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Review

Inclusive and Digital Science Education—A Theoretical Framework for Lesson Planning

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Abstract: The design of learning environments aimed at all students in the learning group is a requirement of modern lesson planning. In science education research, especially in the German tradition of didactics, the model of educational reconstruction (MER) is widely established for the planning of research programs and lesson planning. This model offers linking points in the conception of inclusive learning environments that have not yet been sufficiently considered. From an educational science perspective, Universal Design for Learning diclusive (UDL diclusive) provides a theoretical basis in the context of inclusive and digital lesson planning. In this paper, both MER and UDL diclusive are briefly presented. We argue for the combination of both frameworks for contemporary lesson planning. At the center of our considerations, we present possible points of linkage between the two frameworks. Connection points are illustrated by planning an inclusive and digital experiment-based physics lesson.

Keywords: lesson planning; physics teaching; inclusion; digitalized practical work; video experiment

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1. Introduction

Over the past decade, two key topics have continued to receive significant attention in the field of school development: the advancement of inclusion and associated changes in the educational system on the one hand, and the use of digital media in classrooms on the other hand. These themes, while extensively researched, continue to challenge educational systems worldwide as they seek to address diverse learner needs. Inclusion, as defined by UNESCO (UNESCO—United Nations Educational, Scientific and Cultural Organization, 2009), encompasses the right of all learners to quality education that fosters their full potential, irrespective of social, economic, or cultural backgrounds, special educational needs, or disabilities. Different countries approach inclusion through different philosophies and practices, influenced by their sociocultural and educational contexts. For instance, in the United States, inclusion, as highlighted for example in the NGSS, often focuses on traditionally underserved students, reflecting an emphasis on equity, while in Nordic countries such as Sweden, the debate on inclusion centers on human rights, democratic principles, placement of SEN students, participation, and belonging (Buli-Holmberg et al., 2023).

Based on the understanding defined by UNESCO, inclusive teaching in Germany is not only related to special needs schools, but also to the goals of every type of school (Ainscow, 2021; Hossain, 2012; KMK—Kultusministerkonferenz, 2011; Lee et al., 2015;

UNESCO—United Nations Educational, Scientific and Cultural Organization, 2009) by targeting the large variety of different learning conditions and the learner's specific needs. In addition to migration processes and ease of possibility of transition in the German school system, this demand leads to increased heterogeneity in the classroom. It is essential to mention that inclusion does not only aim at the dichotomy between students with and students without special educational needs, e.g., due to a visible impairment. A broad understanding of inclusion entails the right of all learners to quality education and the development of their full potential, regardless of social, economic, or cultural backgrounds, special educational needs, disability, or sex (Deutsche UNESCO-Kommission, 2021, p. 1).

Similarly, digitization and the integration of digital media into classrooms has sparked international debate (Eickelmann et al., 2019) on teaching methods with digital media (Heusinger, 2020; Michaelsen, 2021), competencies regarding teachers and students (Böttinger, 2023b; Thumel et al., 2020; Voogt et al., 2018), the availability of digital media in classrooms (Drossel et al., 2017; Lorenz et al., 2022) and on risks of exclusion in a digital world (e.g., digital divide) (AlSadrani et al., 2020; Dertinger, 2020; van Dijk, 2020). The ICIL study showed that Germany has a considerable backlog in the mentioned fields (Eickelmann et al., 2024, 2020).

While inclusion and digitalization have been discussed separately in the past (Abels & Stinken-Rösner, 2022), international publications (CISL—Centre on Inclusive Software for Learning, 2021; Gogiberidze et al., 2019) and publications in Germany (Abels & Stinken-Rösner, 2022; Bosse et al., 2019; Böttinger & Schulz, 2021; Filk & Schaumburg, 2021) try to develop a conceptual combination of inclusion and digital media. The aim is to reduce education inequalities and break down learning barriers. In Germany, the Standing Conference of the Ministers of Education (KMK) argues similarly, when it calls for digital learning environments that take all learners into account—separately from educational objectives or individual ways of learning. This includes the key part of learning environments with digital media and technologies to allow teachers to support the learning process considering a broad understanding of inclusive education (KMK—Kultusministerkonferenz, 2021, pp. 4–6).

Although initial ideas for designing inclusive and digitalized (science) lessons already exist (see, e.g., Abels & Stinken-Rösner, 2022), there is a need for an approach that provides guidance for the systematic planning of such lessons. Lesson planning is an important step to achieve an inclusive and proactive understanding of learning and supporting learners. Teachers should not wait until students need particular support or until learning difficulties come up. While planning the lessons, they should consider different ways and methods of learning to provide a variety of learning approaches and learning materials. In this way, all learners benefit from enhanced learning environments and from being able to organize the learning process more individually. Digital media can play a decisive role in reducing learning barriers and implementing adaptive teaching in inclusive classrooms (Böttinger, 2023a, 2023b).

Previous efforts to support the planning of inclusive science education have, in our view, focused either on subject-specific material development or on broad scientific literacy development. In this paper, our main goal focuses on how a lesson plan can be designed that (a) enables all students to gain access to the learning content, despite their very heterogeneous learning requirements, and that (b) makes it possible for all students to work on the same subject matter. To illustrate this, we will take a concrete example from physics lessons. In science education research, especially in the German tradition of didactics, the Model of Educational Reconstruction (MER) (Duit et al., 2012) is widely established for the planning of research programs and lesson planning. This model offers linking points in the conception of inclusive learning environments in the learner-oriented lesson planning that have not yet been sufficiently considered. In this context, the Universal Design for

Learning diclusive (UDL diclusive: (Böttinger & Schulz, 2021, 2023a, 2023b, 2023c)) as an adaption of the evidence-based Universal Design for Learning (CAST—Centre for Applied Special Technology, 2018) can be applied.

This paper seeks to contribute to the ongoing discussions about the implementation of inclusive practices and digital media in the science classroom by exploring how inclusive and digital science education can be realized through the theoretical frameworks of the Model of Educational Reconstruction (MER) and Universal Design for Learning diclusive (UDL diclusive). While MER focuses on subject-specific and learner-centered lesson planning, UDL diclusive offers principles for creating flexible, accessible, and engaging learning environments. By combining these frameworks, we propose a comprehensive approach to lesson planning that addresses diverse learner needs while harnessing the potential of digital media. The approach advances the theoretical foundations of lesson planning by showing how established frameworks can evolve to meet contemporary educational challenges like digitalization and diversity. While UDL is often applied broadly across subjects, its integration with MER provides a discipline-specific approach tailored to science education. This ensures that inclusive teaching is embedded in discipline-specific content.

Therefore, this article is an approach that aims to extend the didactic model of educational reconstruction MER by a diclusive step based on the UDL diclusive to develop a theoretical framework for inclusive and digital lesson planning. The objective of this paper is to address the following research questions: How can MER and UDL diclusive be combined to facilitate the planning of inclusive and digitally enriched science lessons? What does such a lesson look like?

Since physics is traditionally closely linked to digital media, the use of the framework is illustrated by an example of experiment-based physics lessons for the basic topic of optics.

2. Approaches to Lesson Planning

2.1. The Model of Educational Reconstruction

The Model of Educational Reconstruction (MER) is a theoretical framework for developing learning environments in the science classroom (Kattmann et al., 1997); it can also be used as an approach for science education research, which is the primary intention of the model (Reinfried et al., 2009; Duit et al., 2012, see Figure 1).

