

A Teacher Training Course on Using Digital Media for Acquisition, Visualization and 3D Printing of Complex Data and for Fostering Pupils' Experimental Skills



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Abstract In a newly designed course on special questions about multimedia in physics teaching and learning, multicoding, multiple and multimodal (haptovisual) representations of complex measurement data are created (for example, by 3D printing). In addition, the pre-service teachers in this seminar design interactive learning and working materials for pupils. The focus is on selecting, providing and using different task formats and visualizations in a way that is appropriate for the target group. The results of the accompanying pilot study show effective knowledge acquisition, especially in TPACK. Furthermore, the participants were able to implement the acquired learning content in the design of pupil-oriented, inquiry-based learning environments.

1 Introduction

Experiments play a central role in physics teaching. Set-up, preparation and optimal execution are important topics in studies and the focus of various courses. If the set-up of an experiment is too complex, dangerous, costly, or time-consuming, if the experimental material is not available, or if the conduction poses particular dangers, experimentation in the distance laboratory is an alternative way to teach experimental skills and competencies (Thoms and Girwidz 2015). The importance of remote learning for the future is reflected in the large number of highly funded past and present European research projects to develop and implement remote-controlled experiments via the Internet (Auer et al. 2018; Maletić et al. 2021; Persano Adorno and Pizzolato 2020). In particular, conducting an experiment via a computer or mobile device

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opens up new possibilities for training experimental skills such as documenting measurement results (Hoyer and Girwidz 2020). Digital competencies regarding the selection of suitable representations and the visualization of measurement data can also be addressed (Hoyer and Girwidz 2018). Therefore, beyond the acquisition of experimental competencies, the appropriate use of digital media is also promoted. However, an unfavourably moderated use of digital media in the classroom carries the danger of a cognitive overload of the learners (Sweller 2010; Schnotz and Bannert 2003). Therefore, future teachers must be specially trained for this. The selection and provision of digital media for pupils requires sound technological pedagogical content knowledge (TPACK) (Koehler et al. 2013). Since only good teaching experience on the part of the teacher can ensure sustainable acceptance and appropriate use of digital media in the classroom (Mayer and Girwidz 2019), this professional teacher knowledge should already be imparted during university teacher training.

Despite the urgent need to incorporate digital competencies in teacher education (Carrillo and Flores 2020), research reveals a lack of ICT-oriented pre-service teacher training (Fernández-Batanero et al. 2020). In order to promote the integration of the use of digital media in teacher training, the *Joachim Herz Foundation* has founded the *Kolleg Didaktik: digital*, in which it supports teaching projects related to the use of digital media in science teaching.

This chapter describes a newly developed teaching concept to promote the use of digital media in physics education, which is primarily based on cognitive theories of multimedia learning (Mayer 2014). In addition to the benefits that can be achieved by taking into account the principles of multimedia learning, students are also made aware of possible negative influences on the learning process due to unfavourable implementations (Sweller 2010; Schnotz and Bannert 2003).

2 Methods

The teaching project, ‘Promoting experimental skills and training analysis of complex data with digital media’, was developed and has been carried out at the Chair of Physics Education at LMU Munich since the 2018 summer term. The project aims to provide prospective teachers with background knowledge on the targeted use of digital media in physics lessons. New content was integrated into existing seminars for learning and teaching physics, as well as for school-related experimentation. In addition, a compulsory elective in-depth course was offered in the winter term 2018/19 (2 h/week, 15 weeks, 3 ECTS credits, 90 h of total workload). The effectiveness of the implementations on attitudes towards and knowledge about the use of digital media in physics education was investigated through questionnaire surveys in a pre-post design. In addition, the students’ implementation of what they had learned in the learning materials produced was evaluated. The course ‘Teaching with digital media: multimedia and 3D printing in physics lessons’ has a modular structure. In this way, individual modules can easily be transferred to other courses. The modules of the course are briefly presented below.

2.1 Didactic Aspects of Multimedia Learning

When selecting suitable multimedia learning materials, not only technical aspects have to be considered. An unfavourably moderated use of digital media in the classroom harbours the risk of cognitive overload for the learners (Sweller 2010; Schnotz and Bannert 2003). Therefore, theories of multimedia learning are discussed (Mayer 2014). In addition, an online compendium with interactive examples on topics relevant to teaching is available for further illustration (Girwidz et al. 2018). Central to this is always the illustration of what has been learned using interactive examples on topics relevant to teaching. Participants thus not only learn about the theory behind multimedia physics teaching but also practical examples that can be beneficial in later teaching practice.

Figure 1 shows an animation with multiple representations of an accelerated motion as an example of multicoding. At the top left, a film-like representation of the motion of a steam locomotive is shown. At the top right, the motion is shown in a stroboscopic image of the colour-coded rear wheel. At the bottom left, we see in a diagram the position of the locomotive in metres plotted against time in seconds. In addition, the speed in m/s over time is plotted in a diagram at the bottom right. By linking the different representations, learners can deepen the new learning content and connect what they have learned with existing knowledge.

