extends to alumni. Royalty et al. (2012) find that d.school alumni cite *working with cross-disciplinary teams* as one of the most salient memories from learning design thinking.

Many of the alumni interviewed in the study report that their d.school course was the only time they worked in diverse teams during their time in school. However, nearly all of the respondents report working in diverse teams following graduation. In this sense, design thinking uniquely prepared them for collaboration in authentic settings.

Design thinking uses many techniques to create a collaboration culture. For instance, the motto "build on the ideas of others" is used deliberately to help teams grow together (cf. von Thienen & Meinel, 2015, for an overview of techniques). Furthermore, the design thinking process might be a supportive factor. Students are told explicitly that they need to explore problems from multiple perspectives. Different academic backgrounds figure as an obvious advantage in this regard.

## How Students Become Dedicated Problem Solvers: A University Case Study on Different Teaching Formats

The last study to be discussed here concerns a university class that has been taught repeatedly, but in two different teaching paradigms. The content of the class does not change much. It covers philosophy of science and research methodology. However, the class is taught in a traditional teaching paradigm first (before 2014) and in a design-thinking paradigm later on (after 2014).

In the traditional paradigm, sessions include lectures, quiet reading of primary literature, discussions and also group-work. When working in groups, students tackle "fictitious problems". The results of group-work are reported by single volunteering students.

The design-thinking paradigm shall be described in more detail such that interested readers can replicate or modify aspects of the procedure.

The course starts with an introduction to design thinking including the process model and design thinking mottos. Also, in the first session, students hear of the general work routine in class, how they will work on challenges of academic project partners.

The second session gives an introduction to philosophy of science (ca. 30 minutes). Then, project partners from academia introduce research questions they actually work on. In all cases, project partners have a substantive research interest but have not yet decided on a concrete methodology. All project partners specify their research interests by ending the sentence "I want to find out…". Then, students form teams of 4 to 6 members based on their personal interests. They will work on the chosen research challenge for the rest of the semester.

This is a sample challenge regarding tele-work from one project partner:

*Increasingly often, employees are allowed to work at their homes. However, at home many factors can cause bad work results. Some people fail to bestir themselves and do not get going; there can be a lot of distraction at home; it can be difficult to communicate with the employer and people misunderstand*

*their tasks… I want to find out how good tele-workers differ from bad tele-workers. (Chujfi, 10/27/2014, Powerpoint presentation in class, authors' translation)*

The task of the students is not to answer the research question. Rather, they shall suggest different methods for the project partner to pursue his research objective.

In each of the following sessions, there is a lecture of approximately 30 minutes length. It ends with a statement of design maxims for the development of research strategies. For instance, in Logical Positivism, there is the maxim to start research by going out in the world and making observations, which are recorded in a factual language with as little interpretation as possible. By contrast, in Critical Rationalism there is the design maxim to start with courageous hypotheses and try to falsify them.

Throughout class, teams have a lot of craft material at their disposal. They can use coloured felt-tips, scissors, glue and DIN A2 white paper. In addition, all teams have DIN A2 folders to collect suggestions for their project partners.

In each session, design maxims and madlibs are given out to help students implement what they heard during the lecture. For about 30 minutes, teams brainstorm how their project partners could tackle his or her research objective, following the design maxims of that particular session. During teamwork, music plays in the background. Then, each team presents their ideas (2 minutes) and obtains feedback from the audience (2 minutes).

At mid-term and at the end of the course, project partners come in. Teams present a selection of their ideas and obtain feedback from the project partners. Final presentations are video-recorded. Teams hand over a folder to their project partners including at least 10 different research ideas, reflecting ten different seminar days and their specific design maxims.

During class, the design thinking process is used to overview team activities. In particular, each session has a different point of view (e.g., the viewpoint of Logical Positivism or that of Critical Rationalism). Given this viewpoint, students pursue the phases "brainstorm" and "test prototypes" by generating ideas, presenting them in class and collecting feedback.

In addition to the design thinking process, mottos are used to guide teamwork. For instance, ad mid-term students notice that they present many research strategies the project partners already had thought about. Thus, team ideas seem to provide little additional benefit. Building on this observation, the design thinking motto "encourage wild ideas" is highlighted as a means to come up with yet more surprising and potentially more yielding ideas.

