

DESIGN THINKING IN SCIENCE TEACHING - EXPERIENCES FROM TWO APPROACHES TO INTEGRATING A NEW LEARNING CONCEPT

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Abstract

Today's students are growing up in a world where they are confronted with a multitude of information that they must organize and evaluate. In order to find their way around, they need not only basic technical knowledge but also skills such as creativity, critical thinking, communication and collaboration (some of the so-called future skills). In order to prepare students for this world and equip them with these competences, an approach based on design thinking seems promising. This approach has gained considerable attention in the implementation of innovations in companies worldwide and has already found its way into schools as a learning method in some cases. Since the future skills also play an important role in the assessment of climate issues, the concept is also suitable for use in schools in the context of Education for Sustainable Development (ESD). Two approaches to integrating design thinking into science teaching in schools were therefore tested in studies conducted as part of PhD projects. Both approaches took special account on ESD aspects. The first project specifically focused on examining the framework conditions and success factors for use in upper secondary school chemistry lessons. To this end, three modules, each comprising 10 lessons, were developed for grades 11-13 and implemented with two parallel classes over three consecutive years. Using a design-based research approach, the lessons were observed and the students' learning diaries were evaluated. It was proven that the integration of design thinking was successful with regard to some future-oriented competences. In particular, students' creativity and evaluation skills increased, and the suitability of the framework conditions was demonstrated. In the second project, building on the experience gained, a broader, interdisciplinary approach was chosen. For this, another design thinking approach was implemented at a school over a period of three years. This approach was expanded to include the aspect of service learning within a project-based format to create a positive effect on society. Groups of 12th grade students were given one school year each to independently develop sustainable projects. In a qualitative research design approach based on the CIPP model (Context, Input, Product and Process), students and teachers were interviewed in detail about their expectations and experiences before and after every round, with the annual results being used to optimize the approach. The findings demonstrate that the project participants achieved learning gains across various competence domains.

Keywords: *Design thinking, service learning, science education, ESD.*

1. Introduction

Design thinking is an innovation approach that was developed at Stanford University with the aim of helping companies find solutions to complex problems for which there is no clear answer. These may involve the development of new products, the design of new processes, or other challenges. The method can therefore also be applied to issues in all areas of life. A fundamental prerequisite for successful implementation is an open attitude of everyone involved towards new ideas (Lor, 2017; Gerling & Gerling, 2018).

Design thinking is characterized by a consistent user-centeredness, iterative development loops, and work in interdisciplinary teams, thereby promoting key competencies such as creativity, critical thinking, communication and problem-solving skills (Meinel & Krohn, 2022). In school contexts in particular, it is seen as a method that combines project-based learning with the aim of addressing real challenges from the learners' everyday lives and developing practical solutions (Feldhaus et al., 2018).

Against this background, Design Thinking can be applied as a framework that supports competence-oriented science education by structurally linking inquiry-based learning, real-world problem contexts, and iterative knowledge construction. In this sense, the approach offers a coherent pedagogical structure for addressing future-oriented learning goals (the so-called future skills) in science education and has been increasingly taken up in school-based practice (Rampelt et al., 2025; Fadel et al., 2017).

The approach is still relatively new in the field of education and offers considerable scope for research and development projects, especially in schools. Thus, we conducted two research projects as part of doctoral studies to investigate the integration of Design thinking into school-based science education, with particular consideration of Education for Sustainable Development (ESD). The first project examined framework conditions and success factors for implementation in upper secondary chemistry education through the development and iterative refinement of modular teaching units, demonstrating positive effects on students' future skills, particularly creativity and evaluative competences. Building on these findings, the second project adopted a broader interdisciplinary perspective by embedding Design thinking within a project-based service-learning format, enabling students to develop sustainability-oriented projects over an extended period. Using a qualitative evaluation framework, the results indicated learning gains across multiple competence domains for both students and teachers. The following sections present these two approaches in detail.

2. First study

Building on insights from prior empirical research, potential framework conditions for the successful integration of Design thinking into upper secondary science education were identified and examined. In line with findings by Wrigley and Straker (2017), a modular structure consisting of three consecutive units was identified as a promising approach and subsequently implemented. The intervention was conducted with two parallel upper secondary courses (approximately 40 students) across grades 11 to 13 at a secondary school in North Rhine-Westphalia, Germany. Each module comprised ten teaching hours. Drawing on the work of Taheri et al. (2016), the design was informed by evidence suggesting that participants' creative self-efficacy can be effectively fostered even within relatively short instructional formats.

Research approach: In alignment with the modular structure of the design, a design-based research (DBR) approach was adopted to enable iterative refinement of the concept across successive modules. Following methodological guidelines proposed by Plomp (2013), the research design allowed for the systematic incorporation and evaluation of potential improvements during the ongoing implementation process. The overarching research question, informed by the framework of Plomp and Niewen (2010), examined whether the derived framework conditions support the integration of Design thinking into upper secondary chemistry education.