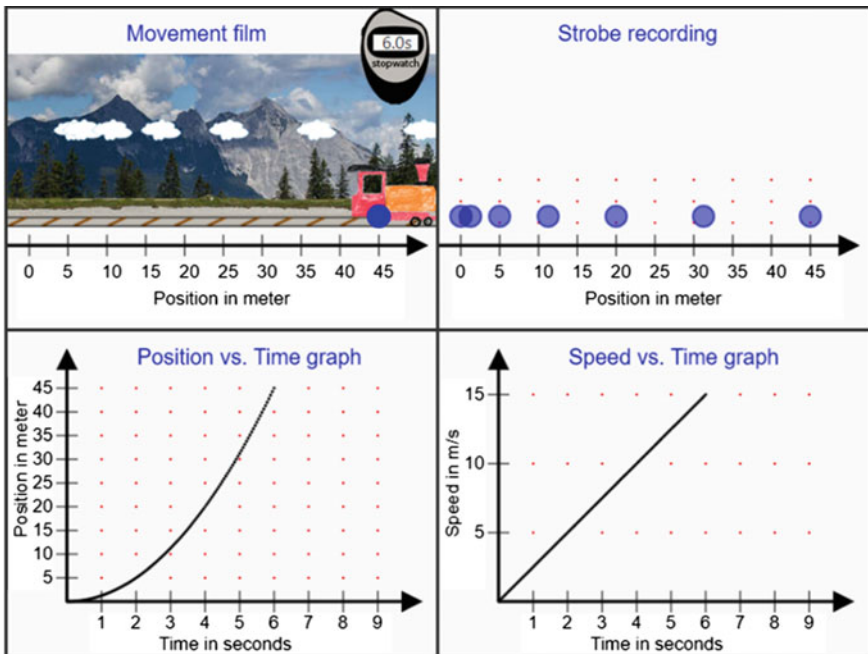


Fig. 1 Example of multiple representations of a constantly accelerated movement

Another example of multicoding is given in Fig. 2. The Boyle-Mariotte law is shown as a graph in a diagram, as an iconic model of the gas particles in a closed cylinder with variable volume and as a logical representation in the form of a mathematical formula. With the help of a 3D printer, three-dimensional models can be printed out and then be viewed by the learners and palpated with their hands at the same time. Figure 3 shows a multimodal representation of the p - V - T state curved surface of the ideal gas. An isotherm is drawn in the model. By rotating and tilting the model, the projections of the isotherm into the possible viewing plane become comprehensible for students.

Fig. 2 Multicoding. Boyle-Mariotte law as graph, graphical representation and formula

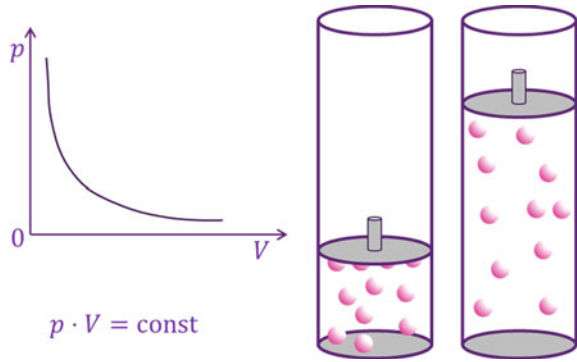
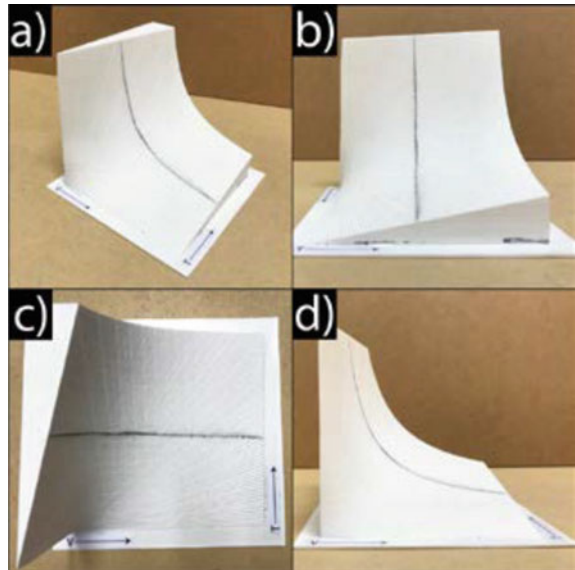


Fig. 3 Multimodality. 3D print of the p - V - T state curved surface of the ideal gas: **a** top view on the state surface, **b** p - T perspective, **c** T - V perspective, **d** p - V perspective (Hoyer et al. 2020)



2.2 *Digital Media in Physics Lessons*

The students learn about different types of multimedia applications and their advantages and disadvantages. Using an established evaluation scheme, animations, simulations and remote labs are analysed and categorized regarding motivational aspects, content and methodology (Altherr et al. 2003; Dębowska et al. 2013). This gives participants an overview of multimedia applications for physics teaching and learning. In addition, the assessment skills of the students are promoted.

