



**HAL**  
open science

# Learning, designing and reflecting: Prospective teachers acquire digital competencies by designing digital learning environments

Annabelle Speer, Andreas Eichler

## ► To cite this version:

Annabelle Speer, Andreas Eichler. Learning, designing and reflecting: Prospective teachers acquire digital competencies by designing digital learning environments. Thirteenth Congress of the European Society for Research in Mathematics Education (CERME13), Alfréd Rényi Institute of Mathematics; Eötvös Loránd University of Budapest, Jul 2023, Budapest, Hungary. hal-04412368

**HAL Id: hal-04412368**

**<https://hal.science/hal-04412368v1>**

Submitted on 23 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Learning, designing and reflecting: Prospective teachers acquire digital competencies by designing digital learning environments

Annabelle Speer and Andreas Eichler

University of Kassel, Germany; [annabelle.speer@mathematik.uni-kassel.de](mailto:annabelle.speer@mathematik.uni-kassel.de)

*In classrooms today, mathematics teachers need to have digital competencies to digitally enrich their teaching. However, research has shown that even prospective and beginning teachers are not able to efficiently integrate digital tools into their teaching. Therefore, university teacher training should focus on the acquisition of digital competencies. For this purpose, we developed a university training course aimed at fostering prospective mathematics teachers' digital competencies by enabling them to design and use digital learning environments using the digital tool STACK. The key elements of the training course and one prospective teacher's experiences are discussed in this paper. The results indicate that this course concept has a positive impact on the development of digital competencies.*

*Keywords: Teacher education, feedback, digital competencies, prospective teachers, STACK.*

## Introduction

The ongoing digitalisation in our society provides new demands and standards for schools (Frailon et al., 2020) and is thus related to a growing relevance of digital tools in mathematics education. Research has shown that the integration of digital tools can positively influence school students' mathematics learning, for example by eliminating misconceptions (Narciss, 2008). In particular, intelligent tutoring systems, which are characterised by the ability to give individualised feedback, can have great impact on school students' learning (Hillmayr et al., 2020). The digital tool STACK (Sangwin, 2013) can be seen as an intelligent tutoring system as it offers the possibility to design digital mathematical tasks, randomise them and give individualised feedback for different inputs. We focus on STACK as it is considered to be a promising digital tool for mathematics education that positively influences school students' learning processes.

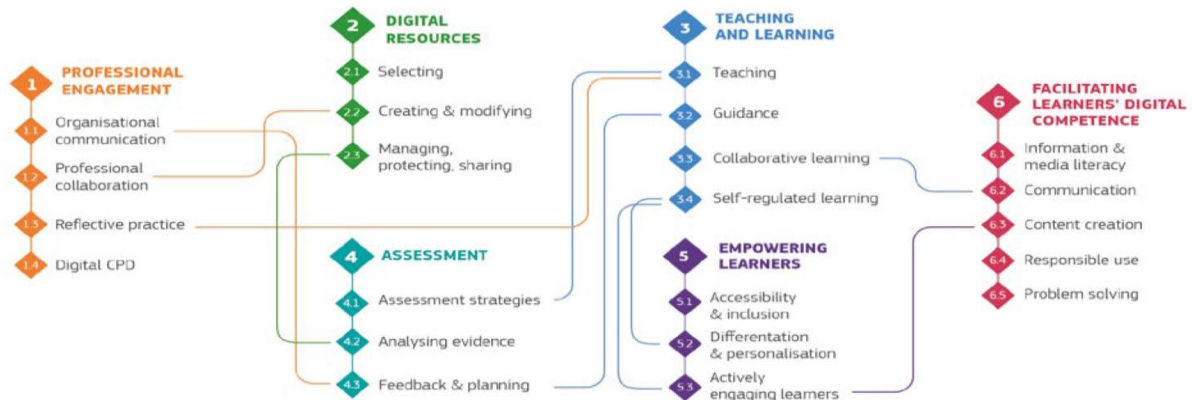
However, it has been shown that digital tools can even have negative effects on school students' mathematical understanding (Jankvist et al., 2019). Consequently, teachers require further training in how to implement digital tools to exploit their didactical potential (Hillmayr et al., 2020; Jankvist et al., 2019). In fact, even prospective teachers do not seem to be adequately prepared to design and implement these tools in the classroom (Tondeur et al., 2012). For this reason, a goal of university teacher training is to foster prospective mathematics teachers' digital competencies (Redecker, 2017).