Table 1 summarizes key differences of the seminar before and after 2014.

**Qualitative Observations:** In both teaching paradigms, the seminar receives positive feedback from the students. However, some differences become apparent. First, in the traditional paradigm many students hesitate to tackle fictitious problems. At best, groups seem driven by single "leading students". Without them, group work tends to be sluggish. While some students seem interested, others seem rather bored. When teams are asked to report their results, most students remain silent. Generally, the atmosphere is rather serious.

By contrast, in the design thinking paradigm basically all students immediately seem engaged. Throughout teamwork, the room appears lively and students laugh a lot. In team presentations, each student contributes something. Throughout the presentations, the mood seems to fluctuate between

*Table 1. Features of a seminar on philosophy of science, taught traditionally versus design thinking style*

| | **Class before 2014:Traditional Teaching Paradigm** | **Class after 2014:Design Thinking Paradigm** |
|---|---|---|
| Process Model | NO: Students are not asked to specify a plan for their group-work upfront. Neither is there a process model to guide teamwork. | YES: Students use the design thinking process to overview their activities. |
| Human-Centred Problem | NO: The problems handed out do not focus on the needs of real or fictitious people. | YES: Teams work on behalf of project partners and their personal research concerns. |
| Real-World Challenges | NO: It is not foreseeable that team solutions have any impact on the world after the seminar. | YES: Teams help to design research projects that will take place one way or other. |
| Presentations and Feedback | NO: Single students report teamwork results. There is little feedback. | YES: All students present their teamwork results and obtain feedback in each session. |
| Creative Space | NO: Teams work in a traditional seminar room. | YES: Teams work in an enriched environment with typical design thinking craft materials. Music creates an informal atmosphere. |

nervousness and having fun. Expressions of boredom are rarely observable. If they occur at all, it is most likely during the lectures.

When looking at one and the same cohort of students in different seminars, their behaviour seems to vary greatly. While teachers of other seminars complain that students behave like school children, doing only what they have to do and trying to limit the tasks they are assigned, in the design thinking class students show almost an opposite behaviour. For instance, in the week before the final presentations, most students decide to stay in class after the seminar has ended, and after the teacher has left, to prepare even better presentations for their project partners. This decision does not only imply an additional investment of time. It also means the students have to take care of heavy and bulky craft materials including piles of DIN A2-pages that need to be taken home and brought back to class the next time. Better grades cannot be a motiving factor for this engagement, because there are no grades in this seminar. Thus, students seem to have a lot of intrinsic motivation and they seem to identify with the jobs they do.

Since more positive effects have been observed in the design thinking paradigm, the class continues to be taught this way.

## RESOURCES FOR DESIGN THINKING EDUCATION

To view an example of design thinking education, we suggest the *Stanford Design Thinking Virtual Crash Course* (d.school, 2012c). There is a *process guide* (d.school, 2010b) for creative problem solving that lays out objectives of each process phase. The *bootcamp bootleg* (d.school, 2010a) introduces methods for every phase. The *teaching guide* helps to prepare design thinking challenges (d.school, 2015a). Mindfulness cards (d.school, 2012a) help to create the typical verve of design thinking projects. Royalty, Ladenheim and Roth (2015) overview several techniques to create verve. Music samples for different stages of the process are available online (d.school, 2012c). Von Thienen et al. (2012) discuss the setup of design thinking spaces. Rhinow, Köppen, Jobst and Meinel (2013) lay out prototyping techniques.

In general, the *K-12 lab* at Stanford (d.school, 2015b, 2015c) provides many resources for design thinking education. For instance, there are collections of improve-activities (d.school, 2014) and material

lists (d.school, 2011) describing useful equipment for design thinking projects. There are also sample schedules for design thinking projects at schools (2015d).

Readers interested in books on design thinking might consult Plattner et al. (2009) for an easy to read introduction. Meinel et al. (2015) let different stakeholders including researchers, students, teachers and project partners voice their experiences with design thinking. *Creative confidence* (Kelley & Kelley, 2013) and *the achievement habit* (Roth, 2015) describe philosophies, strategies and tools of design thinking. *Make space* (Doorley & Witthoft, 2012) discusses how to set up spaces for creative teamwork.