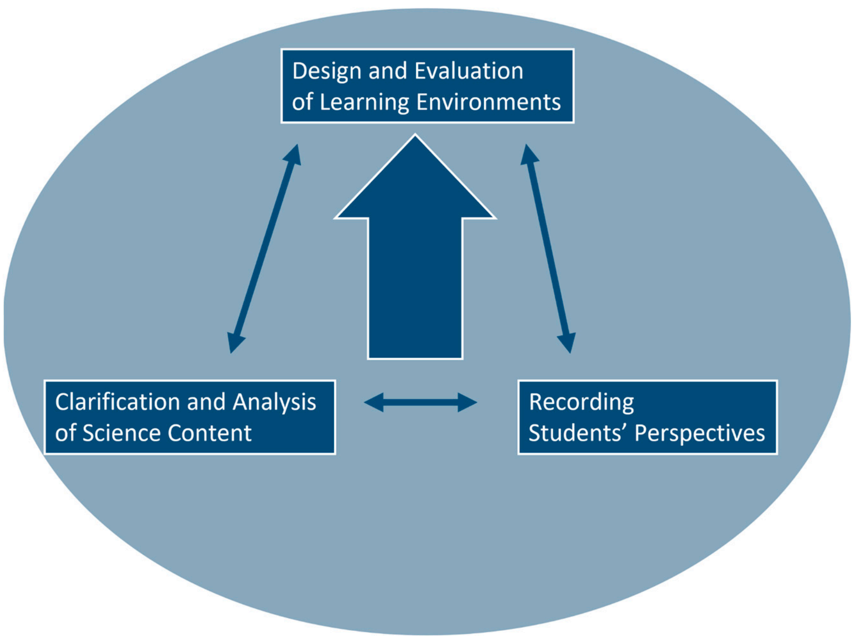

Figure 1. The Model of Educational Reconstruction, adapted from Duit et al. (2012).

Building on education–theoretical justifications of learning objects, the MER combines the analysis of content elements (Klafki, 1964) and aspects of exemplarity (Wagenschein, 1988) with recording the learner's beliefs and interests. Against the background of a broad learning objective, MER describes three dimensions to consider when planning lessons to achieve the learning objective. The mutual reference to the (1) clarification and analysis of science content ("science-oriented"), (Duit et al., 2012, p. 15) on the one hand and (2) recording students' perspectives ("student-oriented"), (Duit et al., 2012, p. 15), on the other hand, is central. The interaction between content and pedagogical aspects results in (3) a design and evaluation of learning environments that ultimately enable conceptual learning. In the MER, the design and evaluation dimensions are necessarily reciprocal, together with clarification and recording the students' perspectives.

2.1.1. Clarification and Analysis of Science Content

The clarification and analysis of science content include crucial science concepts and principles (learning science), science processes and practices, and views of the nature of science (learning about science). Subject-systematic structures are examined, and the aspects that are elementary for the lessons to be planned are identified. This process should not be interpreted in terms of merely "simplifying" science content, although reflecting on idealizations comes into play within the scientific process of knowledge acquisition (Winkelmann, 2023). In addition, elementarization takes place within the educational process of lesson instruction, namely, the reduction of the abstraction and complexity of the subject matter, the identification of the elementary elements of a learning object (e.g., basic phenomena and principles, general laws), and the breakdown of the content into (methodical) components.

2.1.2. Recording Students' Perspectives

This dimension of the MER focuses on the analysis of individual students' learning conditions and requirements. The students' prerequisites are the central starting point for lesson planning. Cognitive and psychological aspects, affective variables such as interests, self-concepts, and attitudes, as well as students' preconceptions on learning objects, are considered. For a long time, it has been known from science education research that knowledge about students' preconceptions and the adequate handling of these preconceptions is necessary to design physics lessons more successfully (Clement et al., 1989). Students' preconceptions describe dispositions to interpret science concepts in a certain way or to describe phenomena in a certain way that differs from technical science presentations. Ideas that deviate from subject-specific concepts are often domain-specific (e.g., physics: Schecker and Duit (2018), biology: Coley and Tanner (2015) and Hammann and Asshoff (2014), chemistry: Taber (2002) but can also be described for broader concepts such as the Nature of Science (Clough, 2006; Deng et al., 2011). The ideas that are inappropriate from a technical point of view are often plausible for the learners in everyday life, and thus have explanatory power (for example: the shadow of the earth is responsible for the half moon; a jumper makes you warm). Alternative concepts of students should therefore be the starting point for a conceptual development (Vosniadou, 2019).

2.1.3. Design and Evaluation of Learning Environments

"The key idea of educational reconstruction includes the idea that a certain science content structure has to be transformed into the content structure for instruction" (Duit et al., 2012).

The underlying assumption of learning theory is that knowledge structures can be changed, expanded, networked, restructured, or newly formed by learners (Bransford & Donovan, 2005; Steffensky & Neuhaus, 2018). Especially for science lessons at the primary and lower secondary level, the systematics of a subject, e.g., biology or physics, cannot be adopted for one-to-one learning. A structure determined by the teacher always characterizes curriculum planning. The aim of such a structure is that all students can follow it so that technically correct concepts develop or deviating concepts experience a change to technically correct ones, i.e., a conceptual change can occur (for a current review on conceptual change see Lin et al. (2016). The didactic restructuring is based on the iterative mutual reference between the previously described facets of MER (Clarification and Analysis of Science Content and Recording Students' Perspectives).

2.2. The Universal Design for Learning Diclusive

The Universal Design for Learning diclusive (UDL diclusive) is a framework for teaching with digital technologies in inclusive classrooms (Böttinger & Schulz, 2021, 2023a, 2023b, 2023c). Used for lesson planning, it points out different ways to consider the "full range of learners' natural variation of [learning] styles, needs, and preferences" (Dalton, 2017, p. 27) to enable all learners to participate in class, to follow the lessons and successfully work on the tasks given. On the other hand, the UDL diclusive can help to reduce or eliminate barriers and risks of exclusion, which emerge from the use of digital technology itself or from learning environments designed for a more or less homogenous group of learners (Nieminen & Pesonen, 2019, p. 2). For example, students can easily be overstrained using digital technologies, because a higher amount of self-regulated and self-planned learning is necessary (Schaumburg, 2021). Other learners have hearing impairments or reading difficulties. In this context, the framework supports teachers to provide appropriate kinds of learning support with digital technologies.

The UDL diclusive has two theoretical roots. On the one hand, the discussion is about combining the two main topics, inclusion and the use of digital technology in classrooms (Bosse et al., 2019; Filk & Schaumburg, 2021), or, as we call it, diclusion as a neologism made of the words inclusion and digital technology (Böttinger & Schulz, 2021; Schulz & Böttinger, 2022; Schulz & Krstoski, 2022). On the other hand, it is based on the Universal Design for Learning (CAST—Centre for Applied Special Technology, 2018). As a didactic concept with various basic principles to support learning, it follows the four primary principles of inclusive teaching (Salend, 2011), like equal access for all learners, sensitivity to strengths and challenges, reflective practices and differentiated instruction and an established community, where collaboration is essential. Normally, schools' curriculums aim at more or less homogeneous groups of learners. The UDL is trying to meet the different learning needs by enhancing intentional lesson planning and personalized materials: "With UDL, teachers design lessons in such a way that all learners can access the material, engage interest and express knowledge" (Pilgrim & Ward, 2017, p. 283), including those with disabilities or different learning needs. The aim is to offer multiple learning opportunities, rather than focusing on the weakness of students.

In sum, the UDL can be used to provide appropriate instruction and to give all students equitable access to learning (Boothe et al., 2018, p. 3). In comparison to assistive technology (AT), there is one difference that explains the UDL's benefit in a descriptive way: "UDL is proactive and anticipates the potential needs of students, whereas AT is reactive and responds to student needs as they arise" ((Boothe et al., 2018, p. 3). This proactive approach is the reason why the UDL can be helpful for all learners. For example, studies showed that subtitles can be used as some kind of universal support, as most of the learners benefit from them (Kent et al., 2018; Linder, 2016).

2.2.1. The Three Main Principles of the UDL Diclusive

As research suggests, there is no single style of learning that fits the diversity of learners (see, e.g., Sanger (2020, p. 36) or Friesen et al. (2021)). In order to meet the diverse learning requirements, the best way of learning is to expose students to a range of representations and modalities (see, e.g., Bui and McDaniel (2015); Mayr (2021)). Therefore, the UDL diclusive relies on three main principles for successful learning, also used in the Universal Design for Learning, which offers a set of concrete suggestions that can be applied to any discipline or domain to ensure that all learners can access and participate in meaningful, challenging learning opportunities (CAST—Centre for Applied Special Technology, 2018). In the UDL diclusive, these principles are related to learning with digital technologies (see Figure 2).

(a) *Provide multiple means of engagement* by stimulation interest and motivation for learning

- by recruiting interest, e.g., by optimizing relevance, authenticity and individual choices or minimizing distractions;
- by sustaining effort and persistence, e.g., by varying demands and resources to optimize challenges or fostering collaboration and community;
- by supporting self-regulation, e.g., by facilitating personal coping skills or developing self-assessment and reflection.