In this paper, we present a Design-Based Research approach to develop the training course "Digital tasks" for prospective mathematics teachers. This course aims to increase prospective teachers' digital competencies by focusing on the digital tool STACK. From this approach, we refer to a result of a design cycle by portraying an exemplary training course participant and her considerations during the university course. In this contribution, we aim to answer the following research question:

How can prospective teachers in a university training course with a focus on learning, designing and reflecting acquire digital competencies in relation to the design of digital tasks with digital feedback?

## Digital competencies and the integration into university teacher training

This paper follows the European framework for the Digital Competence of Educators (DigCompEdu, Redecker, 2017), in which digital competencies encompasses six areas focusing on different aspects on teachers' professional lives (Figure 1).



**Figure 1: The DigCompEdu framework (Redecker, 2017, p. 8)**

Area 1 (Professional engagement) particularly emphasises that teachers should critically reflect on their digitally enriched teaching practice individually and collectively. Area 2 (Digital resources) comprises the selection, creation and modification of digital tools. The third area (Teaching and learning) focuses on the integration of digital tools in teaching practices and methods to promote self-regulated learning. Area 4 (Assessment) highlights the use of digital tools to assess and guide school students' learning, including the use of feedback. The fifth area (Empowering learners) focuses on responding to school students' needs and promotes differentiation. Area 6 states that teachers should facilitate their school students' digital competencies.

One area of prospective teachers' digital competencies that should be fostered in the university course "Digital tasks" is the technical design of digital STACK tasks (2.2 Creating and Modifying, Redecker, 2017). The technical design of digital STACK tasks is closely mentored as Tondeur et al. (2012) stated that prospective teachers need mentoring as well as collaboration with peers while designing digital tools. Another digital competency this course focusses on is feedback (4.3 Feedback & planning, Redecker, 2017). To design digital STACK tasks, prospective teachers also need to design digital feedback on specific inputs/errors. In doing so, they need to be aware of the extent to which their designed feedback guides, supports and assesses school students' learning process. Another part of the training course includes teaching with digital tools (3.1 Teaching, Redecker, 2017). Prospective teachers should gain practical experiences in planning and using their designed digital STACK tasks and feedback with school students. Research emphasises that observing and analysing how other (prospective) teachers implement digital tools cannot replace own practical experiences (Dunst et al., 2019; Tondeur et al., 2012). To ensure that prospective teachers are not overwhelmed by practice, the practical experiences should be controlled and repeated (Dunst et al., 2019). In order to increase reflective parts of prospective teachers' digital competencies (1.3 Reflective practice, Redecker, 2017), phases of self- and peer-reflection, also with reference to school students' feedback, are considered in the training course "Digital tasks" (Tondeur et al., 2012; Tulgar, 2019).

## Feedback as one area of digital competencies

Feedback can be seen as information which focuses on aspects of performance and understanding (Hattie & Timperley, 2007). Different forms of feedback can be distinguished: “Feedback is more effective the more information it contains. Simple forms of reinforcement and punishment have low affect, while high-information feedback is most effective” (Wisniewski et al., 2020, p. 12). Feedback which contains information about errors made while processing, information about terminology used in the task or information about meta-cognitive strategies can be defined as high-information or elaborated feedback (Narciss, 2008). In the classroom, it can be assumed that non-digital feedback is undifferentiated due to the large number of school students (Voerman et al., 2012). Within digital learning environments, there are numerous possibilities to provide feedback on learning processes (Narciss, 2008), so that there is a greater scope for teachers’ action.

## Materials and methods

### The digital tool STACK and its potential of providing individualised feedback

STACK (System for Teaching and Assessment using Computer algebra Kernel, Sangwin, 2013; more information and exemplary STACK tasks can be found by following <https://stack-assessment.org/>) is an open source digital tool which can be used to design digital mathematical tasks using different representations (graphical, symbolic). STACK offers the possibility to create tasks randomly and thus generate different variants of tasks automatically. Furthermore, STACK uses the computer algebra system Maxima, which allows the input of algebraic expressions and the validation of mathematical properties of the inputs. Another key functionality of STACK is the ability to provide individualised feedback for specific inputs and errors. This is made possible via the so-called potential response trees which consist of different nodes. At each node, the algebraic input made can be examined for certain mathematical property or certain typical errors and thus be answered with a specific feedback. However, the characteristics of feedback in STACK depend on those who develop digital STACK tasks and on how these developers perceive the possibilities and importance of feedback.