2.3 *Digital Data Acquisition in Real, Remote and Virtual Experiments*

The possibilities of digital measurement acquisition in physics teaching have been immensely expanded by technological progress in recent years. Prospective teachers should have a broad knowledge of the available methods and the associated exciting and interesting new possibilities for conducting experiments, recording measured values and subsequent evaluation. Hence, students get to know different systems and use them in various experiments relevant to physics teaching. The course thus provides an overview of common methods for digital data acquisition. At the same time, the students have the opportunity to integrate these procedures into practical teaching scenarios and to try them out independently using common school experiments.

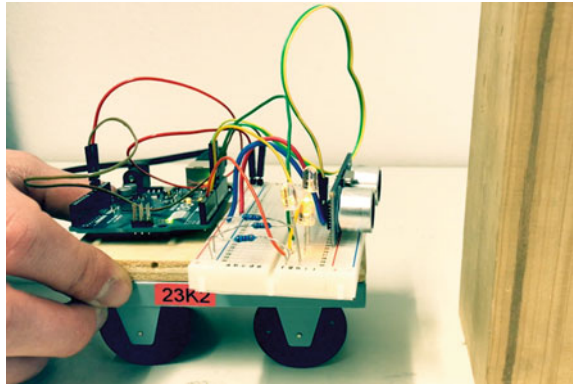
Digital data acquisition systems from the manufacturers of teaching aids are well established in physics teaching and are available in many schools. However, it is not possible to predict which system will be available at the future school of a prospective teacher. The different systems also have various advantages and disadvantages, depending on the specific purpose. Therefore, we attach great importance to the fact that our teacher candidates get to know different data acquisition systems during their studies and build up a teaching-related assessment competence regarding the use of digital data acquisition.

For tablets and smartphones, manufacturers of teaching aids also offer so-called smart sensors. These can be coupled directly with a mobile end device via Bluetooth. The sensors are set-up and the data is collected, processed and displayed directly on the mobile device. In addition, the data can also be transferred to other people or devices for further evaluation.

Smartphones and tablets have a variety of built-in sensors that can also be used for digital data acquisition. Depending on the model, some or all the following sensors can be used:

- GPS (indicates location)
- Accelerometer (measures acceleration)
- Gyroscope (measures rotation)
- Magnetometer (measures magnetic flux density)

Fig. 4 Measuring distance with an Arduino and an ultra-sonic sensor



- Light sensor
- Proximity sensor (measures distance to an object)
- Barometer (measures air pressure)
- Pulse oximeter (measures oxygen saturation in blood and pulse rate).

The use of different **video analysis** apps, such as *Viana*, *Vernier Video Physics*, *VidAnalysis* and *Tracker*, is also tested in the seminar. For example, the students record the vertical throw of a ball from a moving car with *Viana* and evaluate the recording regarding different physical laws.

Microcontrollers and microcomputers such as **Arduinos and Raspberry Pis** can also be used to record measured values in physics lessons (Girwidz and Watzka 2018). Firstly, the acquisition costs are many times lower than for systems designed for a long service life and mechanical stability. Secondly, working with Arduino, Raspberry Pi and Co. also builds interdisciplinary skills. In the seminar, various experiments are carried out with the Arduino Uno, with the participants writing programme code themselves under guidance, planning and building circuits and then developing their own experimental instructions for later use in teaching practice (Fig. 4).

Remote and virtual laboratories allow student-friendly and independent experimentation, even in expensive or dangerous experiments (Thoms and Girwidz 2017). Students are given an overview of existing remote and virtual laboratories (Table 1, for exemplary remote labs, see Fig. 5, for a review of virtual and remote labs in education see (Heradio et al. 2016)). Furthermore, the implementation in teaching scenarios is discussed.

2.4 Two and Three-Dimensional Representations of Measured Values

If measured values are recorded digitally, they can be presented very easily, for example, via a beamer. However, modern technology offers many more possibilities

Table 1 Exemplary remote lab projects

Project	Country	Link
Remotely Controlled Laboratories—RCL	Germany	http://rcl-munich.informatik.unibw-muenchen.de/
Relle	Brazil	http://relle.ufsc.br/labs/
Rexlab	Brazil	https://rexlab.ufsc.br/
Ises	Czech Republic	http://ises.info/
Weblabdeusto	Spain	https://weblab.deusto.es/website/
GO-LAB	The Netherlands	https://www.golabz.eu/
FREI—Ferngesteuerte Reale Experimente über das Internet	Germany	https://frei.web.th-koeln.de/HTML/index.php
UNILabs	Spain	https://unilabs.dia.uned.es/
OpenSTEM Labs	United Kingdom	http://stem.open.ac.uk/study/openstem-labs
iLab Project @ MIT	USA	https://icampus.mit.edu/projects/ilabs/
Remote Farm	Germany	https://remote.physik.tu-berlin.de/

