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Perceiving the usage of external representations in physics

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Abstract

Prior research shows the importance of external representations in learning physics at school. This research often focuses on the teaching of as well as learning with different forms of representations, such as graphs and tables, and their impact on understanding professional content. Teachers' and students' perception and the matching of both have not been in the focus of previous research. One open question in this regard is, how teachers estimate the adequacy of how they use external representations to teach physics compared to how students perceive it. To investigate this question, we conducted a survey of teachers as well as students of 6th, 8th, and 10th grade in German schools. The development and validation of the questionnaire is part of the research method. The results show differences between how teachers estimate the frequency and adequacy of the representations they use and how adequate students perceive this to be. As a practical consequence, these insights could be used for teachers to reflect upon the materials they use to teach physics.

Keywords: educational offer, external representations, perceived adequacy, physics

INTRODUCTION

In most science lessons, no matter whether at school or university, external representations such as pictures, tables, formulas, or diagrams are fundamental for learning and teaching of scientific content (Härtig et al., 2022). In this regard, especially multiple representations have been in the focus of research that investigates their relevance for the comprehension of scientific content. So far, most of this research has focused on characteristics of the representations (Ainsworth, 2006) or how they should be combined to enhance learning (e.g., Mayer, 2020). Furthermore, characteristics of the learners, for instance their prior knowledge or their visual model comprehension (e.g., Dickmann et al., 2019) are considered to play a major role for how multiple representations are encoded and understood and for the question, whether they foster or even impair learning, for instance by causing disorientation and cognitive overload (e.g., Kalyuga, 2014). All these insights, however, require that learners know they learn with certain types of representations (no matter whether they understand these representations) and that teachers use them appropriately. In other words, the way in which a learning content is perceived, has a remarkable impact on how it is processed and whether a learner experiences benefits or cognitive (over)load (Sweller et al., 2011). In this regard and from a cognitive, but also motivational point of view, the matching between learners' and teachers' perception of the application and use of external multiple representations might give valuable insights into the question, how teaching with and learning from external multiple representations in science lessons can be supported. This, however, has not been taken up by research so far.

The present study aims to fill this gap by investigating, how 6th, 8th, and 10th grade students from German high schools perceive the multiple representations that are used in the learning materials and presented by their teachers in their physics lessons. Furthermore, the respective perceptions of their teachers were assessed as well, and we had a look on how these two are related. In the following paper, the theoretical section comprises a description of characteristics, functions, and the relevance of external representations in science lessons. Subsequently, our study on the

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Contribution to the literature

- This study investigates whether *teachers' perceptions* of the usefulness of external representations are in line with theories like the cognitive theory of multimedia learning (e.g., Mayer, 2020), which would be a crucial prerequisite for whether and how teachers use such representations in their (science and physics) lessons.
- Furthermore, the question, how *students' perceptions match those of their teachers*, has an impact on how they process external representations and thus benefit from them.
- We show significant differences between perceptions of teachers and students in using multiple representations. This finding can influence teaching and learning with different forms of representations.

perception of the use of multiple representations in physics lessons is presented.

THEORETICAL BACKGROUUND

Three Theories of Learning With Representations

The following section gives an overview on relevant theoretical assumptions regarding learning with multiple representations. On the basis of the cognitive theory of multimedia learning (CTML) (Mayer, 2020), multimedia materials support deep understanding and meaningful learning. Multimedia in this theory primarily means text-picture-combinations, which, according to Mayer (2020), are more suitable than text only to develop a coherent understanding of what must be learned. This "multimedia principle" assumes of dual coding of incoming information in working memory (cf. Paivio, 1986), that is, information can be processed in a visual (what we see) and in an auditory (what we hear) channel, which should both be used during learning instead of overloading only one channel. However, the mere usage of two different forms of representations is not enough, they must be well-designed according to the learning goals. For instance, the pictures added to text should be instructional and not purely decorative. In addition, both spatial and temporal contiguity of text and pictures are important to ensure schema construction and avoid unnecessary search or memory processes (Mayer & Fiorella, 2014). Furthermore, multiple forms of representations should be coherent in content and structure and not redundant, for example identical written and spoken text should be avoided (Mayer, 2020; Opfermann et al., 2017).