Methodology: A pilot study was conducted to identify suitable instruments for systematically capturing classroom implementation, prior to drawing conclusions regarding the proposed framework conditions. To this end, teachers in training observed the students' teams during chemistry lessons in which design thinking was applied and produced detailed observation protocols. These observational data were triangulated with students' learning diaries, in which the teams documented and reflected on their learning processes throughout the lessons. Subsequently, the learning diaries were subjected to qualitative content analysis to examine whether, how, and to what extent design thinking was enacted, with particular attention to students' progression through the individual phases and their use of core design thinking principles, such as iterative development. The degree of implementation was operationalized through the extent and depth of phase-related coding and the frequency of Design thinking-related competencies. Variations in implementation quality were interpreted in relation to potential influencing factors, including time management, team collaboration, problem engagement, and methodological proficiency (Wolthaus & Gröger, 2024).

The newly integrated evaluation phase was examined in particular with reference to sustainability-related criteria developed by Eggert and Bögeholz (2006). Indicators of creativity were identified in the learning diaries using the subdimensions of originality, flexibility, and number of ideas. In addition to these qualitative assessments, quantitative data were collected through paper-and-pencil instruments. Specifically, constructs such as students' self-efficacy beliefs and their subject-related self-concept in chemistry were measured using a pre-post design based on established and validated questionnaires (Spitzer, 2017; Weßnigk, 2013; Jerusalem & Schwarzer, 1999).

Results and discussion: The pilot study, which comprised three consecutive modules addressing different sustainability-related topics, demonstrated the suitability of the students' learning diaries as a meaningful instrument for data collection. The analyses indicate that learners progressed through all phases of the design thinking process and applied core principles such as iterative development and visualization.

Overall phase-related coding and the use of Design thinking-related competencies increased across the modules and reached their highest levels in the third module. This pattern suggests a positive effect of the modular structure, with particularly strong gains observed among students with initially lower performance levels.

With regard to creativity, the number of solution ideas generated by the student teams increased over the course of the modules, reflecting one dimension of creativity alongside flexibility and originality. These findings point to the potential for further targeted strategies aimed at fostering additional dimensions of creative thinking. In the newly integrated evaluation phase, students demonstrated continuous improvements in their assessment skills throughout the modules.

The analysis of questionnaire data on self-efficacy beliefs revealed comparable changes in mean values across all three modules, with consistently lower scores reported by female students (cf. Hinz et al., 2006). Reliability analyses yielded Cronbach's alpha values comparable to those reported in related studies (ibid.), indicating satisfactory internal consistency of the instruments.

Paired-sample t-tests identified a statistically significant increase in self-efficacy expectation in the third module, with mean scores rising from pre- to post-intervention. Additional findings include an improvement in students' subject-related perceptions of chemistry in the final module, as well as evidence that the student groups progressed through identifiable team-building phases during the course of the intervention.

3. Second study

Research approach: The second study was designed as evaluation research, in which a school project was systematically assessed in terms of its implementation, goal achievement, and impact. This study aimed to evaluate the conditions for success of an educational format that was developed and tested as part of the project "Next Generation Design for Climate" (NGDfC) in cooperation with the University of Siegen, the Sparkasse, and secondary schools in the region.

By combining project-based learning, service learning, and design thinking as educational approaches, the study sought to investigate: under which conditions this combination could be effectively implemented in a school context; which factors promote or inhibit the success of the format; and what specific requirements arise from it for the further development of comparable educational initiatives. Secondly, interdisciplinary skills, attitudes, and experiences that enable students to understand social challenges and work on solutions to them were also to be identified. The investigation took the perspectives of the two central stakeholders, namely students and teachers, into consideration (Souza de Oliveira, 2025).

As a framework for conducting the evaluation, the four-dimensional CIPP Evaluation Model developed by Stufflebeam & Coryn (2014) was used. This model provides guidance for evaluating the *context* (in terms of an organization's need for correction or improvement); *inputs* (strategies, operational plan, resources, and agreements for implementing a necessary intervention); *process* (implementation and costs of the intervention); and *products* (the positive and negative outcomes of the efforts) (Stufflebeam & Coryn, 2014).

The research questions for the evaluation of the NGDfC project, referred to here as evaluation questions, have then been developed based on the CIPP model. The four dimensions gave rise to six evaluation questions, each of which containing formative and summative aspects and addressing the specific evaluation parameters of the project: needs, innovation character, implementation, execution improvement, success indicators and side effects.