Regarding design thinking research and theory, Bryan Lawson (1980), Donald Schön (1983), Peter Rowe (1987), Kees Dorst and Nigel Cross (2001), Dorst (2010) and Cross (2011) have studied how designers and other creative practitioners work in practice and what distinguishes novices from experts. Lindberg (2015) provides a literature review and illuminates several only partially overlapping discourses on "design thinking". Rittel and Webber (1973), Buchanan (1992) and von Thienen et al. (2014) have discussed "wicked problems" or their role in design thinking. Von Thienen & Meinel (2015) attempt an overview and systemization of interventions that figure in design thinking. Plattner, Meinel and Leifer (2011, 2012a, 2012b, 2014, 2015, 2016) discuss objectives and findings of recent design thinking research.

## REFERENCES

Amabile, T. M., Barsade, S. G., Mueller, J. S., & Staw, B. M. (2005). Affect and creativity at work. *Administrative Science Quarterly*, *50*(3), 367–403. doi:10.2189/asqu.2005.50.3.367

Asquith, L., Dorst, C. H., Kaldor, L., & Watson, R. (2013). Design+Crime: Introduction to a special issue of Crime Prevention and Community Safety. *Crime Prevention and Community Safety*, *15*, 169–174. doi:10.1057/cpcs.2013.7

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, *68*(68), 3–12. doi:10.1002/tl.37219966804

Bott, N., Quintin, E.-M., Saggar, M., Kienitz, E., Royalty, A., & Hong, D. W.-C. et al. (2014). Creativity training enhances goal-directed attention and information processing. *Thinking Skills and Creativity*, *13*, 120–128. doi:10.1016/j.tsc.2014.03.005

Brown, T. (2009). *Change by design: How design thinking transforms organizations and inspires innovation*. New York: Harper Collins.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, *8*(2), 5–21. doi:10.2307/1511637

Carleton, T., & Leifer, L. (2009). Stanford's ME310 course as an evolution of engineering design.*Proceedings of CIRP Design Conference 2009*.

Cross, N. (2011). *Design Thinking*. London: Bloomsbury.

Dewey, J. (1916). *Democracy and education: An introduction to the philosophy of education*. New York: MacMillan.

Dewey, J. (1931/1935). Ausweg aus dem pädagogischen Wirrwarr. Inglis Vorlesung 1931. In P. Petersen (Ed.), *Der Projekt-Plan. Grundlegung und Praxis*. Weimar: Böhlau.

Doorley, S., & Witthoft, S. (2012). *Make Space*. Hoboken, NJ: Wiley & Sons.

Dorst, K. (2010). The nature of design thinking. In: K. Dorst, S. Stewart, I. Staudinger, B. Paton, & A. Dong (Eds.), *Proceedings of the 8th Design Thinking Research Symposium (DTRS8)*, 131 - 139.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies*, *22*(5), 425–437. doi:10.1016/S0142-694X(01)00009-6

Dow, S. P., & Klemmer, S. R. (2011). The efficacy of prototyping under time constraints. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Understand – improve – apply* (pp. 111–128). Heidelberg, Germany: Springer. doi:10.1007/978-3-642-13757-0_7

HPI School of Design Thinking. (2015). *Mindset.* Retrieved October 26th, 2015, from http://hpi.de/en/school-of-design-thinking/design-thinking/mindset.html

Jobst, B., Köppen, E., Lindberg, T., Moritz, J., Rhinow, H., & Meinel, C. (2012). The faith-factor in design thinking: Creative confidence through education at the design thinking schools Potsdam and Stanford? In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design Thinking Research. Measuring Performance in Context* (pp. 35–46). Heidelberg, Germany: Springer. doi:10.1007/978-3-642-31991-4_3

Kanning, U. P. (2009). *Inventar sozialer Kompetenz (ISK). Manual and test*. Göttingen: Hogrefe.

Kelley, T., & Kelley, D. (2013). *Creative confidence*. London: Harper Collins.

Kilpatrick, W. H. (1918). The project method. *Teachers College Record*, *19*, 319–335.