The ITPC model (integrated model of text and picture comprehension) of Schnotz (2005) addresses learning with multiple representations in form of text-picture combinations similar to how CTML assumes this takes place. ITPC similarly proposes an auditory and visual channel of perception in which incoming information is processed and integrated with already existing knowledge stored in long term-memory. Both theories, CTML as well as ITPC, see the construction of a coherent mental model as the central goal of learning with text and pictures (and thus, the basic form of multiple representations). Unlike CTML, which supposes that information in the verbal and auditory channel is "fully" processed first and then merged with existing long-term memory knowledge, ITPC assumes that information that is processed in these two channels is already being matched with each other from the beginning of the processing. This requires that visual as well as pictorial information are available in the working memory channels and that learners are fully aware of them. In conclusion, learners go through three stages in this process of learning with multiple representations: At first, in the extraction of information the representation is identified (e.g., a text or word is being read, a picture is being seen). This is followed by the conscious processing of relevant information in both working memory channels. The last step is the integration of information. For instance, a text and a diagram are integrated into one coherent mental model in which (relevant) parts of the diagram are suitable to enhance text comprehension and the other way around (Horz & Schnotz, 2010).

Finally, a very popular model of learning with multiple representations has been introduced by Ainsworth (2006). In DeFT model (design, functions, and tasks), multiple representations can be understood the best way when the following aspects are considered: design, function, and cognitive purpose of the representations. This includes that multiple representations are suitable to support learning (compared to single representations) when they fulfil complementary, constraining or/and integrative functions. Unlike CTML or ITPC, DeFT model does not limit learning with multiple representations to text-picture combinations. Multiple representations according to Ainsworth (2006) can include any combination of texts, figures, diagrams, tables, photographs, concept maps, etc. Multiple representations in this regard also support learning in that different cognitive processes are addressed so that learners are also able to choose the representation(s) that best fit(s) their preferences and their individual skills.

All these three theories emphasize the importance of learners recognizing the matching of relevant representations regarding the content to be learned and to each other. Only then, information can be processed and merged with already existing knowledge and accordingly be stored in long-term memory (Opfermann et al., 2017).

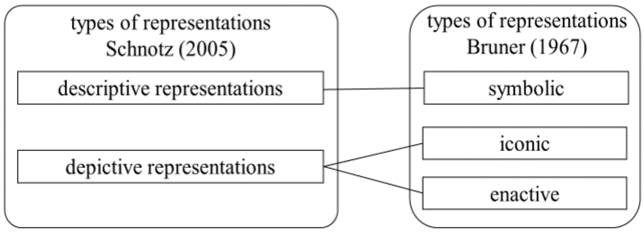

Figure 1. Classifications of representation types following Bruner (1967) and Schnotz (2005)

Types of Representations

As described above, external representations can be everything from pure text to complex graphics. Simply said, an external representation is everything that a learner can perceive visually. Such representations can be classified into several types. Two basic and popular classifications have been introduced by Bruner (1967) and Schnotz (2005). These are depicted and compared in **Figure 1** (own illustration) based on the definitions and descriptions of the representation types.

According to Schnotz (2005), there are two basic types of representations, which he calls descriptive and depictive. Descriptive representations have no structural similarity to their reference object. For example, the word *tree* has no structural similarity with a real tree in nature. The word *tree* is a description of a real tree. Synonyms or symbols describing a real object (e.g., ♂ and ♀) belong to this type of representation for example. Contrary to this, depictive representations show structural similarities to their reference object. For example, photography or drawing of a tree is structurally like real tree, or simply said, it really looks like a tree. Depictive representations are often more complete and have more information than descriptive representations (Opfermann et al., 2017; Schnotz, 2005).

Similar to Schnotz (2005), Bruner (1967) divided representations into iconic (depictive) and symbolic (descriptive) representations, but he additionally introduced so called enactive representations (**Figure 1**). The classification by Bruner (1967) is classical but topical as well. Iconic representations can be illustrations like drawings of an experimental setup in physics. Iconic representations accordingly are like Schnotz' (2005) depictive types of representations. In contrary, formulas and texts are symbolic representations. These representations comprise abstract symbols and thus are like Schnotz' (2005) descriptive representations. The third type of representations introduced by Bruner (1967) are enactive representations, which includes so called acts, for instance experimenting. Two types of acts are distinguished: On the one hand learners watch an act like teachers presenting an experiment (demo experiment), which is comparable to learning with other external representations (e.g., reading a book or watching an animation). On the other hand, there are acts that learners must *imagine*, and which are thus *internal* representations in their mind. Both acts are nonverbal and can be assigned to the depictive type of representation (Ainsworth, 2006; Schnotz & Bannert, 2003).