(b) *Provide multiple means of representation* by presenting information and content in different ways

- by providing options for perception, e.g., by offering ways of customizing the display of information or offering alternatives of auditory or visual information;
- by providing options for language and symbols, e.g., by clarifying vocabulary, symbols und syntax or by illustrating through multiple media;
- by providing options for comprehension, e.g., by activating or supplying background knowledge or by guiding information processing and visualization.

(c) *Provide multiple means of action and expression* by differentiating the ways that students can express their *knowledge*

- by providing options for physical action, e.g., by varying the methods for response and navigation or by optimizing access to tools;
- by providing options for expression and communication, e.g., by using multiple media for communication or by using multiple tools for construction and composition;
- by providing options for executive functions, e.g., by guiding appropriate goal-setting or by supporting planning and strategy development.

To summarize, the UDL diclusive offers various ways to use digital technologies for inclusive teaching (Böttinger & Schulz, 2021, 2023a, 2023b, 2023c). For individual learners, assistive technology can be a relief for different impairments (e.g., screen reader, digital translator, talker). Furthermore, digital technologies focus on individual ways and types of learning, as they offer possibilities for differentiation and individualization, and for adapting teaching and content (e.g., adaptive learning systems, individual feedback, visualization). With a view to the learning group, especially for knowledge construction in a collaborative learning environment, digital technologies can be used as tools, e.g., for illustration or cognitive activation, by collecting important terms and definitions on a digital board. Furthermore, active media work has an outcome linked to the content and the learning process (e.g., video, podcast, interactive book, blog, website). With a wider perspective, digital technologies are deeply implemented in everyday life. In this context, digital technologies and media education play an important role in making participation possible (e.g., regarding media literacy, such as being able to search for information and identify fake news).

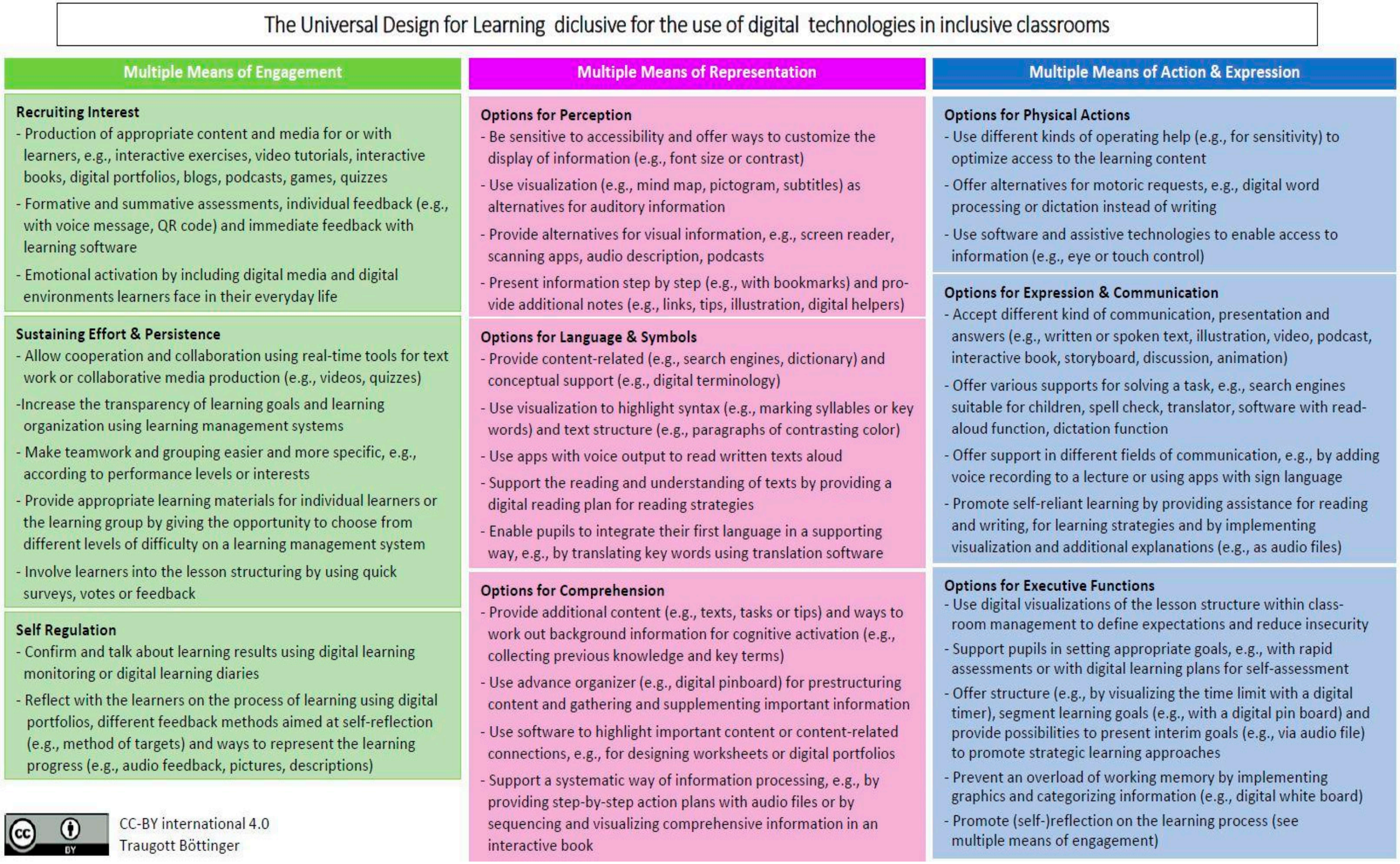

Figure 2. The UDL diclusive for the use of digital technology in inclusive classrooms. Based on the Universal Design for Learning (CAST—Centre for Applied Special Technology, 2018), expanded and adapted by Böttinger and Schulz (2023b).

2.2.2. How to Use the UDL Diclusive in Classrooms

It is valid to assert that the mere use of digital media does not automatically support learning or reduce learning barriers. Appropriate lesson planning is necessary to consider the students' learning needs and competencies. Also, it is important to mention that the UDL diclusive does not aim at lesson planning or teaching that only focuses on digital media. Rather, good inclusive teaching needs a combination with common (including non-digital) methods, materials and didactic approaches (Schulz & Beckermann, 2020).

The separate fields of the framework are not selective; on the contrary, some are supplementary to others. That is why the focus while planning a lesson should not be on working through every single one of the nine fields, as the UDL diclusive is not meant to be some kind of checklist, but is dependent on the content: "It is left to a teacher's discretion to add flexibility and options in ways that are best suited to the standards and content being addressed" (Rao & Meo, 2016, p. 5). Rather, it is meant to help teachers recognize the different opportunities of digital technologies and the need to adapt the use of such technologies equally to the individual learners and the learning group, as you will never find a universal solution that fits all learners or classes.

3. Bringing the Perspectives Together: Planning Digitally Enhanced and Inclusive Lessons

In order to plan inclusive and digitally enhanced lessons, we suggest extending the MER by a diclusive step, based on the UDL diclusive, to achieve a learning objective. The MER, a well-established framework for science lesson planning, provides a strategic approach to aligning subject-specific content with learners' perspectives. The addition of the methodological principles of the UDL diclusive (Böttinger & Schulz, 2021, 2023a, 2023b, 2023c; Schulz & Böttinger, 2022) adds a layer of ideas to enrich these science lessons with digital-based actions, to make them more accessible for all learners.

In two aspects of MER in particular, we consider an extension to be useful: 'Recording Students' Perspectives' and 'Design and Evaluation of Learning Environments'. The aspect 'Clarification and Analysis of Science Content' remains interrelated to the other two, but can also be considered separately, for instance, through curricular requirements. Nevertheless, in MER, the science subject matter issues, as well as students' perspectives, play an equally important role in lesson planning (Duit et al., 2012). Often, the 'recording student perspective' aspect of the MER refers to students' perceptions and interest or attitudes to science. The UDL diclusive as a proactive approach goes beyond that, and tries to see all diversity dimensions of the individual. With the UDL diclusive, we aim to expand the MER to include specific support measures for individual students (see Figure 3).

With inclusive learning groups, it is not an easy task to create learning opportunities that meet the needs of all learners. To design learning environments that are accessible to all learners, we need the help of digital media. For example, interactivity enables students to control their own learning process by deciding which content to start with and to obtain the help they need. Thereby, we suggest a second expansion of the MER, enriching the 'Design and Evaluation of Learning Environments' with digital media to support all learners. The UDL diclusive offers ideas to incorporate digital media for inclusion at the level of the actual material.