Kress, G. L., & Schar, M. (2012). Teamology: The art and science of design team formation. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Studying co-creation in practice* (pp. 189–210). Heidelberg, Germany: Springer. doi:10.1007/978-3-642-21643-5_11

Lawson, B. (1980). *How designers think*. London: Architectural Press.

Leifer, L. (2012). *Dancing with ambiguity - design thinking in action, theory from practice*. Retrieved October 26th, 2015, from https://www.youtube.com/watch?v=N38_XgoL28k

Leifer, L. (2013). *Engineering design thinking.* Retrieved October 26th, 2015, from https://www.youtube.com/watch?v=mid6agTYnTU

Liedtka, J., & Ogilvie, T. (2011). *Designing for growth: A design thinking tool kit for managers*. New York: Columbia Business School Publishing.

Lindberg, T. (2014). *Design Thinking Diskurse. Bestimmung, Themen, Entwicklungen.* (Doctoral Dissertation). University of Potsdam, Potsdam, Germany. Retrieved October 26th, 2015, from http://d-nb.info/1048223701/34

Mehan, H. (1979). 'What time is it, Denise?': Asking known information questions in classroom discourse. *Theory into Practice*, *28*(4), 285–294. doi:10.1080/00405847909542846

Meinel, C., Weinberg, U., & Krohn, T. (2015). *Design Thinking Live*. Hamburg: Murmann.

Noweski, C., Scheer, A., Büttner, N., von Thienen, J. P. A., Erdmann, J., & Meinel, C. (2012). Towards a paradigm shift in education practice: Developing twenty-first century skills with design thinking. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Measuring performance in context* (pp. 71–94). Heidelberg, Germany: Springer. doi:10.1007/978-3-642-31991-4_5

Plattner, H. (2009). Entstehungsgeschichte der HPI School of Design Thinking. In H. Plattner, C. Meinel, & U. Weinberg (Eds.), *Design Thinking* (pp. 11–26). München: MI Wirtschaftsbuch.

Plattner, H., Meinel, C., & Leifer, L. (2011). *Design thinking. Understand – improve – apply*. Heidelberg, Germany: Springer.

Plattner, H., Meinel, C., & Leifer, L. (2012a). *Design thinking research. Measuring performance in context*. Heidelberg, Germany: Springer.

Plattner, H., Meinel, C., & Leifer, L. (2012b). *Design thinking research. Studying co-creation in practice*. Heidelberg, Germany: Springer.

Plattner, H., Meinel, C., & Leifer, L. (2014). *Design thinking research. Building innovation eco-systems*. Cham: Springer.

Plattner, H., Meinel, C., & Leifer, L. (2015). *Design thinking research. Building innovators*. Cham: Springer.

Plattner, H., Meinel, C., & Leifer, L. (2016). *Design thinking research. Making design thinking foundational*. Heidelberg, Germany: Springer. doi:10.1007/978-3-319-19641-1

Plattner, H., Meinel, C., & Weinberg, U. (2009). *Design Thinking*. München: MI Wirtschaftsbuch.

Rasfeld, M. (2015). Schule neu denken. In C. Meinel, U. Weinberg, & T. Krohn (Eds.), *Design Thinking Live* (pp. 54–62). Hamburg: Murmann.

Rauth, I., Köppen, E., Jobst, B., & Meinel, C. (2010). Design thinking: An educational model towards creative confidence. In *Proceedings of the 1st International Conference on Design Creativity*.

Rhinow, H., Köppen, E., Jobst, B., & Meinel, C. (2013). *Design thinking prototyping cardset*. Potsdam: Hasso Plattner Institut für Softwaresystemtechnik.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. doi:10.1007/BF01405730

Roth, B. (2015). *The achievement habit*. New York: Harper Collins.

Rowe, P. G. (1987). *Design thinking*. Cambridge, MA: MIT Press.