The image shows a screenshot of a STACK task interface. The top section, labeled 'Task', contains the following text: "Imagine the following situation: A student in your 11th grade class says to you: 'If a function is continuous at  $x_0$ , then it is also differentiable there.' Show your student with a counterexample at  $x_0 = 0$ , that his statement is not correct. Your counterexample:  $f(x) =$  [input field containing 'abs(x)']". Below the input field, it says "Your last answer was interpreted as follows:  $|x|$ " and "The variables found in your answer were:  $[x]$ ". A "Check-Button" is located at the bottom right of this section. The bottom section, labeled "Individualised feedback for the input made", contains the following text: "Very good, your entered function is continuous, but not differentiable at  $x_0 = 0$ . You have found a counterexample for the statement of your student. To help your student understand that a function at  $x_0 = 0$  can be continuous but not differentiable, it may be helpful to graph your counterexample:". Below this text is a graph of the absolute value function  $f(x) = |x|$  on the interval  $[-1, 1]$ . The graph shows a V-shape with its vertex at the origin (0,0). The x-axis ranges from -1 to 1, and the y-axis ranges from 0 to 1. Below the graph, there is a small text block: "By graphing your counterexample, basic ideas about functions can be supported in your student, such as the object imagination. 'The graph as a geometric object represents the function as a whole. Properties of the function are reflected as properties of the graph (e.g. [...] continuity, differentiability [...]).' (Greefrath et al., 2016: S. 54) (Look also at Greefrath, G., Oldenburg, R., Siller, H.-S., Ulm, V. & Weigand, H.-G. (2016): Didaktik der Analysis. Aspekte und Grundvorstellungen zentraler Begriffe. Berlin: Springer Spektrum) Marks for this submission: 1.00/1.00."

Figure 2: An exemplary STACK task and individualised feedback

## **Setting and phases of the university training course “Digital tasks”**

This training course is an elective module in the teacher education programme at the University of Kassel. The development of the course concept followed the Design-Based Research approach (Collins et al., 2004). The first cycle of the course took place in the winter semester 2020/21. Also considering the participants’ evaluations, the course was refined in two cycles. The course lasts one semester and comprises a total of 14 sessions of 90 minutes each. The intended audience of the course are prospective high school and vocational school teachers from the 5<sup>th</sup> semester onwards. The prospective teachers have already taken courses about mathematics and mathematics education.

*Phase 1. Development of theoretical knowledge:* Within the first phase of the course, prospective teachers acquire theoretical knowledge about task and feedback construction as well as about how to deal with errors in the classroom, without a specific focus on digital STACK tasks.

*Phase 2. Learning with STACK:* Prospective teachers get to know the digital tool STACK from the learners’ perspective. Afterwards, the prospective teachers assess their learning experiences with STACK. Afterwards, they change the perspective from learner to teacher by evaluating the digital STACK tasks and defining criteria for digital STACK tasks that support mathematics learning.

*Phase 3. Designing:* In preparation for designing their own digital STACK tasks, the prospective teachers first design an analogue mathematical task. The didactical decisions made by the prospective teachers in the design process, the anticipated errors and the designed feedback are presented, discussed and optimised with their fellow students. With this peer-feedback, the prospective teachers revise their task before programming it in the digital tool STACK.

*Phase 4. Technical design of the digital task:* The prospective teachers acquire necessary technical knowledge by receiving a technical introduction to the design of a digital STACK task. During this introduction, prospective teachers modify an existing digital STACK task, for example by adding nodes to the potential response tree. With guidance and in collaboration with peers, the prospective teachers programme their own digital STACK task with appropriate feedback for different inputs.

*Phase 5. Practical experiences:* In this phase, the prospective teachers implement their digital STACK task in a small group of school students. As only a small group work on the task, the practical experiences can be seen as controlled. The school students learn with the digital STACK task independent of time and location. The prospective teachers can observe learning process asynchronously by tracking the inputs made in each case within an automatically created table.