Integrating MER and UDL diclusive presents several potentialities for inclusive and digital science education. First, it improves accessibility. MER focuses on understanding students' preconceptions and aligning these with scientific concepts. When combined with UDL diclusive, which emphasizes multiple means of engagement, representation, and action, lesson plans can be designed to address diverse learning needs proactively. For instance, digital tools like interactive simulations or videos with subtitles enable students with auditory or visual impairments to engage more effectively. Furthermore, the combination encourages self-regulated learning. The UDL diclusive's emphasis on learner autonomy complements MER's structure-oriented approach. For example, interactive digital media can provide step-by-step guidance and fade-in/fade-out support, allowing students to control their learning pace as they work on science tasks.

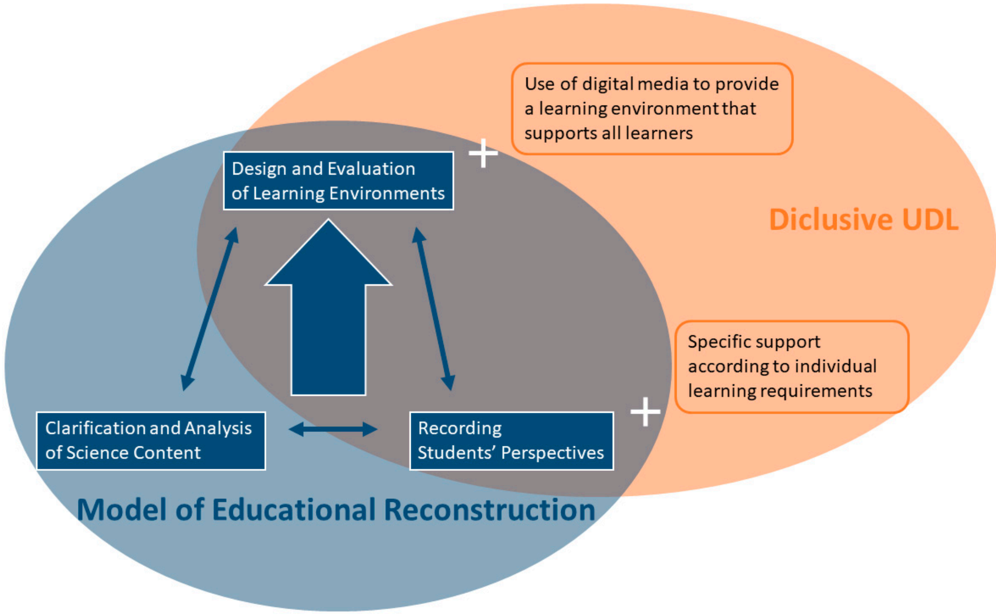

Figure 3. The Expansion of the MER with two diclusive aspects.

The combination of MER and UDL diclusive offers a structured, yet flexible, framework for designing lessons, prioritizing inclusivity and digital enhancement. A detailed methodology includes, firstly, the 'Clarification and Analysis of Science Content' (Duit et al., 2012). This remains a cornerstone of MER, ensuring the science content is accurate, structured, and accessible. The second step is 'Recording Students' Perspectives' (Duit et al., 2012). UDL diclusive enriches this aspect by emphasizing diversity dimensions. Teachers can gather input through digital surveys or adaptive learning platforms, which help identify individual needs and preferences. Lastly, 'Designing and Evaluating Learning Environments' (Duit et al., 2012) benefits from the combined strengths of both frameworks. For instance, a digital physics experiment on light refraction can include interactive features like pause-and-explain videos or adjustable difficulty levels, ensuring that all students can engage with the material at their level (see next section).

To illustrate this integration, we will present a physics lesson focusing on the refraction of light.

4. Implementation in the Classroom: An Inclusive and Digitally Enhanced Learning Environment for Practical Work

In the following, we focus on planning practical work, and want to apply the presented combination of the frameworks for planning inclusive and digitally enhanced experimental environments (practical work) in physics lessons. The example presented in this section—a digitally enhanced, inclusive physics lesson on light refraction—is designed for heterogeneous groups of secondary school students (typically grades 7 and 8 in Germany).

Practical work is a central element of science lessons (Committee on High School Science Laboratories: Role and Vision, 2004). A huge part of lessons is spent carrying out experiments. Although practical work is a very important part of the regular school routine, it is not an easy task to design practical work for learners in mixed-ability groups.

To illustrate the combination of the -mentioned frameworks, we have planned a teaching unit for the context "(in)visibility", which centers around light refraction in the field of optics. The lesson goal is an understanding of how the refractive index influences the "visibility" of a material. Our instruction is built on a digital experiment. In this, students work with a video of an experiment, which contains interactive elements such as buttons offering additional help or controls for the experimental process. The learners are guided accessibly through the experiment, which is ideal for learners for whom independent experimentation is hardly possible, e.g., due to physical disabilities.

Our example unit consists of three steps. The unit starts with (first) a demonstration experiment, in which water beads are made to appear invisible by pouring water over them. After the demonstration, the teacher (second) collects assumptions about the phenomenon. In the (third) experimental phase, students determine the material of a rod in an interactive video experiment. After the experimentation phase, (fourth), the results collected in the video experiment are compared to the demonstration experiment (Pannullo, 2024).

The following paragraphs describe dimensions of lesson planning following the structure of MER combined with aspects of UDL diclusive (see Figure 3).

4.1. Example: Clarification and Analysis of Science Content

Geometric optics deals with the propagation of light through optical devices, usually with the aim of creating an image of an object. In real optical systems, the degree of sharpness of the image is limited by diffraction. For a good approximation, phenomena such as interference and diffraction, which are due to the wave nature of light, are neglected in geometrical optics. Instead, an idealized domain is assumed, in which light propagates in a straight line—as a ray of light. The great simplicity gained outweighs the inaccuracy accepted in many situations. Thematically, therefore, it is about the "controlled manipulation of [...] rays by means of the interpositioning of reflecting and/or refracting bodies, neglecting any diffraction effects" (Hecht, 2017, p. 159).

In the course of such a manipulation of light propagation, laws for reflection and refraction can be formulated. When light passes from one optical medium to another, it changes its direction of propagation, and it is refracted. Part of the light is reflected and reaches our eye—we recognize that there must be something there (in our example: water beads). According to Snell's law of refraction, the angles of incidence and refraction, as well as the refractive indices of the two media, relate to each other, as follows:

$$n_1 \cdot \sin(\alpha) = n_2 \cdot \sin(\beta)$$

The context of our example unit is a phenomenon in which so-called water beads appear invisible when put into water. The reason for their apparent disappearance is that water beads and water have a similar refractive index. The refractive index of a medium is a number that gives the indication of the light-bending ability of that medium. When a clear material is surrounded by a clear liquid with the same refractive index it appears invisible, because there is no refraction and reflection (as shown in the calculation below)—all the light spreads out further, at the same angle:

$$\begin{gathered} n_1 \cdot \sin(\alpha) = n_2 \cdot \sin(\beta) \\ n_{water} \cdot \sin(\alpha) = n_{water\ bead} \cdot \sin(\beta) \\ \text{with } n_{water} = n_{water\ bead} = 1.33 \\ 1.33 \cdot \sin(\alpha) = 1.33 \cdot \sin(\beta) \\ \sin(\alpha) = \sin(\beta) \\ \alpha = \beta \end{gathered}$$

From our point of view, three different complexity levels of the science subject matter are possible:

- Level 1 (low complexity): Under special circumstances, transparent objects may appear invisible;
- Level 2: The same refractive index of the object and surrounding material means that the object appears invisible;
- Level 3 (high complexity): The same refractive index of the object and surrounding material means that the object appears invisible because there is no longer an optical interface. This can also be explained by the law of refraction.

4.2. Example: Recording Students' Perspectives + Individual Support Needs

Students need an adequate understanding of how light interacts with matter. From their everyday observations, learners often have the idea that light "stays" on non-transparent surfaces because a bright spot is visible at that spot. What is obviously difficult is the fact that the interaction—i.e., reflection and refraction—also takes place on matter that is transparent (but has a different refractive index).