On the basis of the different types, some representations can be more reasonable for conveying certain scientific contents or aspects than others (Treagust et al., 2017). For example, diagrams and graphs are suitable to explain relations between various kinds of information because of their symbolic character. Formulas can describe these relations mathematically and compactly. Texts can describe the relations more detailed in a linguistic/semantic way. The order of experimental materials can be shown in a depictive, iconic representation (Bruner, 1967; Schnotz, 2005).

Learning With Different Forms of Representations

Taking all the above mentioned into account and looking at common learning materials in physics or other science lessons, representations are rarely used in a single, standalone way. It is much more likely that we find graphs accompanied by tables or explaining texts in a physics book, to name just one example (Ainsworth, 2006). Gilabert et al. (2005) and O'Reilly and McNamara (2007) investigated the importance of cohesion in texts for text comprehension. The cohesion influences the recall and inference measures positively. Explicit connections improve the comprehension of learners with low prior knowledge and increase learners' inferences. Furthermore, results of some studies investigating how inferences are drawn when reading texts show the relevance of combining different representations (Best et al., 2005; Opfermann et al., 2017; O'Reilly & McNamara, 2007). Learners had a better text comprehension when drawing inferences. Learning with representations like diagrams (Butcher, 2006) also improves the inferences compared to learning with texts only. Cromley et al. (2010b) found that inferences are "strongly associated with comprehension of both text and diagrams".

To use representations in science lessons effectively, it should be considered that different forms of representations have distinct functions depending on their type, combination, and usage. Diagrams with an axis for example have the function to visualize abstract data. They can reflect theories and support the analysis of hypotheses. Representations in general are an important aid for interpreting results (Treagust et al., 2017). In comparison to diagrams or tables, formulas have a symbolic function. A formula is an expression combining mathematics and physics to give a detailed description of abstract information. Because of the concise conclusion of results of experimental data, formulas can express a relation of different information or describe regularity. For example, formulas can be used to describe a physical process by representing the changes in time- or location-dependent variables.

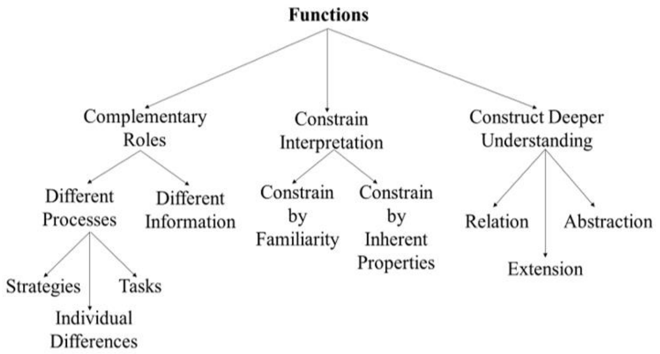

Figure 2. Functions of multiple representations according to Ainsworth (2006)

The usage of representations can support the interactivity in general, but the form must be chosen appropriately. The learners' choice of representation depends more on the frequency of usage and thus familiarity than on the effects and meaning in the respective context (Fredlund et al., 2012).

According to Larkin and Simon (1987), a representation is more efficient than another, when it is easier and faster to gather information when using that certain representation. The highest efficiency of a form of representation defines the best representation for the corresponding function. Diagrams and tables with measured values for example, illustrate the functional relation. Nevertheless, graphs can be more efficient for learning than tables when the graph only has to be watched coarsely to solute the exercise (Treagust et al., 2017).

In addition to the usage of forms of representations with a high efficiency, the diverse types of learning must be taken into consideration. In this regard, according to the cognitive theory of flexibility, the ability to construct and to change between multiple perspectives (in this case representations) is fundamental for successful learning (Opfermann et al., 2017; Spiro & Jehng, 1990). The usage of multiple representations can be helpful in explaining complex contents and thus increase learning success. Moreover, when provided with multiple representations, learners can choose the form of representation they prefer for learning (Opfermann et al., 2017; Rau et al., 2015).