Implementation: The project was initially implemented in two elementary schools in the form of project courses (project-oriented elective courses) for middle and high school students over the course of three years. At school, participants first worked intensively in working groups on the technical basics of a problem (the so-called challenge), specifically on environmental topics and related socio-political issues. One challenge that was used for two rounds was, for example: "How can we reduce our city's ecological footprint, taking into account technological or social concepts, while at the same time generating added value for the city's citizens?". Using the knowledge and skills acquired, students developed solutions using the design thinking methodology, which they discussed with stakeholders from the region's business, political, civil society, and scientific communities. These solutions could be implemented both as prototypes and in concrete terms.

Methodology: The evaluation process was conducted as follows: first, data was collected through guided interviews before and after each round. On this basis, the key challenges were identified and an optimization plan was developed. In the following round, specific measures were implemented and the data was collected again. This cycle was then repeated, and at the end of the third round, the last optimization plan was developed for possible future project phases.

The data was collected on the basis of semi-structured interviews in order to capture the individual experiences and perspectives of those involved in an open but also targeted manner. The interview guidelines were based on the CIPP model and the six evaluation questions, which served as a framework for eleven interview questions. The interviews were conducted formatively and summatively, i.e., before and after the project cycles. The guidelines were adapted in terms of language and content for each stakeholder group.

The interview data was analysed using the *focused analysis of qualitative interviews* method developed by Kuckartz and Rädiker (2024), which was specifically designed for the computer-assisted evaluation of semi-structured interviews using MAXQDA. The analysis process is divided into six clearly defined steps that build on each other: 1. Data preparation and exploration; 2. Development of the category system; 3. Basic coding; 4. Further development of the category system and detailed coding; 5. Analysis of the coded data, and 6. Report and documentation.

Results and Discussion: The following results refer to the data collected from one school, where the project was consistently conducted over the course of three years with high school students. The format at this school consisted of a one-year project course combining the subjects of chemistry and social sciences.

The evaluation of the three-year project course confirms that the combination of project-based learning, design thinking, and service learning offers great potential for promoting technical, social, and personal skills among students. The interviews showed that self-selected topics, real-world problems, and interdisciplinary forms of work were particularly motivating and effective for learning. The students developed a strong sense of responsibility for their projects and repeatedly described personal development steps in the areas of self-organization, communication skills, and social engagement.

From the teachers' perspective, the project proved to be challenging in terms of supervision, but at the same time didactically innovative and conducive to development. The findings indicate that the effectiveness of the format is strongly associated with structural enabling conditions, including sufficient time resources, consistent supervision, and curricular integration. At the same time, variations became apparent in how individual groups implemented the project, particularly in their interaction with external partners and their ability of self-management. This variability underscores the importance of clearly defined support structures and ongoing reflective phases over the course of the project (Souza de Oliveira, 2025).

4. Conclusion

The findings from the first study indicate that the primary objective of design thinking, understood here as the strengthening of creative self-efficacy, was successfully achieved. The concept developed for chemistry education proved effective in fostering creativity as a key sub-competence, enhancing students' evaluative skills, and contributing to a more positive perception of chemistry as a subject. With the integration of a dedicated evaluation phase, the approach now represents a comprehensive classroom-based implementation of design thinking. The identified framework conditions were likewise confirmed as supportive, with the structured modular design particularly benefiting students with lower initial performance levels. From a pedagogical perspective, the results suggest that a duration of approximately ten lessons per module is appropriate, allowing sufficient time for both curricular competence development and the gradual introduction of Design thinking principles. Implementing multiple modules in sequence appears especially conducive to the internalization of these principles, while the use of learning diaries supports students' reflective capacities and consolidates learning processes (Wolthaus & Gröger, 2024).

For the second study, the findings indicate a high relevance of the project format for fostering future competencies and a culture of innovation within schools. The project was perceived not only as professionally enriching but also as an identity-forming learning experience. In addition, unexpected positive effects emerged with regard to personal development and school visibility. With respect to transferability to other contexts, the interlinking of methodological openness with institutional embedding appears to be a key condition for success (Souza de Oliveira, 2025).

Overall, the findings demonstrate that Design thinking represents a viable and effective approach for science education in the context of ESD. When appropriately structured and institutionally embedded, the approaches support the development of key competencies such as creativity, evaluative and communication skills, organization and social responsibility, while also fostering positive engagement with science learning. By linking subject-specific knowledge with real-world sustainability challenges, Design thinking contributes to both individual competence development and the promotion of innovative learning cultures in schools, thereby offering a transferable framework for ESD-oriented science education.