With regard to the reflection of light, many learners have the idea that light is similar to a billiard ball on the rail or a football on the goal post. This idea is characterized by a "bounce"—without any further influence on the interaction partners. In the context of our example lesson, the students must therefore become aware that the interaction of light and transparent materials depends on their refractive indices (Schecker et al., 2018).

With this subject, it can be necessary to provide options for recruiting interest; for example, learners choose the experiments they want to carry out (Sührig et al., 2021). Furthermore, to help with the understanding of the materials (e.g., when you have students in your class that have reading difficulties) the experiment should be accompanied by experiment manuals and worksheets that use, for instance, icons, screenshots and photos to support the written information and explain key words and technical terms. Another possible option would be the implementation of audio files, so that reading literacy becomes less important. For accessibility, it can be significant to provide visualization (e.g., subtitles) as alternatives for auditory information, or audio descriptions or screen readers as alternatives for visual information. Further examples can be found in Table 1.

Table 1. The elements of the digital extension of UDL diclusive and the implementation of these elements in the digital video experiment.

Element of UDL Diclusive	Implementation by the Example of a Digital Video Experiment	Additional Value
"Produce appropriate content and media for or with learners, e.g., interactive exercises [. . .]"	The digital video experiment contains interactive elements such as buttons.	Interactive elements are necessary to allow the learners to actively engage in the experiment. In addition, the students can control their learning process independently, e.g., by choosing whether they want to watch a certain sequence of the video again. in order to solve one of the intermediate tasks. The students can make their own decisions regarding the help that is shown, e.g., they can only accept the support that they feel is necessary.

Table 1. *Cont.*

Element of UDL Diclusive	Implementation by the Example of a Digital Video Experiment	Additional Value
"Formative and summative assessments, individual feedback [. . .] and immediate feedback via learning software"	Observation questions during the video experiment and an experiment evaluation at the end offers feedback.	The observation questions help the students to focus on the observation task of the experiment and give clues on the way to solving the tasks. Feedback via an experiment evaluation offers anchor points for the students, as students can repeat the experiment, if necessary, to arrive at the correct solution. This encourages a positive approach to mistakes and enables students to continue learning.
"Emotional activation by including digital media and digital environments learners face in their everyday life"	The learners run the digital video experiment on regular school tablets and computers or on their own devices. Videos are part of their everyday life (for example, YouTube).	Videos (e.g., on Youtube) are part of the everyday life of the students and, therefore, often have a motivating effect. As videos are used a lot, the elements of the video experiment (e.g., the play and pause button) are known, and should not be a barrier for the students.
"Allow cooperation and collaboration using real time tools for text work or collaborative media production [. . .]"	The learners can choose their social form (group work, partner work, single-person work) when working on the experiment. Collaborative work is possible with an e-portfolio because they can compare their observations or results in real time.	Collaboration is an important element of lessons, and having an experiment that allows different social forms is helpful for natural and non-pressured collaboration in interaction with the learning material.
"Present information step by step (e.g., using bookmarks) and provide additional notes (e.g., additional links, tips, illustration, digital helpers)."	The video experiment is divided into different sections that learners can jump between. Each section is linked to an observation and contains textboxes with additional information, comprehension questions and help buttons.	It is not only students with attention difficulties who profit from a structure in experiments because they can skip and go back and adapt, in this process, the experiment, to cater for their individual needs. The small-step presentation and the intermediate tasks divide the experiment into small and clear learning sections. All learners benefit from this reduction of complexity in the sense of the Cognitive Load Theory (Sweller et al., 2019), but especially students with learning difficulties. The possibility of choosing from different options for action before each further step is a further learning support that also allows mistakes in the previous steps to be corrected.
"Use visualization to highlight syntax (e.g., marking syllables or key words) and text structure (e.g., paragraphs of contrasting color)."	Technical terms and key words are printed in bold in the experiment instructions.	The learning of subject specific terms is crucial to approach the professional jargon of physics and be part of discussions in the subject. Also, highlighting key words and technical terms supports students with reading difficulties.
"Excite understanding and transfer by providing appropriate task design (e.g., examples, tutorials, explanations) and pursuing questions."	The experiment instructions contain further information and examples.	Examples and further information help learners to understand and perform the task better, so that every student is able to make scientific observations. Again, students can choose the support they need.

Table 1. *Cont.*

Element of UDL Diclusive	Implementation by the Example of a Digital Video Experiment	Additional Value
"Use software and assistive technologies to enable access to information (e.g., eye or touch control)."	The digital video experiment runs on several platforms and devices. It is often used on tablets with touch control.	The digital experiment is highly accessible because you do not need any specific software. Furthermore, it offers a great range of customization options. For example, the playback speed can be reduced and the display and contrast of the video can be increased, to facilitate observations.

4.3. Example: Design and Evaluation of Learning Environments + Digital Media

While developing the learning environment and choosing materials, we should keep in mind that the experiment is accompanied by experiment instructions that enable the learners to carry out the experiment autonomously.

For the digital experiment, we chose a video of an experiment, which was digitally edited with the Software H5P Interactive Video Library (version 1.22) to add interactive elements (see Figure 4).

Figure 4. Screenshot of the video experiment used in the teaching unit (Pannullo, 2024). The video experiment is available under the link https://www.tinygu.de/OoYh5 (accessed on 3 November 2024).

Interactive video experiments are a great mode of experimentation for mixed-ability groups because students are guided through the experiment and are able to make observations without reading (or following) the instructions. Video experiments are low-threshold, and they do not need to be set up or put away. They offer an additional layer to the real experiment, and contain information, help and assessment (such as multiple-choice questions for predictions, observations and/or outcomes). Furthermore, they are suited to learners who are limited in their ability to carry out experiments independently. Students can work at their own pace and watch or pause the video experiment as many times as necessary. Table 1 shows how the practical implementation of the guidelines of the UDL diclusive can be realized in such a video experiment.

5. Discussion

In this paper, we have presented two sophisticated and widely accepted frameworks for lesson planning: one is the Model of Educational Reconstruction (MER) and the other is the Universal Design for Learning diclusive (UDL diclusive). For contemporary lesson planning, we propose to consider both frameworks. For this purpose, we suggest an extension of the MER by elements of the UDL diclusive. In Section 3, we answered the research question on how MER and UDL diclusive can be combined to facilitate the planning of inclusive and digitally enriched science lessons. We illustrated our consideration with lesson planning for practical work in optics based on MER, highlighted the additional value by using UDL diclusive in Table 1, and answered, with this, the second research question, "What does such a lesson look like?".

With MER, the didactic community has a mature model for developing teaching, curriculum, and research design, at its disposal. Based on constructivist and learning psychological considerations, the subject-related dimension ('clarification and analysis of science content') interacts with student aspects ('recording students' perspectives'). The content dimension is not limited to the restructuring of scientific content, but also considers aspects of learning about natural sciences and the relevance of science in daily life and society. In recording students' perspectives, the focus so far has been on preconceptions and affective variables like interests, self-concepts, and attitudes. Thereby, the aspect of inclusive teaching seems to us to be under-represented in the MER.

From our point of view, the more general pedagogical concept of the UDL diclusive can make a significant contribution here. Supplemented and adapted to include the possibilities of digital media (we called it "diclusive"), it also receives a qualitative upgrade and sharpening in lesson planning ('design and evaluation of learning environments' in MER). Furthermore, it enables teachers to take the different learning requirements in inclusive classrooms into account by referring to the three main fields: means of engagement, means of representation and means of action and expression.

From our point of view, previous efforts to implement inclusion in science teaching have been limited to developing specific teaching materials (Baumann et al., 2018; Klautke & Theyßen, 2021), professionalizing students at universities (Schlüter et al., 2018), and promoting particular students' competencies, such as experimentation competence, in specific scientific research methods (Brauns & Abels, 2021; Klautke & Theyßen, 2022).

Aiming for scientific literacy for all, in Germany, the "network for inclusive science education" (NinU) focuses on two perspectives framing learning arrangements at school (Stinken-Rösner et al., 2020). Similar to our approach, they also consider the educational and pedagogical perspectives. Different to our approach, their pedagogical perspective has recourse to the index for inclusion (Booth & Ainscow, 2019) instead of the UDL diclusive. A further difference lies in their educational perspective, based on Hodson (2014). Using these two perspectives, they create a matrix which leads to searching for appropriate tasks in learning arrangements (Stinken-Rösner & Hofer, 2022). This connects to our approach of planning science lessons, by using the described—and well-established—frameworks of MER and UDL diclusive.