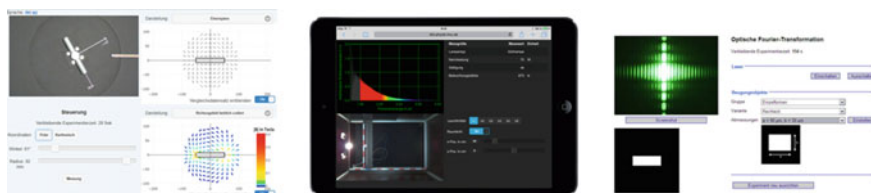


Fig. 5 Selected remote laboratories used in the course: magnetic field of a permanent magnet (left) (http://did.physik.lmu.de/sims/magneticfield/index_de.html), Spectrometric assessment of lamps (middle) (<http://myrcl.net>) and Optical Fourier transformation (right) (<http://rcl-munich.informatik.unibw-muenchen.de/>)

to present experimental results both two- and three-dimensionally. In the seminar, different visualizations of experimentally obtained data are discussed and tried out. Thereby, the use of remote labs has proven to be highly effective, as learners can initially concentrate fully on the characteristics of different forms of representation (Hoyer and Girwidz 2018) (Fig. 6). Thus, measured values are recorded, evaluated and visualized for standard experiments.

2.5 3D Printing in Physics Teaching and Learning

The ability to address multiple senses (multimodality) is one of the strengths of multimedia-based teaching. However, so far, multimodal applications have mostly been used to address content from acoustics (Girwidz et al. 2019a). 3D printing

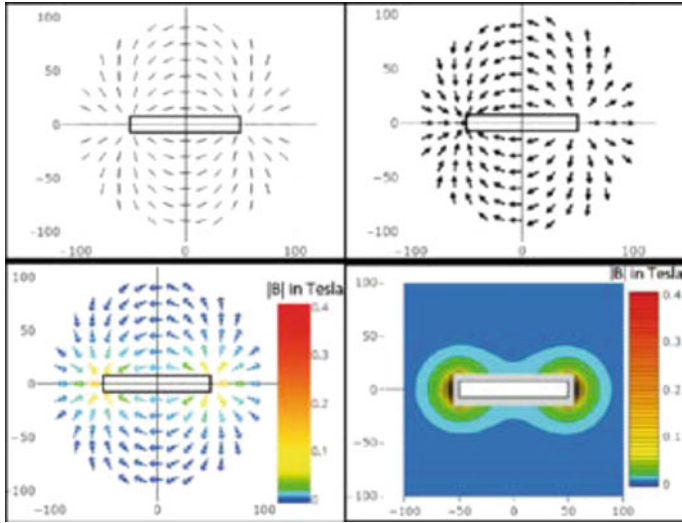


Fig. 6 Representations of the field of a magnet; each representation accentuates different information (Hoyer and Girwidz 2018)

offers an innovative way to produce haptovisual representations of complex relationships. Hence, basic knowledge of 3D printing is imparted. For example, students use *Tinkercad* to design a 3D model by themselves and then print it out. Participants also learn the basics of creating a 3D visualization of experimentally obtained data based on a student experiment they conducted themselves. As creating 3D printable models is usually complex and impractical for school practice, the (prospective) teachers need supportive assistance. Our approach was to provide web pages that can help with the creation of 3D printable models, both for functions and for measurements. For instance, the function plotter can be used to draw an interference pattern of two plane circular waves by using the formula

$$f(x, y) = \cos\left(\frac{2\pi}{10}\sqrt{(x-5)^2 + y^2}\right) + \cos\left(\frac{2\pi}{10}\sqrt{(x+5)^2 + y^2}\right) \quad (1)$$

and the interval for both x and y of $[-50;50]$. The function plotter will then generate a black and white image (Fig. 7) where the colouring of a pixel represents the maxima and minima, respectively, at the time shown. Students can easily import this image into 3D printing software (Fig. 8) and print it out (Fig. 9). 3D printing is particularly suitable for representations of potentials (Fig. 10), as the 3D printer applies individual layers one after the other, thereby automatically making equipotential lines visible (corresponding to the layer thickness).