It can be a challenge for learners to understand multiple representations and their relations in general. That could be a reason for why learners might attempt to understand the representations in separation and are not able to integrate them into a coherent mental model. In the DeFT model, already mentioned in the previous sections, Ainsworth (2006) names three key functions of multiple representations depicted in **Figure 2**.

Constraining interpretation means that multiple representations are useful for learning when the different representations constrain the interpretation possibilities for one another. Consequently, learners are guided in the right direction for a better understanding. In physics for example the word "force" has another meaning than in everyday language. With a pictorial representation the meaning can be limited to the physical content. If multiple representations fulfil complementary functions, the different forms of representations describe different information(al) aspects or similar aspects of information differently. The necessity of both forms of representations for a complete understanding is characteristic for this function.

Finally, using multiple representations can lead to a deeper understanding than learning with only one representation. To achieve this, the different forms of representations must be integrated to enable a deeper processing of the content. This process requires three steps: First, relevant information from different forms of representations is extracted and references between the information nodes are established. Second, the learner connects this information with already existing knowledge stored in long-term memory. Finally, the learner can translate and change between the different forms of representations (Ainsworth, 2006; Opfermann et al., 2017).

Despite the above-mentioned advantages of using multiple representations in learning materials, it must be kept in mind that the more different forms of representations are used similarly, the more difficult it might become for learners to translate between these representations. Additionally, aspects like type and abstraction can maximize the differences (Ainsworth, 2006). The change between representations nevertheless should not be ignored. Although it can be a challenge for learners, it should be practiced so that learners gain more experience. The relations have to be reflected and be clear in order to avoid misunderstanding and to support learners in using different forms of representations (van der Meij & Jong, 2006).

In sum, if designed and combined appropriately, multiple representations can be used in a broad range of scenarios and materials in science lessons. They support learners in their development of understanding and can be used for learning success evaluations (DiSessa, 2004). However, only few studies about the *real* usage of different representations, respectively the *perception* of usage in scientific lessons can be found. As an example, reading skills are perceived as being more important than construction skills although both abilities are linked. The ability of reading diagrams for example is a precondition to construct them. The construction of representations promotes mathematical competences like constituting, communicating and modelling and thus makes thinking about and analyzing of data and diagrams possible (van Oostendorp & Goldman, 2009). To do so, however, learners need support for example from the teacher or through instructional materials (Waldrip & Prain, 2012).

The interpretation and translation between multiple forms of representations are aims of competency acquisition and a central goal of science lessons as well (Treagust et al., 2017). The sub-competencies of constructing diagrams include the division of the scale and the entry of values as well as the drawing of external features such as the coordinate axes. Learners must understand the functions of representations and to recognize their aims. To make use of the potential of representations, learners have to be able to connect different forms of representations (Ainsworth, 1999).

This coherent reference to and translation of information from representations, however, is often difficult in class. According to Pineker-Fischer (2017) especially the change between representations is a challenge for learners. When constructing diagrams on their own, learners often have difficulties in the division and labelling of the axes, in constructing a regular scale and in assigning scale and axe unambiguously. In addition, the change between representations could be a challenge for reading skills, if learners have to switch between graphic and numeric representations (Treagust et al., 2017), as working with diagrams and tables is often seen as part of the reading competency (Barton et al., 2002; Fang & Wei, 2010). These difficulties in understanding are often linked to problems in changing representations. One reason is learners' low ability with regard to representational coherence (cf. visual model comprehension; Dickmann et al., 2019), that precisely describes the ability of relating one form of representation with its respective referent (Seufert, 2003). Representational competence, on the other hand, is the ability to use forms of representations in a reflective manner, both individually and in combination (Kozma & Russell, 2005). Learners are expected to acquire a repertoire of representational skills. Combined with past experiences, this can have a positive influence on the development of own representations (DiSessa, 2004).

To summarize the above-mentioned theories, the usage of multiple representations is necessary for a deeper understanding, but the benefit is not self-evident. Some aspects like the forms or functions of representations must be considered. What is additionally important is explained below.

Perception of Educational Offer Regarding Multiple Representations

As discussed in the previous sections, supporting students regarding their skills when learning with multiple representations seems a crucial aim for science teachers. But just using different forms of representations might not be enough to increase representational competence. Instead, the deliberate usage of *certain* forms of representations must be explicitly promoted, so that they prove to be conducive to learning and reduce learning difficulties. Furthermore, changes between representations are both a linguistic requirement and supporting action (Pineker-Fischer, 2017).