We see our proposal of combining MER and UDL diclusive as a contribution to the development of teaching. The proposal will have to undergo empirical testing in teaching practice. We see the need for empirical findings, particularly in practicability in everyday school life. A possible question would be to what extent the proposed structures are helpful for teachers in their lesson planning. Overall, empirical findings on the effectiveness of inclusive lesson planning for science lessons have been rare, and further efforts are needed (Abels, 2015; GFD—Gesellschaft für Fachdidaktik, 2015). This finding is not surprising, since any empirical studies would face the dilemma of comparing politically and socially required inclusive teaching with teaching without inclusive considerations. Empirical evidence should not aim at whether learning is better or whether the students' learning performance is improved (the limitation of inclusion to a cognitive perspective). Inclusion, from the perspective of involvement and participation, also means giving all students access to learning. We believe we can meet this requirement with our approach. We would like to encourage teachers and science education researchers to rethink science teaching based on our diclusive teaching approach, and to broaden the widely known MER.

6. Conclusions

With the proposal to expand MER to include inclusive and digital aspects through the UDL diclusive model, MER, as an established model for lesson planning, is experiencing further contemporary development. This extension is essential and expedient for the training of pre-service teachers at universities and the professional development of teachers.

While this paper is primarily theoretical, the proposed framework's potential is illustrated through a practical example. We were able to show how the framework was used to plan inclusive lessons using digital media, in the example of a teaching unit on optics. The approach shown in the article can also be used for other planning processes.

Future work will focus on empirical testing and refinement of the framework in real classroom settings. Limitations include the challenge of addressing diverse national educational contexts and missing empirical evidence. Further research will explore the proposed approach's effectiveness and its adaptability across disciplines and educational systems.

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References

Abels, S. (2015). Der Entwicklungsbedarf der Fachdidaktiken für einen inklusiven Unterricht in der Sekundarstufe [The development needs of subject didactics for inclusive teaching in secondary schools]. In G. Biewer, E. Böhm, & S. Schütz (Eds.), *Inklusive pädagogik in der sekundarstufe* (pp. 135–148). Kohlhammer.

Abels, S., & Stinken-Rösner, L. (2022). "Diklusion" im naturwissenschaftlichen Unterricht—Aktuelle Positionen und Routenplanung ["Diclusion" in science education—Current positions and route planning]. In E. M. Watts, & C. Hoffmann (Eds.), *Digitale NAWIgation von inklusion* (pp. 5–20). Springer Fachmedien Wiesbaden. [CrossRef]

Ainscow, M. (2021). Inclusion and equity in education: Responding to a global challenge. In A. Köpfer, J. J. W. Powell, & R. Zahnd (Eds.), *International handbook of inclusive education. Global, national and local perspectives* (1st ed., pp. 75–88). Barbara Budrich. [CrossRef]

AlSadrani, B., Alzyoudi, M., Alsheikh, N., & Elshazly, E. E. (2020). The digital divide in inclusive classrooms. *International Journal of Learning, Teaching and Educational Research*, *19*(3), 69–85. [CrossRef]

Baumann, T., Kieserling, M., Struckholt, S., & Melle, I. (2018). Verbrennungen—Eine Unterrichtseinheit für inklusiven Unterricht [Burns—A lesson unit for inclusive teaching]. *CHEMKON*, *25*(4), 160–170. [CrossRef]

Booth, T., & Ainscow, M. (2019). *Index für Inklusion: Ein Leitfaden für Schulentwicklung* [Index for inclusion: A guide for school development] (B. Achermann, Ed.; 2nd ed.). Beltz.

Boothe, K. A., Lohmann, M. J., Donnell, K. A., & Dean Hall, D. (2018). Applying the principles of universal design for learning (UDL) in the college classroom. *The Journal of Special Education Apprenticeship*, *7*(3), 1–13. [CrossRef]

Bosse, I., Schluchter, J.-R., & Zorn, I. (Eds.). (2019). *Handbuch Inklusion und Medienbildung [Handbook of inclusion and media education]* (1st ed.). Beltz Juventa.

Böttinger, T. (2023a). Bildung für alle? Zur Rolle digitaler Medien beim Überwinden von Lernbarrieren [Education for all? The role of digital media in overcoming learning barriers]. *Spuren—Zeitschrift Des VDS Bayern*, *23*(4), 4–10.

Böttinger, T. (2023b). Inklusion in der Digitalität—Herausforderungen und Lösungsansätze [Inclusion in—Challenges and solutions]. In T. Irion, M. Peschel, & D. Schmeinck (Eds.), *Grundschule und digitalität: Grundlagen, herausforderungen, praxisbeispiele* (Vol. 155, pp. 157–174). Grundschulverband e.V.

Böttinger, T., & Schulz, L. (2021). Diklusive Lernhilfen—Digital-inklusiver Unterricht im Rahmen des Universal Design for Learning [Diclusive learning aids—Digital-inclusive teaching within the framework of universal design for learning]. *Zeitschrift Für Heilpädagogik*, *2021*(9), 436–450.

Böttinger, T., & Schulz, L. (2023a). Digital-inklusiver Unterricht mit dem UDL diklusiv [Digital-inclusive teaching with the UDL diclusive]. *ON—Lernen in Der Digitalen Welt*, *12*, 26–27.

Böttinger, T., & Schulz, L. (2023b). Teilhabe an digital-inklusiven Bildungsprozessen—Das Universal Design for Learning diklusiv als methodisch-didaktischer Unterrichtsrahmen [Participation in digital-inclusive educational processes—The universal design for learning diclusive as a methodological-didactic framework]. QfI—Qualifizierung Für Inklusion. *Online-Zeitschrift Zur Forschung Über Aus-, Fort- Und Weiterbildung Pädagogischer Fachkräfte*, *5*(2), 1–19. [CrossRef]

Böttinger, T., & Schulz, L. (2023c). Wie können digitale Medien ein Gewinn sein? Unterrichtsgestaltung aus Sicht der Diklusion [How can digital media be an asset? Lesson planning from the perspective of diclusion]. *Die Grundschulzeitschrift*, *340*, 14–17.

Bransford, J. D., & Donovan, M. S. (2005). Scientific inquiry and how people learn. In M. S. Donovan, & J. D. Bransford (Eds.), *How students learn: Science in the classroom* (pp. 397–420). National Academies Press. [CrossRef]

Brauns, S., & Abels, S. (2021). Die Anwendung naturwissenschaftlicher Untersuchungsmethoden inklusiv gestalten—Naturwissenschaftsdidaktische Theorie und Empirie erweitern mit dem Kategoriensystem inklusiver naturwissenschaftlicher Unterricht (KinU) [Designing the application of scientific inquiry methods inclusively—Expanding science education theory and empiricism with the category system of inclusive science teaching (KinU)]. *Zeitschrift für Didaktik der Naturwissenschaften*, *27*(1), 231–249. [CrossRef]

Bui, D. C., & McDaniel, M. A. (2015). Enhancing learning during lecture note-taking using outlines and illustrative diagrams. *Journal of Applied Research in Memory and Cognition*, *4*(2), 129–135. [CrossRef]

Buli-Holmberg, J., Sigstad, H. M. H., Morken, I., & Hjörne, E. (2023). From the idea of inclusion into practice in the Nordic countries: A qualitative literature review. *European Journal of Special Needs Education*, *38*(1), 79–94. [CrossRef]

CAST—Centre for Applied Special Technology. (2018). *Universal design for learning guidelines, version 2.2*. Available online: https://udlguidelines.cast.org/ (accessed on 3 November 2024).

CISL—Centre on Inclusive Software for Learning. (2021). *Creating digital tools to empower students*. Available online: https://cisl.cast.org (accessed on 3 November 2024).

Clement, J., Brown, D. E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding 'anchoring conceptions' for grounding instruction on students' intuitions. *International Journal of Science Education*, *11*(5), 554–565. [CrossRef]

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education*, *15*(5), 463–494. [CrossRef]

Coley, J. D., & Tanner, K. (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. *CBE—Life Sciences Education*, *14*(1), 1–19. [CrossRef]

Committee on High School Science Laboratories: Role and Vision. (2004). The role of practical work in the teaching and learning of science. In *America's lab report*. National Academy of Sciences.