We have also created a suitable website, especially for processing three-dimensional measurement data. The data is copied into a text field in a predefined format (Fig. 11) and again a black and white image is created in which the

Fig. 7 Visualization of the interference of two circular waves

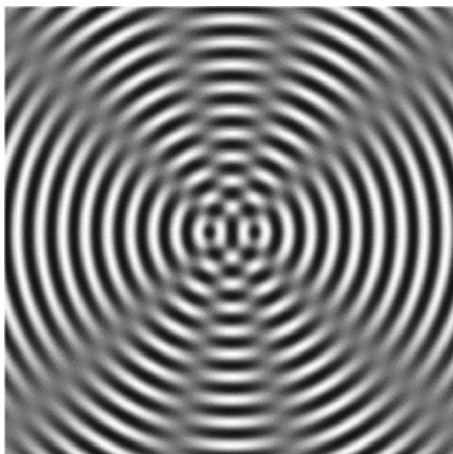


Fig. 8 The black and white image can easily be converted into a 3D model

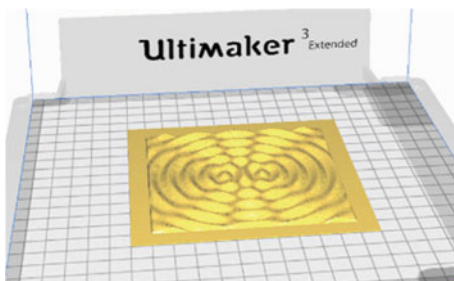
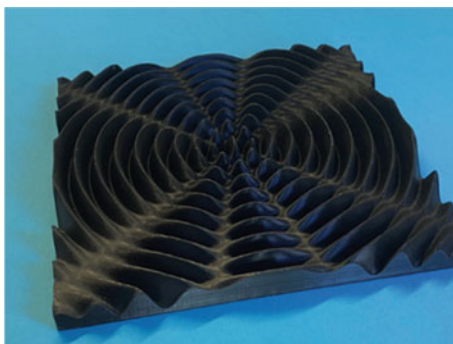


Fig. 9 3D print of the interference of two circular waves



z-component is coded in the pixel colour (Fig. 12), so that the measurement data can easily be printed out in three dimensions (Fig. 13).

Sometimes even direct recordings from a webcam can be usefully processed for 3D printing. For example, diffraction patterns can be recorded with a webcam (Fig. 14 left). The diffraction image can be used for 3D printing, whereby the brightness of

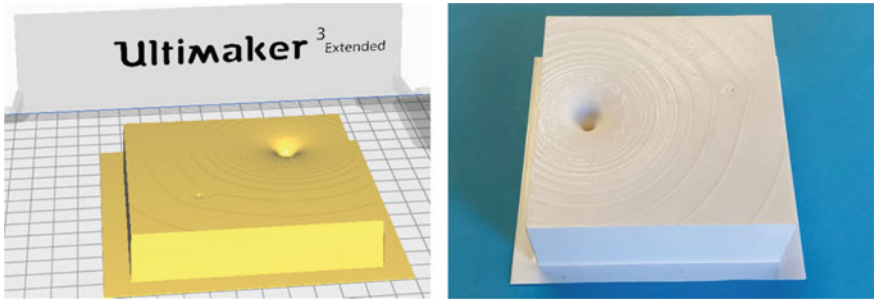


Fig. 10 3D model (left) and 3D print (right) of a two-dimensional slice of the gravitational potential of the earth and moon

Fig. 11 The function plotter accepts comma-separated values

Data plotter for 3D printing

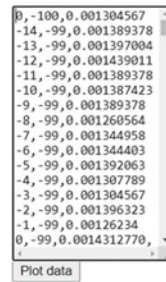


Fig. 12 Magnetic flux density around a bar magnet visualized as black and white image



the pixels is interpreted as a z-component in 3D printing so that a three-dimensional representation of the diffraction image can be viewed and palpated (Fig. 14 right). The intensities can be seen much better from the 3D model. Nevertheless, sources of error must be considered, such as possible saturation of the camera and non-linear

Fig. 13 3D print of the magnetic flux density around a bar magnet

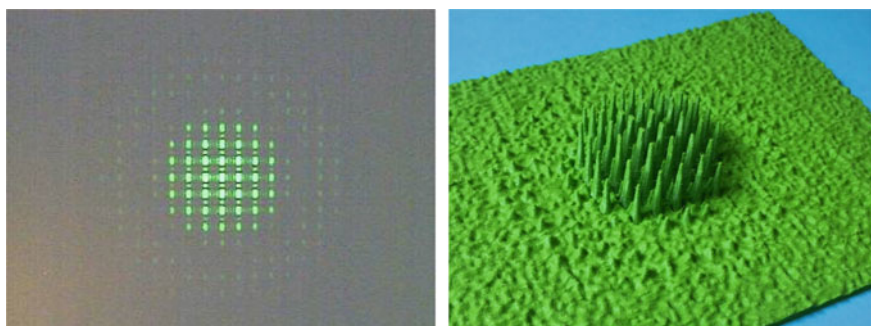
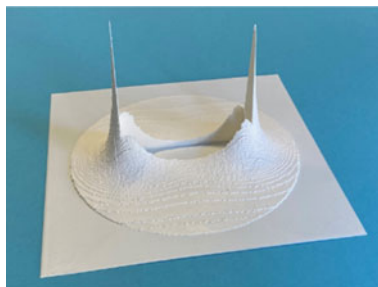


Fig. 14 Webcam image of a diffraction pattern (left) and 3D print made from it (right)

conversions, so that the 3D printout created may only be regarded as a qualitative interpretation aid.