The provision and usage of (multiple) representations in learning materials could be seen as some kind of *educational offer* (from teachers) according to the utilization-of-learning-opportunities model of Helmke and Schrader (2019). This offer in form of learning opportunities is used by learners individually. In an ideal case, the usage leads to an increase in competence. The benefits are reflected in the learning outcomes. The better the quality of the offer the higher the probability of learning success. In addition to the influence of the school context, individual characteristics of learners like prior knowledge and motivation have an impact on the usage frequency. In this model, learning is seen as an active, self-controlled, and individual process. In this way, learners perceive and interpret the usage of forms of representations as an educational offer individually (Helmke & Schrader, 2019). Sanchez and Wiley (2006) for example found that learner characteristics can influence the usage of diagrams. In addition, the results of Cromley et al. (2010a) suggest that the level of text comprehension is influenced by learners' background knowledge like vocabulary, which could also be shown for different science texts. Learners' scientific background knowledge can have a positive effect on their reading comprehension because of their different prerequisites and their effects on strategies and inference as already described previously (see also Härtig et al., 2022). In other words, if a teacher works with several graphs and tables during a physics lesson, not all learners in his or her class might interpret these equally or perceive these as just right, too little or too much in the same way (Opfermann et al., 2017).

Teachers also perceive their educational offer in a certain way. Teachers' conscious perception and interpretation of lessons belong to their professional action competencies. Noticing is part of professional perception and describes the ability of perceiving situations in class relevant for learning and teaching. The assessment of the situations relevant for learning success is made from the professional perspective of the teachers (Könings et al., 2014). Regarding forms of representations, this means that teachers recognize and assess the need for assistance and the intensity of the teaching offer from their professional and very individual point of view.

However, little is yet known about science teachers' perceptions of their offer regarding multiple representations. In one solitary study about biology teachers in Germany, Nitz et al. (2012) investigated the perception of technical language in biology lessons. However, the questionnaire developed for this purpose only addressed the learners' perceptions and did not consider the teachers. In Ditton (2002) the learners' point of view was additionally investigated only with regard to how they perceive their teachers. However, certain teaching-learning-situations or the usage of certain materials in class were neglected. A project by Kämpfe (2009) investigated the informative value of learners' points of view for the teacher. The results show a slight deviation of learners' mean scores from teachers' mean scores, with the learners showing a more positive perception than the teachers. So far, however, all the above-mentioned theories and explanations show, it is still unclear how learners perceive the usage of forms of representations as a teaching offer in comparison to their teachers.

RESEARCH QUESTIONS

To investigate the perception of learners and the offer of their teachers regarding the usage of and learning with multiple representations in physics lessons, we conducted a survey to calculate the degree to which these perceptions match for different classes (and thus, various levels of experience with certain kinds of representations in physics). The questionnaire for both groups that includes a range of parallel items was newly developed for the purpose of this research. The study is based on an explorative quantitative approach and focuses on the following research questions:

Research question 1a. How does teachers' estimated frequency regarding their usage of several types of representations in physics lessons differ from what the learners in their classes indicate to consider appropriate?

Research question 1b. Does this difference (between estimated frequency and indicated appropriateness) differ as a function of grade level?

Research question 2a. How does teachers' indicated adequacy of their usage of different representations in physics differ from what their students perceive to be adequate?

Research question 2b. Does this difference (between teachers' indicated and students' perceived adequacy) differ as a function of grade level?

METHODOLOGY & RESEARCH DESIGN

For this explorative quantitative research study, a questionnaire assessing how students and teachers perceive the use of external representations in physics was developed and validated during a longitudinal data collection phase. All methodological aspects and data collection procedures were approved by the university's data protection commissioner. In addition, the study was conducted in accordance with current German laws on the implementation of scientific studies at schools. Written consent to take part in the study was collected by the schools' responsible persons, the pupils, and their parental authorities. The pupils were also informed that they could end their participation anytime during the study without giving reasons. The questionnaire is based on the above mentioned questionnaire of Nitz et al. (2012), whereby we adapted the items to representations used in physics lessons and developed respective parallel scales for teachers' perceptions. The development of the items and scales is described in more detail in the following.