Dalton, E. M. (2017). Universal design for learning: Guiding principles to reduce barriers to digital & media literacy competence. *Journal of Media Literacy Education*, *9*(2), 17–29. [CrossRef]

Deng, F., Chen, D., Tsai, C., & Chai, C. S. (2011). Students' views of the nature of science: A critical review of research. *Science Education*, *95*(6), 961–999. [CrossRef]

Dertinger, A. (2020). Grundsatzfragen und Begründungslinien einer inklusiven Medienbildung in der Grundschule—Theoretische und konzeptionelle Überlegungen [Fundamental questions and justifications of inclusive media education in primary schools—Theoretical and conceptual considerations]. In M. Thumel, R. Kammerl, & T. Irion (Eds.), *Digitale bildung im grundschulalter. Grundsatzfragen zum primat des pädagogischen* (pp. 275–298). Kopaed.

Deutsche UNESCO-Kommission. (2021). *Für eine chancengerechte Gestaltung der digitalen Transformation in der Bildung*. Resolution der 81. Mitgliederversammlung [For an equitable design of the digital transformation in education. Resolution of the 81st general assembly]. Available online: www.internationaler-bund.de/fileadmin/user_upload/storage_ib_redaktion/resolution_unesco_digitalisierung-bildung.pdf (accessed on 3 November 2024).

Drossel, K., Eickelmann, B., & Gerick, J. (2017). Predictors of teachers' use of ICT in school—The relevance of school characteristics, teachers' attitudes and teacher collaboration. *Education and Information Technologies*, *22*(2), 551–573. [CrossRef]

Duit, R., Gropengiesser, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The Model of Educational Reconstruction—A framework for improving teaching and learning science. In D. Jorde, & J. Dillon (Eds.), *Science education research and practice in europe: Retrospective and prospective* (pp. 13–37). Sense Publishers. [CrossRef]

Eickelmann, B., Bos, W., Gerick, J., Goldhammer, F., Schaumburg, H., Schwippert, K., Senkbeil, M., & Vahrenhold, J. (Eds.). (2019). *ICILS 2018 #Deutschland: Computer- und informationsbezogene Kompetenzen von Schülerinnen und Schülern im zweiten internationalen Vergleich und Kompetenzen im Bereich Computational Thinking [ICILS 2018 #Germany: Computer and information-related competencies of students in the second international comparison and competencies in the area of computational thinking]*. Waxmann.

Eickelmann, B., Bos, W., & Labusch, A. (2020). Die Studie ICILs 2018 im Überblick. Zentrale Ergebnisse und mögliche Entwicklungsperspektiven [The ICILS 2018 study at a glance: Key findings and possible development perspectives]. In B. Eickelmann, W. Bos, J. Gerick, F. Goldhammer, H. Schaumburg, K. Schwippert, M. Senkbeil, & J. Vahrenhold (Eds.), *ICILS 2018 #deutschland. Computer- und informationsbezogene kompetenzen von schülerinnen und schülern im zweiten interna-tionalen vergleich und kompetenzen im bereich computational thinking* (pp. 7–31). Waxmann. Available online: https://www.pedocs.de/frontdoor.php?source_opus=18319 (accessed on 3 November 2024).

Eickelmann, B., Fröhlich, N., Bos, W., Gerick, J., Goldhammer, F., Schaumburg, H., Schwippert, K., Senkbeil, M., Vahrenhold, J., & Bos, W. (Eds.). (2024). *ICILS 2023 #Deutschland: Computer- und informationsbezogene Kompetenzen und Kompetenzen im Bereich Computational Thinking von Schüler*innen im internationalen Vergleich [ICILS 2023 #Germany: Computer and information literacy and computational thinking competencies of students in international comparison]*. Waxmann.

Filk, C., & Schaumburg, H. (2021). Editorial: Inklusiv-mediale Bildung und Fortbildung in schulischen Kontexten [Editorial: Inclusive media education and professional development in school contexts]. *MedienPädagogik: Zeitschrift Für Theorie Und Praxis Der Medienbildung*, *41*, i–ix. [CrossRef]

Friesen, M. E., Leuders, T., & Loibl, K. (2021). Flexibles Gruppieren nach lernzielrelevanten Voraussetzungen [Flexible grouping based on learning objective-relevant prerequisites]. *PÄDAGOGIK*, *3*, 42–45. [CrossRef]

GFD—Gesellschaft für Fachdidaktik. (2015). *Positionspapier Nr. 19. Stellungnahmen zum inklusiven unterricht* [Position paper No. 19: Statements on inclusive teaching]. Available online: https://www.fachdidaktik.org/wordpress/wp-content/uploads/2015/09/GFD-Stellungnahme-zum-inklusiven-Unterricht-Stand-28.01.2017.pdf (accessed on 3 November 2024).

Gogiberidze, G., Isakov, V., Ershova, T., & Shulgina, O. (2019). Development of innovations in the educational environment. Inclusive education and digital technologies. *Revista inclusiones*, *7*, 147–158.

Hammann, M., & Asshoff, R. (2014). *Schülervorstellungen im Biologieunterricht: Ursachen für Lernschwierigkeiten* [Students' conceptions in biology lessons: Causes of learning difficulties] (1st ed.). Klett/Kallmeyer.

Hecht, E. (2017). *Optics* (5th ed.). Pearson.

Heusinger, M. (2020). *Lernprozesse digital unterstützen: Ein Methodenbuch für den Unterricht* [Supporting learning processes digitally: A method book for teaching] (1st ed.). Beltz.

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, *36*(15), 15. [CrossRef]

Hossain, M. (2012). An overview of inclusive education in the United States. In J. E. Aitken, J. P. Fairley, & J. K. Carlson (Eds.), *Communication technology for students in special education and gifted programs* (pp. 1–25). IGI Global. [CrossRef]

Kattmann, U., Duit, R., Gropengießer, H., & Komorek, M. (1997). Das Modell der Didaktischen Rekonstruktion—Ein Rahmen für naturwissenschaftsdidaktische Forschung und Entwicklung [The model of educational reconstruction—A framework for research and development in science education]. *ZfDN*, *3*(3), 3.

Kent, M., Ellis, K., Latter, N., & Peaty, G. (2018). The case for captioned lectures in Australian higher education. *TechTrends*, *62*(2), 158–165. [CrossRef]

Klafki, W. (1964). *Das pädagogische Problem des Elementaren und die Theorie der kategorialen Bildung* [The pedagogical problem of the elementary and the theory of categorical education]. Beltz.

Klautke, F., & Theyßen, H. (2021). Gemeinsames Lernen im Physikunterricht. Gestaltung eines differenzierenden Lernangebotes zu Stromkreisen [Collaborative learning in physics lessons: Design of a differentiated learning offer on electric circuits]. *MNU*, *74*(4), 4.

Klautke, F., & Theyßen, H. (2022, March 21–23). *Akzeptanz und Nutzung von UDL-basierten Unterstützungsangeboten zum Experimentieren* [Acceptance and use of UDL-based support options for practical work]. DPG-Frühjahrstagung 2022, virtual.

KMK—Kultusministerkonferenz. (2011). *Inklusive Bildung von Kindern und Jugendlichen mit Behinderungen in Schulen* [Inclusive education for children and adolescents with disabilities in schools]. Available online: https://www.kmk.org/dokumentation-statistik/beschluesse-und-veroeffentlichungen/bildung-schule/allgemeine-bildung.html#c1315 (accessed on 3 November 2024).

KMK—Kultusministerkonferenz. (2021). *Lehren und Lernen in der digitalen Welt. Ergänzung zur Strategie der Kultusministerkonferenz "Bildung in der digitalen Welt."* [Teaching and learning in the digital world: Supplement to the conference of ministers of education and cultural affairs' Strategy 'education in the digital world']. Available online: https://www.kmk.org/dokumentation-statistik/beschluesse-und-veroeffentlichungen/bildung-in-der-digitalen-welt.html (accessed on 3 November 2024).