As another example, thermographic images can be prepared for 3D printing in such a way that the height profile of the 3D print corresponds to the temperature profile of the captured object (Fig. 15). In this way, the false colour representation of the thermographic camera is converted into a haptovisual representation of the temperature conditions.

2.6 Use of Digital Media to Train Experimental Skills

In addition, the module teaches how the development of experimental competencies in the classroom can be supported by the use of digital media. For this purpose, various experimental competencies are systematically considered together with a suitable use of digital media as well as appropriate examples. Exemplarily, different multimedia applications for physics education are described regarding their role in physics education as well as their contribution to the promotion of media competence. (Girwidz et al. 2019b).

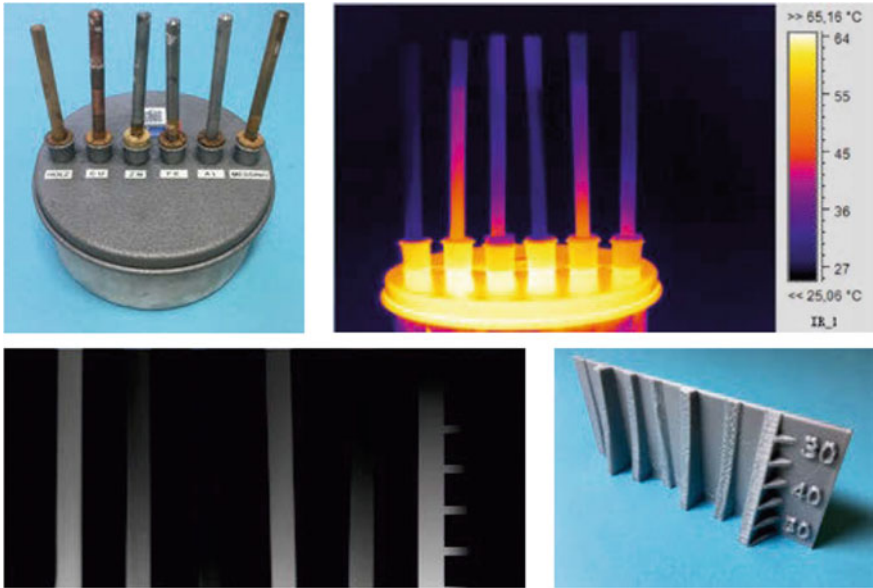


Fig. 15 Thermal images as an example of multicoding and multimodality (Thoms et al. 2020)

2.7 Interactive Learning and Working Material

Interactive task formats can activate and individually support learners. With learning management systems (LMS) such tasks can be organized, structured and provided. The students use various LMS (Moodle, Graasp and WISE) to create digital learning materials for remote inquiry activities (Fig. 16). Differences between the various LMS are also discussed.

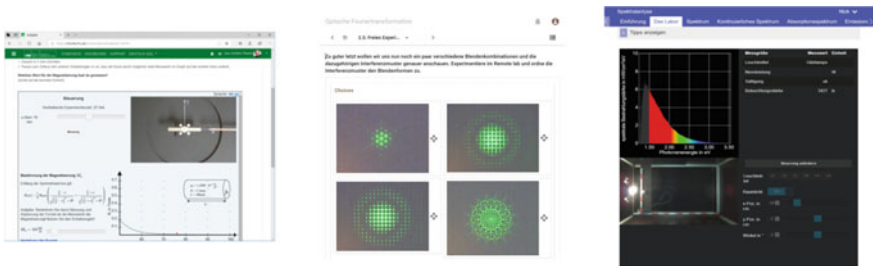


Fig. 16 Exemplary learnings path created by participants and implemented in moodle (left), WISE (middle), or Graasp (right)

3 Results

The effectiveness of the newly developed teaching project on attitudes towards and knowledge about the use of digital media in physics teaching was investigated in a pilot study by means of questionnaire surveys in a pre-post design. The results show a clear gain in technological pedagogical content knowledge (TPACK) for all participants. With regard to the attitude towards the use of digital media, a differentiated picture emerges. While the intention to use digital media in the classroom has increased overall, some participants had a very positive attitude at the beginning and put it into perspective somewhat after the course.

In addition, the students' implementation of what they had learned in the learning materials produced was evaluated. This allowed us to check whether and which of the learning objectives of the seminar were also implemented by the students in the creation of pupil-oriented learning environments. The product analysis showed that all participants have absorbed the essential knowledge content and can now apply it. The marks awarded by the students were also correspondingly good.

Overall, it can be said that the modular design of the seminar is advantageous. The module on theories of multimedia learning was particularly helpful as an introduction. On this basis, the students selected digital media and planned the implementation of their experiment in the LMS. Hence, the students were able to link their course project—the creation of interactive learning and working materials for inquiry-based learning in a remote lab in an LMS—with the weekly meetings and homework. This gave them more time to develop the materials and allowed them to familiarize themselves with the respective learning platform. By presenting their products in plenary, the students received feedback from their peers and lecturers on how to improve their work. At the end of the course, all participants had carried out their own measurements with digital data acquisition systems. The recorded data were processed on the computer and visualised in a pupil-friendly way. Among others, the students prepared selected examples in 3D and printed them out. Compared to three-dimensional visualizations on the screen, three-dimensional printouts can be viewed freely and intuitively from all sides.