Royalty, A., Ladenheim, K., & Roth, B. (2015). Assessing the development of design thinking: From training to organizational application. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Building innovators* (pp. 73–86). Cham: Springer. doi:10.1007/978-3-319-06823-7_6

Royalty, A., Oishi, L., & Roth, B. (2014). Acting with creative confidence: Developing a creative agency assessment tool. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Building innovation eco systems* (pp. 79–96). Cham: Springer. doi:10.1007/978-3-319-01303-9_6

Royalty, A., Oishi, L. N., & Roth, B. (2012). "I use it every day": Pathways to adaptive innovation after graduate study in design thinking. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Measuring performance in context* (pp. 95–105). Heidelberg, Germany: Springer. doi:10.1007/978-3-642-31991-4_6

Royalty, A., & Roth, B. (2016). Developing design thinking metrics as a driver of creative innovation. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Making design thinking foundational*. Heidelberg, Germany: Springer. doi:10.1007/978-3-319-19641-1_12

Saggar, M., Quintin, E.-M., Kienitz, E., Bott, N. T., Sun, Z., & Hong, W.-C. et al. (2015). Pictionary-based fMRI paradigm to study the neural correlates of spontaneous improvisation and figural creativity. *Scientific Reports*, *5*, 10894. doi:10.1038/srep10894 PMID:26018874

Schmidt, H. G. (1983). Problem-based learning. Rationale and description. *Medical Education*, *17*(1), 11–16. doi:10.1111/j.1365-2923.1983.tb01086.x PMID:6823214

Schön, D. A. (1983). *The reflective practitioner. How professionals think in action*. New York: Basic Books.

d school – Hasso Plattner Institute of Design at Stanford. (2010a). *Bootcamp Bootleg*. Retrieved October 26th, 2015, from http://dschool.stanford.edu/wp-content/uploads/2011/03/BootcampBootleg2010v2SLIM.pdf

d. school – Hasso Plattner Institute of Design at Stanford. (2010b). *An introduction to design thinking. Process guide.* Retrieved October 26th, 2015, from https://dschool.stanford.edu/sandbox/groups/design-resources/wiki/36873/attachments/74b3d/ModeGuideBOOTCAMP2010L.pdf?sessionID=c2bb722c7c1ad51462291013c0eeb6c47f33e564

d school – Hasso Plattner Institute of Design at Stanford. (2011). *Materials list*. Retrieved October 26th, 2015, from https://dschool.stanford.edu/groups/k12/wiki/56b69/Materials_List.html

d school – Hasso Plattner Institute of Design at Stanford. (2012a). *Mindfulness Cards*. Retrieved October 26th, 2015, from http://dschool.stanford.edu/wp-content/uploads/2012/05/MindfulnessCards.pdf

d. school – Hasso Plattner Institute of Design at Stanford. (2012b). *Mixtapes*. Retrieved October 26th, 2015, from http://dschoolmixtapes.blogspot.de

d. school – Hasso Plattner Institute of Design at Stanford. (2012c). *Stanford design thinking virtual crash course*. Retrieved October 26th, 2015, from https://www.youtube.com/watch?v=-FzFk3E5nxM

d. school – Hasso Plattner Institute of Design at Stanford. (2014). *Improv activities for design thinking.* Retrieved October 26th, 2015, from https://dschool.stanford.edu/groups/k12/wiki/3091c/Improv_activities_for_Design_Thinking.html

d. school – Hasso Plattner Institute of Design at Stanford. (2015a). *Design thinking teaching guide. Ideas and strategies for implementing design thinking in schools*. Retrieved October 26th, 2015, from https://dschool.stanford.edu/sandbox/groups/k12/wiki/14340/attachments/e55cd/teacher%20takeaway.pdf?sessionID=4a0b9f72819331fd36a92ede4be5c622d3af2923

d. school – Hasso Plattner Institute of Design at Stanford. (2015b). *The K12 Lab Wiki*. Retrieved October 26th, 2015, from https://dschool.stanford.edu/groups/k12

d. school – Hasso Plattner Institute of Design at Stanford. (2015c). *K12 Lab Network*. Retrieved October 26th, 2015, from http://www.k12lab.org

d school – Hasso Plattner Institute of Design at Stanford. (2015d). *Curriculum for K12 students*. Retrieved October 26th, 2015, from https://dschool.stanford.edu/groups/k12/wiki/47957/Curriculum_for_K12_students.html

Sinclair, J., & Coulthard, M. (1975). *Towards an analysis of discourse*. Oxford University Press.