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References

- Eggert, S., & Bögeholz, S. (2006). Göttinger Modell der Bewertungskompetenz-Teilkompetenz „Bewerten, Entscheiden und Reflektieren“ für Gestaltungsaufgaben Nachhaltiger Entwicklung. *Zeitschrift für Didaktik der Naturwissenschaften*, 12, 177-197.
- Fadel, C., Bialik, M., & Trilling, B. (2017). *Die vier Dimensionen der Bildung*. Berlin, Germany: ZLL21 Zentralstelle für Lernen und Lehren im 21. Jahrhundert e.V.
- Feldhaus, L., Primavera, J., & Kleibl, A. (2018). *Design Thinking und Schule: Das Handbuch für den Schulalltag* (2nd ed.). Weinheim, Germany: INNOKI GmbH & Co. KG.
- Gerling, A., & Gerling, G. (2018). *Der Design-Thinking-Werkzeugkasten*. Heidelberg: dpunkt.verlag.
- Hinz, A., Schumacher, J., Albani, C., Schmid, G., & Brähler, E. (2006). Bevölkerungsrepräsentative Normierung der Skala zur allgemeinen Selbstwirksamkeitserwartung. *Diagnostica*, 52(1), 26-32.
- Jerusalem, M., & Schwarzer, R. (1999). *Skala zur allgemeinen Selbstwirksamkeitserwartung: Skalen zur Erfassung von Lehrer- und Schülermerkmalen. Dokumentation der psychometrischen Verfahren im Rahmen der wissenschaftlichen Begleitung des Modellversuchs Selbstwirksame Schulen*. Berlin, Germany: Freie Universität Berlin.
- Kuckartz, U., & Rädiker, S. (2024). *Fokussierte Interviewanalyse mit MAXQDA: Schritt für Schritt* (2nd ed.). Wiesbaden, Germany: Springer Fachmedien.
- Lor, R. (2017). Design thinking in education: a critical review of literature. *Asian Conference on Education & Psychology, Conference Proceedings* (pp. 36-68). Bangkok, Thailand.
- Meinel, C., & Krohn, T. (2022). *Design thinking in education*. Cham, Switzerland: Springer International Publishing.
- Plomp, T. (2013). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *Educational design research – Part A: An introduction* (pp. 10-51). Enschede, The Netherlands: SLO.
- Plomp, T., & Nieveen, N. M. (2010). An introduction to educational design research. In: T. Plomp & N. M. Nieveen (Eds.), *Proceedings of the seminar conducted at the East China Normal University, Shanghai (PR China), November 23–26, 2007* (3rd print ed.). Enschede, The Netherlands: Stichting Leerplan Ontwikkeling (SLO).
- Rampelt, F., Matthes, W., Hannken-Illjes, K., Sandmeir, A., Gehrs, V., Horstmann, N., Kunz, A. M., Eigbrecht, L., Johannsen, T., Blum, S., Frank, S., Sutter, C., & Koch, H. (2025). *Future Skills 2030. Ein aktualisiertes Framework für Zukunftskompetenzen*. Berlin: Stifterverband. DOI: 10.5281/zenodo.17910748
- Souza de Oliveira, K. (2025). *"Next Generation Design for Climate" mit Schulen im Siegerland: Eine Evaluationsstudie zu Design Thinking verbunden mit Service-Learning in fächerverbindenden Projekten* (Doctoral dissertation, University of Siegen, Germany). DOI: 10.25819/ubsi/10822
- Spitzer, P. (2017). *Untersuchungen zur Berufsorientierung als Baustein eines relevanten Chemieunterrichts im Vergleich zwischen Mittel- und Oberstufe sowie Darstellung des Chem-Trucking-Projektes als daraus abgeleitete Interventionsmaßnahme für den Chemieunterricht* (Doctoral dissertation, University of Siegen, Germany).
- Stufflebeam, D. L., & Coryn, C. L. S. (2014). *Evaluation theory, models, and applications* (2nd ed.). San Francisco, CA: Jossey-Bass et Pfeiffer Imprints, Wiley.
- Taheri, M., Unterholzer, T., Hölzle, K., & Meinel, C. (2016). An educational perspective on design thinking learning outcomes. *Proceedings of the ISPIM Innovation Symposium* (1). Boston, USA: The International Society for Professional Innovation Management (ISPIM).
- Weßnigk, S. (2013). *Kooperatives Arbeiten an industrienahen außerschulischen Lernorten* (Doctoral dissertation, Christian-Albrechts-Universität Kiel, Germany).
- Wolthaus, P., & Gröger, M. (2024). Design thinking in teaching science: Suitable framework conditions for the development and implementation of a new teaching concept. *EDULEARN24 Proceedings: 16th International Conference on Education and New Learning Technologies* (pp. 804-808). Palma, Spain: IATED. DOI: 10.21125/edulearn.2024.0296
- Wrigley, C., & Straker, K. (2017). Design thinking pedagogy: The educational design ladder. *Innovations in Education and Teaching International*, 54(4), 374-385.