4 Discussion

The course on the use of digital media in physics teaching described here was designed in such a way that both general and subject-specific digital competences of prospective teachers are promoted. In developing the course, the TPACK model (Koehler et al. 2013) was primarily used as a basis for designing the development of physics-related digital teaching skills. Now, DiKoLAN—a framework for the digital competencies for teaching in science education—provides an orientation aid that can be used to specify and check the addressed competencies (Becker et al. 2020; Kotzebue et al. 2021; Thyssen et al. 2020). An analysis of the learning objectives

pursued in the teaching concept shows that core competencies from all competence areas of DiKoLAN are promoted, albeit to varying degrees (Thoms et al. 2020b).

A special feature of this course was that it was open to students from all semesters of the physics teacher training programme, especially to first-year students. The course was designed accordingly. Neither specific technical knowledge nor pedagogical competences nor special media skills were required. All basics were worked out in the seminar. Nevertheless, advanced knowledge, in word processing (especially paragraph layout) and spreadsheets (especially formulas and diagrams) proved to be helpful. The semester assignment was to create interactive learning and work materials for inquiry-based learning in the distance lab. The knowledge imparted in the individual modules can thus be directly applied. Setting up, using and maintaining the 3D printer must be done conscientiously and requires additional knowledge (Assante et al. 2020). Although models can be created very quickly by students using a computer, the operation of the printer should first be supervised by a professional.

Acknowledgements We would like to thank the Joachim Herz Foundation for accepting us into the *Kolleg Didaktik: digital* and for the associated support for our teaching project.

References

- Altherr S, Wagner A, Eckert B, Jodl HJ (2003) Multimedia material for teaching physics (search, evaluation and examples). *Eur J Phys* 25:7–14. <https://doi.org/10.1088/0143-0807/25/1/002>
- Assante D, Cennamo GM, Placidi L (2020) 3D Printing in education: an European perspective. In: Cardoso A, Alves GR, Restivo T (eds) Proceedings of the 2020 IEEE global engineering education conference (EDUCON), 27–30 April, 2020, Porto, Portugal. IEEE, Piscataway, New Jersey, pp 1133–1138. <https://doi.org/10.1109/EDUCON45650.2020>
- Auer ME, Azad AK, Edwards A, de Jong T (2018) Cyber-physical laboratories in engineering and science education. Springer International Publishing, Cham. <https://doi.org/10.1007/978-3-319-76935-6>
- Becker S, Bruckermann T, Finger A et al (2020) Orientierungsrahmen Digitale Kompetenzen Lehramtsstudierender der Naturwissenschaften – DiKoLAN. In: Becker S, Messinger-Koppelt J, Thyssen C (eds) Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften. Joachim Herz Stiftung, Hamburg, pp 14–43
- Carrillo C, Flores MA (2020) COVID-19 and teacher education: a literature review of online teaching and learning practices. *Eur J Teach Educ* 43:466–487. <https://doi.org/10.1080/02619768.2020.1821184>
- Dębowska E, Girwidz R, Greczyło T et al (2013) Report and recommendations on multimedia materials for teaching and learning electricity and magnetism. *Eur J Phys* 34:L47–L54. <https://doi.org/10.1088/0143-0807/34/3/L47>
- Fernández-Batanero JM, Montenegro-Rueda M, Fernández-Cerero J, García-Martínez I (2020) Digital competences for teacher professional development. Systematic review. *Eur J Teacher Educ* 1–19. <https://doi.org/10.1080/02619768.2020.1827389>
- Girwidz R, Hoyer C (2018) Didaktische Aspekte zum Einsatz digitaler Medien – Leitlinien zum Lehren mit Multimedia, veranschaulicht an Beispielen. In: Meßinger-Koppelt J, Maxton-Küchenmeister J (eds) Naturwissenschaften digital: Toolbox für den Unterricht. Joachim Herz Stiftung Verlag, Hamburg, pp 6–23