Lee, O., Miller, E. C., & Januszyk, R. (2015). Next generation science standards: All standards, all students. *Journal of Science Teacher Education*, *25*(2), 2. [CrossRef]

Lin, J.-W., Yen, M.-H., Liang, J., Chiu, M.-H., & Guo, C.-J. (2016). Examining the factors that influence students' science learning processes and their learning outcomes: 30 years of conceptual change research. *EURASIA Journal of Mathematics, Science and Technology Education*, *12*(9), 2617–2646. [CrossRef]

Linder, K. (2016). *Student uses and perceptions of closed captions and transcripts: Results from a national study*. Oregon State University Ecampus Research Unit.

Lorenz, R., Yotyodying, S., Eickelmann, B., & Endberg, M. (Eds.). (2022). *Schule digital—der Länderindikator 2021. Lehren und Lernen mit digitalen Medien in der Sekundarstufe I in Deutschland im Bundesländervergleich und im Trend seit 2017 [The digital school—The federal state indicator 2021: Teaching and learning with digital media in lower secondary education in Germany in comparison across federal states and trends since 2017]*. Waxmann. [CrossRef]

Mayr, K. (2021). Bildungsprozesse in heterogenen Lerngruppen gestalten [Designing educational processes in heterogeneous ability groups]. *Pädagogik*, *7–8*, 7–8. [CrossRef]

Michaelsen, A. S. (2021). *The digital classroom: Transforming the way we learn* (1st ed.). Routledge.

Nieminen, J., & Pesonen, H. V. (2019). Taking universal design back to its roots: Perspectives on accessibility and identity in undergraduate mathematics. *Education Sciences*, *10*(1), 12. [CrossRef]

Pannullo, L. (2024). *Wahlmöglichkeiten beim Experimentieren: Entwicklung und Erprobung eines Konzeptes für Experimente in inklusiven Lerngruppen im Physikunterricht [Choice in lab work: Development and trial of a concept for experimentation in inclusive learning groups in physics lessons]* [Ph.D. thesis, Goethe University]. [CrossRef]

Pilgrim, J., & Ward, A. K. (2017). Universal design for learning: A framework for supporting effective literacy instruction. In C. M. Curran, & A. J. Petersen (Eds.), *Handbook of research on classroom diversity and inclusive education practice* (pp. 282–310). IGI Global. [CrossRef]

Rao, K., & Meo, G. (2016). Using universal design for learning to design standards-based lessons. *SAGE Open*, *6*(4), 4. [CrossRef]

Reinfried, S., Mathis, C., & Kattmann, U. (2009). Das Modell der Didaktischen Rekonstruktion. Eine innovative Methode zur fachdidaktischen Erforschung und Entwicklung von Unterricht [The model of educational reconstruction: An innovative method for didactics research and development of teaching]. *Beiträge zur Lehrerinnen- und Lehrerbildung*, *27*(3), 3.

Salend, S. J. (2011). *Creating inclusive classrooms: Effective and reflective practices* (7th ed). Pearson.

Sanger, C. S. (2020). Inclusive pedagogy and universal design approaches for diverse learning environments. In C. S. Sanger, & N. W. Gleason (Eds.), *Diversity and inclusion in global higher education* (pp. 31–72). Palgrave Macmillan. [CrossRef]

Schaumburg, H. (2021). Personalisiertes Lernen mit digitalen Medien als Herausforderung für die Schulentwicklung: Ein systematischer Forschungsüberblick [Individualized learning with digital media as a challenge for school development: A systematic research overview]. *MedienPädagogik: Zeitschrift Für Theorie Und Praxis Der Medienbildung*, *41*, 134–166. [CrossRef]

Schecker, H., & Duit, R. (2018). Schülervorstellungen und Physiklernen [Students' conceptions and physics learning]. In H. Schecker, T. Wilhelm, M. Hopf, & R. Duit (Eds.), *Schülervorstellungen und physikunterricht* (pp. 1–21). Springer. [CrossRef]

Schecker, H., Wilhelm, T., Hopf, M., & Duit, R. (Eds.). (2018). *Schülervorstellungen und Physikunterricht: Ein Lehrbuch für Studium, Referendariat und Unterrichtspraxis* [Students' conceptions and physics lessons]. Springer Spektrum.

Schlüter, A.-K., Krabbe, C., Melle, I., Krause, K., Wember, F. B., Grimminger-Seidensticker, E., Lautenbach, F., Heberle, K., & Kranefeld, U. (2018). Universitäre Vorbereitung angehender Lehrkräfte auf inklusiven Unterricht. Seminarkonzeptionen zur Professionalisierung für inklusiven Fachunterricht [University preparation of pre-service teachers for inclusive teaching: Seminar concepts for professionalization in inclusive subject teaching]. *Zeitschrift für Heilpädagogik*, *69*(12), 582–595.

Schulz, L., & Beckermann, T. (2020). Inklusive Medienbildung in der Schule: Neun Aspekte eines guten diklusiven Unterrichts [Inclusive media education in schools: Nine aspects of good diclusive teaching]. *Computer Und Unterricht*, *117*, 4–8.

Schulz, L., & Böttinger, T. (2022). Digitale Barrieren abbauen—Das diklusive Universal Design for Learning [Breaking down digital barriers—The universal design for learning diclusive]. In L. Schulz, I. Krstoski, M. Lüneberger, & D. Wichmann (Eds.), *Diklusive lernwelten: Zeitgemäßes lernen für alle schülerinnen und schüler* (1st ed., pp. 54–60). Visual Ink Publishing UG. Version 1.5.

Schulz, L., & Krstoski, I. (2022). Diklusion [Diclusion]. In L. Schulz, I. Krstoski, M. Lüneberger, & D. Wichmann (Eds.), *Diklusive lernwelten: Zeitgemäßes lernen für alle schülerinnen und schüler* (1st ed., pp. 31–43). Visual Ink Publishing UG.

Steffensky, M., & Neuhaus, B. J. (2018). Unterrichtsqualität im naturwissenschaftlichen Unterricht [Teaching quality in science lessons]. In D. Krüger, I. Parchmann, & H. Schecker (Eds.), *Theorien in der naturwissenschaftsdidaktischen forschung* (pp. 299–313). Springer.

Stinken-Rösner, L., & Hofer, E. (2022). Re-thinking tasks in inclusive science education. *Progress in Science Education (PriSE)*, *5*, 33–46. [CrossRef]

Stinken-Rösner, L., Rott, L., Hundertmark, S., Baumann, T., Menthe, J., Hoffmann, T., Nehring, A., & Abels, S. (2020). Thinking inclusive science education from two perspectives: Inclusive pedagogy and science education. *Research in Subject-Matter Teaching and Learning*, *3*, 30–45.

Sührig, L., Teichrew, A., Erb, R., & Winkelmann, J. (2021). Practical work for all learners. In G. S. Carvalho, A. S. Afonso, & Z. Anastácio (Eds.), *Fostering scientific citizenship in an uncertain world (Proceedings of ESERA 2021)* (Vol. 3, pp. 216–223). CIEC, University of Minho. Available online: https://www.esera.org/wp-content/uploads/2023/02/CNF21-Proceedings_Stand-3_p.187-252.pdf (accessed on 3 November 2024).

Sweller, J., van Merrienboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, *31*(2), 2. [CrossRef]

Taber, K. (2002). *Chemical misconceptions: Prevention, diagnosis and cure: Theoretical background* (Vol. 1). Royal Society of Chemistry.

Thumel, M., Kammerl, R., & Irion, T. (Eds.). (2020). *Digitale Bildung im Grundschulalter: Grundsatzfragen zum Primat des Pädagogischen [Digital education at primary school age: Fundamental questions on the primacy of pedagogy]*. Kopaed.

UNESCO—United Nations Educational, Scientific and Cultural Organization. (2009). *Policy guidelines on inclusion in education*. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000177849 (accessed on 3 November 2024).

van Dijk, J. (2020). *The digital divide*. Polity.

Voogt, J., Knezek, G., Christensen, R., & Lai, K.-W. (Eds.). (2018). *Second handbook of information technology in primary and secondary education* (2nd ed.). Springer International Publishing. [CrossRef]

Vosniadou, S. (2019). The development of students' understanding of science. *Frontiers in Education*, *4*, 32. [CrossRef]

Wagenschein, M. (1988). *Naturphänomene sehen und verstehen: Genetische lehrgänge* [Observing and understanding natural phenomena: Genetic instructional courses] (2nd ed.). Klett.

Winkelmann, J. (2023). On idealizations and models in science education. *Science & Education*, *32*(1), 1. [CrossRef]