Development of the Questionnaire

There are two versions of the questionnaire, one for teachers and one for students. In both versions, the general content of the items is the same (e.g., perceived usage frequency of diagrams), but the wording has been slightly modified in accordance with the target groups of teachers and students. For the students of 6th, 8th and 10th grades, identical scales were used. That is, there is only one learner questionnaire (and one for teachers, respectively). We aimed at using clear and understandable language. For example, short and concise main sentences were used. The items are distributed across five scales:

1. Learning with diagrams
2. Learning with tables
3. Learning with texts
4. Learning with formulas/calculations
5. Change and transition between different forms of representations.

The items for these scales were produced based on the theoretical background and the possible usage of popular representations in physics. In general, the items focus on the construction and interpretation of representations. The types of representations (diagram, table, text, and formula/calculation) were chosen because of their relevance for science (which is for instance reflected in the frequency with which they can be found in textbooks). In addition, all these forms of representation are important components of experimental protocols in science education. It should be noted that, students in sixth grade often do not yet have much experience with classical formulas in physics. Therefore, items in scale (4) were enriched with the term "calculations." Prior to the main study, a pilot study was conducted to verify the validity, reliability, and functionality of the instrument. The pilot study was conducted separately with a different sample.

To make sure that all learners (and teachers) have similar prerequisites when answering the questionnaire, the actual scales are preceded by an instruction and a brief explanation. These supplements contain comments on how to answer the items and explanations of what the term "representations" means, including examples and advice for the different forms of representations. Diagrams in this questionnaire include for example pie charts, bar charts and dot plots with graphs. If the students do not understand something regarding the

Table 1. Example items of the questionnaire for teachers (translated version of the original questionnaire)

Statement	Never	→			Always
9. We practice generating diagrams.	☐	☐	☐	☐	☐
10. We generate diagrams to better recognize correlations between different variables.	☐	☐	☐	☐	☐
11. If a student has difficulties to enter measured values into a diagram, I support him/her.	☐	☐	☐	☐	☐
	Too little		Just right		Too much
12. Overall, from my point of view we work with diagrams in physics lessons …	☐	☐	☐	☐	☐

Table 2. Example items of the questionnaire for students (translated version of the original questionnaire)

Statement	Too little		Just right		Too much
9. We practice generating diagrams.	☐	☐	☐	☐	☐
10. We generate diagrams to better recognize correlations between different variables.	☐	☐	☐	☐	☐
11. If a student has difficulties to enter measured values into a diagram, I support him/her.	☐	☐	☐	☐	☐
12. Overall, from my point of view we work with diagrams in physics lessons …	☐	☐	☐	☐	☐

representations in the items, they are able to use the explanation at the beginning of the questionnaire. Additionally, demographic data such as grade, age and gender were assessed.

To investigate the teachers' estimated frequency of their educational offer, they were asked how often they use several types of representations in their classes. The content of these items was semantically like the learners' version, but the scaling differentiated. In the teachers' version, items were answered on a 5-point Likert scale from "never" to "always", while in the learners' version, this 5-point Likert scale ranged from "too little" to "too much". Translated into numbers, the answers of the learners' version are scaled, as follows: 1 for "too little", 2 for "rather little", 3 for "just right", 4 for "rather much" and 5 for "too much". The answers of the teacher version are translated analogously into numbers: 1 for "never" to 5 for "always". Furthermore, teachers indicated whether from their point of view, the usage of representations is "too little", "just right" or "too much" in one overall item for each representation type (e.g., altogether, from my point of view, we work with graphs in physics lessons … "too little"–"just right"–"too much"). This perceived adequacy of usage of representations was assessed with parallel (identical) items in the learner questionnaire. In the following, we show parts of the translated version of the original first scale Learning with diagrams of both versions to illustrate the differences between the items for students versus teachers.

In **Table 1**, items 9 to 11 are about the perceived frequency of teachers whereas items 9 to 11 with the similar content in **Table 2** assessed the perceived adequacy that students indicate.

Item 12 in both tables refers to the perceived adequacy in general. In total, both versions of the questionnaire contain 44 items. It must be noted that we differentiated between perceived frequency and perceived adequacy because one does not necessarily correspond to the other. That means a student could for instance indicate that tables are used very often in his or her class and think that this is too much, while at the same time another student from the same class indicates that tables are used very often and thinks that this is just right. Similarly, teachers might indicate that diagrams are almost never used, but that does not necessarily reflect whether this is also perceived as being adequate by this teacher.