- Girwidz R, Thoms L-J, Pol H, López V, Michelini M, Stefanel A, Greczyło T, Müller A, Gregorcic B, Hömöstreit M (2019a) *Int J Sci Educ* 25:1–26
- Girwidz R, Thoms L-J, Pol H et al (2019b) Physics teaching and learning with multimedia applications: a review of teacher-oriented literature in 34 local language journals from 2006 to 2015. *Int J Sci Educ* 25:1–26. <https://doi.org/10.1080/09500693.2019.1597313>
- Girwidz R, Watzka B (eds) (2018) *Arduino, Raspberry Pi & Co (Naturwissenschaften im Unterricht Physik, 167)*. Friedrich, Seelze
- Heradio R, de La Torre L, Galan D, Cabrerizo FJ, Herrera-Viedma E, Dormido S (2016) Virtual and remote labs in education: a bibliometric analysis. *Comput Educ* 98:14–38. <https://doi.org/10.1016/j.compedu.2016.03.010>
- Hoyer C, Girwidz R (2018) A remote lab for measuring, visualizing and analysing the field of a cylindrical permanent magnet. *Eur J Phys* 39:65808. <https://doi.org/10.1088/1361-6404/aae35a>
- Hoyer C, Thoms L-J, Girwidz R (2020) Lehren mit Multimedia, Fernlaboren und 3D-Druck im Physikunterricht. In: Habig S (ed) *Naturwissenschaftliche Kompetenzen in der Gesellschaft von morgen*. Universität Duisburg-Essen, Essen, pp 979–982
- Hoyer C, Girwidz R (2020) Animation and interactivity in computer-based physics experiments to support the documentation of measured vector quantities in diagrams: an eye tracking study. *Phys Rev Phys Educ Res* 16. <https://doi.org/10.1103/PhysRevPhysEducRes.16.020124>
http://did.physik.lmu.de/sims/magneticfield/index_de.html
<http://myrcl.net>
<http://rcl-munich.informatik.unibw-muenchen.de/>
- Koehler MJ, Mishra P, Cain W (2013) What is technological pedagogical content knowledge (TPACK)? *J Educ* 193:13–19. <https://doi.org/10.1177/002205741319300303>
- Kotzebue L von, Meier M, Finger A, Kremser E, Huwer J, Thoms LJ, Becker S, Bruckermann T, Thyssen C (2021) The Framework DiKoLAN (Digital Competencies for Teaching in Science Education) as Basis for the Self-Assessment Tool DiKoLAN-Grid. *Educ Sci* 11:775. <https://doi.org/10.3390/educsci11120775>
- Maletić S, Ivančev-Tumbas I, Brossas A et al (2021) Overview of Erasmus+ NETCHEM project: ICT networking for overcoming technical and social barriers in instrumental analytical chemistry education. *Environ Sci Pollut Res Int* 28:2479–2483. <https://doi.org/10.1007/s11356-020-11506-4>
- Mayer RE (ed) (2014). *The Cambridge handbook of multimedia learning*. Cambridge University Press, New York. <https://doi.org/10.1017/CBO9781139547369>
- Mayer P, Girwidz R (2019) Physics teachers' acceptance of multimedia applications—adaptation of the technology acceptance model to investigate the influence of TPACK on physics teachers' acceptance behavior of multimedia applications. *Front Educ* 4:73. <https://doi.org/10.3389/educ.2019.00073>
- Persano Adorno D, Pizzolato N (2020) Teacher professional development in the context of the “Open Discovery of STEM laboratories” project: is the MOOC methodology suitable for teaching physics? *J Phys: Conf Ser* 1512:12030. <https://doi.org/10.1088/1742-6596/1512/1/012030>
- Schnotz W, Bannert M (2003) Construction and interference in learning from multiple representation. *Learn Instr* 13:141–156. [https://doi.org/10.1016/S0959-4752\(02\)00017-8](https://doi.org/10.1016/S0959-4752(02)00017-8)
- Sweller J (2010) Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educ Psychol Rev* 22:123–138. <https://doi.org/10.1007/s10648-010-9128-5>
- Thoms L-J, Girwidz R (2015) Training and assessment of experimental competencies from a distance: optical spectrometry via the Internet. *Il Nuovo Cimento C* 38:1–10. <https://doi.org/10.1393/ncc/i2015-15113-3>
- Thoms L-J, Girwidz R (2017) Virtual and remote experiments for radiometric and photometric measurements. *Eur J Phys* 38:55301–55324. <https://doi.org/10.1088/1361-6404/aa754f>
- Thoms L-J, Hoyer C, Girwidz R (2020b) Mit digitalen Medien experimentelle Kompetenzen fördern und komplexe Datenauswertungen schulen. In: Becker S, Messinger-Koppelt J, Thyssen C (eds) *Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften*. Joachim Herz Stiftung, Hamburg, pp 111–114

- Thoms L-J, Hoyer C, Girwitz R (2020) Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften (Becker S, Messinger-Koppelt J, Thyssen C (eds)). Joachim Herz Stiftung, Hamburg, pp 111–114
- Thyssen C, Thoms L-J, Kremser E, Finger A, Huwer J, Becker S (2020) Digitale Basiskompetenzen in der Lehrerbildung unter besonderer Berücksichtigung der Naturwissenschaften. In: Beißwenger M, Bulizek B, Gryl I, Schacht F (eds) Digitale Innovationen und Kompetenzen in der Lehramtsausbildung. Universitätsverlag Rhein-Ruhr, pp 77–98. <https://doi.org/10.17185/duo-publico/73330>