Stanford Medicine. (2015). *Researchers tie unexpected brain structures to creativity – and to stifling it.* Retrieved October 26th, 2015, from https://med.stanford.edu/news/all-news/2015/05/researchers-tie-unexpected-brain-structures-to-creativity.html

von Thienen, J. P. A., & Meinel, C. (2015). Building on a Stages of Change Model to bring home more big design thinking ideas. *Electronic colloquium on design thinking research.* Retrieved from http://ecdtr.hpi-web.de/report/2015/001

von Thienen, J. P. A., Meinel, C., & Nicolai, C. (2014). How design thinking tools help to solve wicked problems. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research. Building innovation eco-systems* (pp. 97–102). Cham: Springer. doi:10.1007/978-3-319-01303-9_7

von Thienen, J. P. A., Noweski, C., Meinel, C., & Rauth, I. (2011). The co-evolution of theory and practice in design thinking – or – "mind the oddness trap! In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking. Understand – improve – apply* (pp. 81–99). Heidelberg, Germany: Springer. doi:10.1007/978-3-642-13757-0_5

von Thienen, J. P. A., Noweski, C., Rauth, I., Meinel, C., & Lang, S. (2012). If you want to know who you are, tell me where you are: The importance of places. In H. Plattner, C. Meinel, & L. Leifer (Eds.), Design thinking research: Studying co-creation in practice (pp. 53-73). Heidelberg, Germany: Springer.

Wagner, T. (2010). *The global achievement gap: Why even our best schools don't teach the new survival skills our children need – and what we can do about it*. New York: Basic Books.

Zhou, C., & Valero, P. (2016). A comparison of creativity in project groups in science and engineering education in Denmark and China. In G. E. Corazza & S. Agnoli (Eds.), *Multidisciplinary contributions to the science of creative thinking* (pp. 133–151). Heidelberg, Germany: Springer. doi:10.1007/978-981-287-618-8_9

## KEY TERMS AND DEFINITIONS

**Comfort Zone:** The behaviours, feelings and solutions someone is familiar with. Since creative solutions often entail the exploration of something new and unfamiliar, interventions to "abandon comfort zones" can support the development of creative problem-solving skills.

**Creative Mastery:** The ability to develop creative problem views and creative solutions.

**Creative Problem View:** A problem view is creative when it is unusual and useful.

**Creative Solution:** The solution to a problem is creative when it is unusual and useful.

**Creative Verve:** A psychological state characterized by a high level of energy, positive emotions towards a subject of interest (excitement, curiosity, amazement), the experience of passion next to a mindset of openness to different viewpoints and new experiences, creative confidence and readiness to persevere.

**Design Thinking:** A work culture where multi-perspective teams seek and solve wicked problems or design challenges by applying a creative problem solving process and using adaptable work spaces.

**Design Thinking Mindset:** The design thinking mottos (focus on human values, bias to action, radical collaboration…) have become manifest in personal beliefs, values, skills and behaviour inclinations.

**Design Thinking Process:** A process of creative problem solving. The process exists in many different versions, such as "Express – Test – Cycle", "What Is – What If – What Wow's – What Works" or "Empathize – Define View – Ideate – Test Prototypes – Bring Home".

**Design Thinking Verve:** The work atmosphere aspired in design thinking education. People partake in design thinking verve when they are excited about their projects, use a high pace of work, readily abandon comfort zones, experiment and learn from failures, lean trustfully into the process, regularly experience and share amazement. Verve is an essential element of design thinking. Many interventions focus on the development of verve.

**Look and Feel of Classes:** Cues in education (room setup, appearance and behaviour of teachers and fellow-students) that suggest a specific scenario (e.g., more or less hierarchical), including roles, motives and emotions of stakeholders (e.g., fearful students that shall demonstrate literacy or excited students who want to showcase creative solutions).

**Problem Space:** The range of possibilities how to frame a wicked problem. In particular, the problem space can cover multiple (a) persons/stakeholders, (b) needs and (c) reasons why a major need is unsatisfied at present.

**Solution Space:** The range of possibilities how to solve a wicked problem that is already framed in a specific way. I.e., it is clear what need of what person(s) shall be addressed.

**Wicked Problem (in Design Thinking):** A problem based on unsatisfied needs. Solutions can be better-or-worse, not right-or-wrong. Typically, creative solutions to wicked problems depend on creative problem views.