*Phase 6. Reflection:* The prospective teachers reflect on their digital STACK task, their designed feedback and their practical experiences, also considering school students’ feedback. In doing so, they refer to possibilities for optimising the task (e.g. by removing linguistic barriers), the potential response tree (e.g. implementing not yet anticipated errors) and the feedback. In a last reflection phase, the prospective teachers review the tasks of their fellow students. At the end of the course, there is a peer-reflection on the use and the possibilities and limits of the digital tool STACK.

*Phase 7. Term paper:* Within the term paper, prospective teachers repeatedly gain practical experiences while designing a second digital STACK-task, implement it in a group of school students and reflect upon it.

## Participants and methods

All prospective teachers who attended the courses in the different semesters were asked to participate in this study. An incentive for participation was offered: a fee for using their training course productions for research, for example. Two prospective teachers in each seminar agreed to participate in this study. In this paper, we will only focus on the prospective high school teacher Madelaine because she has not worked with the digital tool STACK yet. She was 23 years old and in 7<sup>th</sup> semester of study, when she attended the course in winter semester 2021/22. We follow a case study approach aiming to explore Madelaine's considerations and her digital competencies during the training course in depth. In order to trace and reconstruct her digital competencies, we analysed different documents Madelaine created in the seminar: the first draft of her analogue designed task (Phase 3), her digital STACK task (Phase 4), as well as her written reflection after her practical experiences (Phase 6). We analysed these documents using qualitative content analysis with deductively developed codes which correspond to the digital competencies of the DigCompEdu framework (Redecker, 2017).

## An exemplary course participant and her digital competencies

Madelaine designed a mathematical task on exponentiation for 10<sup>th</sup> grade school students. When planning the design of her digital STACK task, Madelaine considers external circumstances: *Since I am currently doing my practicum in a 10<sup>th</sup> grade of a high school, I thought about what topics the school students have already dealt with this school year.* Madelaine's considerations about the learning group and the specific topic her digital STACK task are one part of her digital competencies (2.1 Selecting digital resources and 2.2 Creating and Modifying digital resources, Redecker, 2017). Having in mind that STACK provides the opportunity to give feedback to different inputs, Madelaine anticipated errors that may occur. She found a total of six different errors for which she has designed appropriate feedback. Madelaine includes evaluative and elaborated (e.g. advices on task specific strategies, Narciss, 2008) components in designing her feedback as she wants *to support and motivate school students.* Madelaine's considerations on the components and aim of feedback are part of her digital competencies (4.3. Feedback and planning, Redecker, 2017). After getting peer-feedback within the course, Madelaine has revised her task by adding syntax hints for inputs and expanding feedback with fold-out hint boxes. The phase of peer-reflection seems to have an impact on Madelaine's digital competencies about planning the design of a digital STACK tasks and digital feedback (2.2 and 4.3, Redecker, 2017).

Afterwards, Madelaine programmed her designed mathematical task in the digital tool STACK as we can see in Figure 3.

Task

Simplify the expression  $\frac{a^4}{a^2} \cdot d^3 \cdot a^2 \cdot b^4 \cdot d^{-8}$  as much as possible using exponent rules.

Pay attention to the syntax while you made an input: Use \* as multiplication sign and / for fractions or division and  $\square^{\square}$  for exponentiation.

For example: For  $a \cdot d$  enter  $a*d$ , for  $\frac{b}{c}$  use  $b/c$  and for  $b^3$  enter  $b^3$ .

Figure 3: Madelaine's digital STACK task

Even though Madelaine has no previous programming experiences, we can state that she is able to create a digital STACK task (2.2 Creating and modifying digital resources, Redecker, 2017). In doing so, Madelaine designed a potential response tree consisting of ten nodes. At the first node it is checked whether the input has been correctly simplified. The next six nodes check the input for errors that may occur, and that Madelaine anticipated in the prior phase of the course. Compared to the previous phase, she now considers further inputs such as not fully simplified inputs. One error Madelaine anticipated is the incorrect transformation of the first factor  $\frac{a^4}{a^2} = a^{4+2} = a^6$ . The input containing this error is checked at the second node and gets the following feedback (Figure 4):

Your answer is partially correct. You correctly used the exponent rule of 'multiplication with same bases' by summing the exponents of the variable  $d$ . For the variable  $a$ , you have already summed the exponents within the expression  $\frac{a^4}{a^2}$ , which is unfortunately not correct. Think again about the difference between this expression and the expression with the variable  $d$ , which exponent rule should be used for  $\frac{a^4}{a^2}$  and how it differs from the exponent rule 'multiplication with same bases'. If you get stuck, you can open the fold-out note 1.

▼ Note 1  
For the expression  $\frac{a^4}{a^2}$ , the exponent rule 'division with same bases' must be used, i.e. the exponents have to be subtracted.  
General definition:  $\frac{a^x}{a^y} = a^{x-y}$   
If you do not understand the general definition of the exponent rule, you can open note 2.

▼ Note 2  
Numerical example for the exponent rule 'division with same bases':  $\frac{3^4}{3^2} = 3^{4-2}$

▼ Note: Power, base, exponent  
Exponentiation is an abbreviated notation for the repeated multiplication of a factor:  $x_1 \cdot x_2 \cdot x_3 \cdot \dots \cdot x_n = x^n$ .  $x^n$  is called exponentiation or power.  
The  $x$  in  $x^n$  is called base.  
The  $n$  in  $x^n$  is called exponent.  
Example:  $3 \cdot 3 \cdot 3 \cdot 3 = 3^4$ .  $3^4$  is the exponentiation or power, 3 is the base and 4 is the exponent.

**Figure 4: Appropriate feedback to the input  $a^8 \cdot b^4 \cdot d^{-5}$**

First, there are information about the correctness of the input (evaluative, Narciss, 2008), then the error made is localised and differentiated from correct parts. In this way, a correction hint is given. These components of Madelaine's feedback are elaborated and provide school students with knowledge about their mistakes and how to proceed (Narciss, 2008). According to the peer-feedback in the prior phase, Madelaine decided to use the fold-out hint boxes. In the first hint box, the strategic knowledge is provided in form of the required exponent rule. This is an error-specific corrective hint as it refers to the made mistake (Narciss, 2008). In the second hint box, a numerical example is given, while in the third hint box, conceptual knowledge is addressed by explaining the terms exponentiation, base and exponent in more detail ("knowledge about concepts", Narciss, 2008, p. 135). This feedback seems to have cognitive and motivational function as it informs about the error made and thus serves to overcome task difficulties independently (Narciss, 2008). Metacognitive knowledge such as "monitoring and evaluating" one's own inputs is not addressed (Narciss, 2008, p. 134). We can state that Madelaine is aware of the possibility of the digital tool STACK "to provide targeted and timely feedback to learners" (Redecker, 2017, p. 21). Moreover, she seems to design her digital feedback for formative assessments to support school students individually and according to their mistakes (4.1 Assessment strategies and 4.3 Feedback and planning).

Madelaine's digital competency "Teaching" (Redecker, 2017) should also be promoted as she is supposed to gain practical experiences in teaching with her digital STACK task in a group of five school students. Afterwards, she analysed the learning processes of the school students and realises

that not anticipated errors have occurred: *For example, an error that was made and could still be added [to the potential response tree] is that  $(a^4 \cdot b^4)$  was combined as  $(a + b)^4$ .* An optimisation of the task by adding more errors to the potential response tree is necessary in her opinion. These considerations and the analysis and interpretation of digital learning processes are one part of Madelaine's digital competencies that seem to be promoted through the course (4.2 Analysing evidence, Redecker, 2017). Furthermore, Madelaine critically reflects upon the use of digital feedback in a heterogeneous learning group: *It is possible that especially lower-performing school students need exactly this detailed, graduated feedback [...]. Therefore, I think that it is difficult to design a STACK task that is appropriate for all school students in a class.* To cope with the mentioned heterogeneity, Madelaine reflects on different possibilities to design digital feedback such as that *feedback can be enriched to a large extent by hints, changes of representation, etc.* The fact that Madelaine critically reflects on possibilities and limits of digital feedback (4.3 Feedback and planning, Redecker, 2017) seems to be initiated by her practical experiences which underlines the importance of prospective teachers' own lived practical experiences (Tondeur et al., 2012). In addition, Madelaine critically examines limits of digital STACK tasks in learning processes: *There are certainly school students who are better working with explanations from the teacher or other school students who respond concretely to questions about difficulties that have arisen.* We can observe a development of Madelaine's digital competencies as she is increasingly reflecting on new ways of teaching (3.1 Teaching), possibilities for enhancing school students' learning processes (3.2 Guidance and 4.3 Feedback and planning) but also about limits of the digital tool STACK and the importance of a teacher as a human person (1.3 Reflective Practice, Redecker, 2017).

## **Discussion and conclusion**

It can be concluded that the university training course 'Digital tasks' supported the development of Madelaine's digital competencies while using the digital tool STACK. The course seems to encourage even prospective teachers without prior programming experiences to acquire digital competencies. Particularly emphasised are the components learning, designing and reflecting of the training course 'Digital tasks', whose influence on parts of prospective teachers' professional competencies could already be shown in a qualitative study (Speer & Eichler, 2022).

Despite the new insights in how to design a university training course fostering digital competencies, our research has some limitations. Probably the most important limitation is that we described the results of a case study. The case Madelaine served to examine the development of prospective teachers' digital competencies in depth. To support the hypothesis that this university training course supports the development of digital competencies, other prospective teachers attended this course should be analysed. Future research could also investigate whether the concept of the course 'Digital tasks' can be transferred to other STEM subjects with other digital tools.

## **Acknowledgment**

This project is part of the "Qualitätsoffensive Lehrerbildung", a joint initiative of the Federal Government and the Länder which aims to improve the quality of teacher training. The programme is funded by the Federal Ministry of Education and Research. The authors are responsible for the content of this publication.



## References

- Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences*, 13(1), 15–42.  
[https://doi.org/10.1207/s15327809jls1301\\_2](https://doi.org/10.1207/s15327809jls1301_2)
- Dunst, C., Hamby, D., Howse, R., Wilkie, H., & Annas, K. (2019). Metasynthesis of preservice professional preparation and teacher education research studies. *Education Sciences*, 9(1), 1–36.  
<https://doi.org/10.3390/educsci9010050>
- Fraillon, J., Ainley, J., & Schulz, W. (2020). *Preparing for life in a digital world: IEA International Computer and Information Literacy Study 2018 International Report* (1<sup>st</sup> ed. 2020). Springer.  
<https://doi.org/10.1007/978-3-030-38781-5>
- Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, 77(1), 81–112. <https://doi.org/10.3102/003465430298487>
- Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers & Education*, 153.  
<https://doi.org/10.1016/j.compedu.2020.103897>
- Jankvist, U. T., Misfeldt, M., & Aguilar, M. S. (2019). What happens when CAS procedures are objectified? The case of “solve” and “desolve”. *Educational Studies in Mathematics*, 101(1), 67–81. <https://doi.org/10.1007/s10649-019-09888-5>
- Narciss, S. (2008). Feedback strategies for interactive learning tasks. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. R. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3<sup>rd</sup> ed., pp. 125–144). Lawrence Erlbaum Associates.
- Redecker, C. (2017). *European framework for the digital competence of educators: DigCompEdu*. Publications Office of the European Union. <https://doi.org/10.2760/178382>
- Sangwin, C. (2013). *Computer aided assessment of mathematics*. Oxford University Press.  
<https://doi.org/10.1093/acprof:oso/9780199660353.001.0001>
- Speer, A., & Eichler, A. (2022). Developing prospective teachers’ beliefs about digital tools and digital feedback. *Mathematics*, 10(13), 2192. <https://doi.org/10.3390/math10132192>
- Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, 59(1), 134–144.  
<https://doi.org/10.1016/j.compedu.2011.10.009>
- Tulgar, A. T. (2019). Four shades of feedback: The effects of feedback in practice teaching on self-reflection and self-regulation. *Alberta Journal of Educational Research*, 65(3).
- Voerman, L., Meijer, P. C., Korthagen, F. A., & Simons, R. J. (2012). Types and frequencies of feedback interventions in classroom interaction in secondary education. *Teaching and Teacher Education*, 28(8), 1107–1115. <https://doi.org/10.1016/j.tate.2012.06.006>
- Wisniewski, B., Zierer, K., & Hattie, J. (2020). The power of feedback revisited: A meta-analysis of educational feedback research. *Frontiers in Psychology*, 10, Article 3087.  
<https://doi.org/10.3389/fpsyg.2019.03087>