To analyze the data and to get the results to answer the research questions, descriptive as well as inferential statistics were used. First, to confirm our data from the pilot study in which the questionnaire was validated (Leisen et al., 2022), we determined the internal consistencies (Cronbach's alpha) and the factor structure of the scales. These are shortly described at the beginning of the following section. Second, we conducted interferential statistics to analyze our results according to the research questions. Paired-sample t-tests for the overall sample, paired-sample t-tests separated for the grades and repeated measures analyses of variance (ANOVA) were conducted for this. The paired sample t-test compares the mean scores of teachers' values with the mean scores of students' values to answer the research questions 1a and 2a. Additionally, paired sample t-tests separated for different grades were conducted to answer the research questions 1b and 2b. ANOVA with the grade as a between subject factor was calculated additionally to compare the students' and teachers' answers in dependence of the different grades.

Sample and Research Design

The sample in our study included 41 classes of sixth, eighth and tenth graders of German high schools. A total

Table 3. Cronbach's alpha for internal consistencies of the questionnaire scales

	Cronbach's alpha for student questionnaire	Cronbach's alpha for teacher questionnaire
Learning with diagrams	.818	.933
Learning with tables	.727	.872
Learning with texts	.607	.735
Learning with formulas/calculations	.858	.960
Change & transition between different forms of representations	.875	.890

of 867 students (48.80% male, 48.60% female, 2.20% diverse, and .50% without indication of gender) and 23 teachers (60.90% male and 39.10% female) participated in this study. The students were 10 to 19 years old (mean [M]=13.10; standard deviation [SD]=1.870) and the teachers were between 28 and 65 years old (M=45.00; SD=11.320). Altogether there were 231 students of grade 10 with an average age of 15.62 years (SD=.735) and 235 students of grade 8 between 12 and 15 years (M=13.50; SD=.663). The 401 sixth graders have an average age of 11.42 years (SD=.612). An overview of the sample's descriptive characteristics is shown in **Appendix A**.

We did not gather other descriptive data such as social background or ethnicity for example, because on the one hand, these did not relate to our research focus, and on the other hand, ethnicity is not a variable that is commonly assessed within German learning-related research. Some teachers participated with more than one class, sometimes with classes of different grades. In this case the respective teacher got a separate questionnaire for each of his or her classes. Teachers and students answered the questionnaire in the classroom at the same time. There was no time limit, so everyone had enough time for completing the questionnaire conscientiously. On average, participants needed 20 to 30 minutes to complete the questionnaire.

RESULTS

Psychometric Properties of the Questionnaire

As in the pilot study (Leisen et al., 2021), the reliabilities in terms of internal consistencies of the five scales are acceptable to excellent (**Table 3**). They do not increase after deletion of items, and the selectivity of single items is good. The values of item-scale-correlations are mostly above .600 (minimum: .390 and maximum: .943).

Besides the internal consistencies, we wanted to confirm the structure of the scales; and thus, a factor analysis with varimax rotation was conducted. The exploratory analysis suggests a solution with six factors for both versions of the questionnaire. However, no item of the teachers' questionnaire and only one of the students' questionnaires showed the highest loading on the sixth factor. Therefore, and in accordance with the pilot study, a solution with five factors is also acceptable. The five-factor solution elucidates 51.66% of the variance in the students' questionnaire and 78.72% in the teachers' version. Almost all items in the students' version except those related to learning with texts load on the first factor. In contrast the initial scales (especially *learning with diagrams, learning with formulas/calculations,* and *learning with texts*) are confirmed in the teachers' version. In both cases, most items have a loading clearly above .500 (partly even above .800) on "their" respective factor (that is, the factor, they would be assigned to). Furthermore, many items assessing working with diverse representations load on one factor that can be related to something like "working independently." The scale *change and transition between different forms of representations* is not a separate factor but it depends on one of the representations used in the item (e.g., transition between text and tables loads on a different factor than transition between text and graphs, and the deciding aspect does not seem to be transition, but rather that something regarding working with texts was assessed in the case). **Appendix B** shows questionnaire.

Descriptive Data

The mean scores and standard deviations for each of the five scales of the student and teacher questionnaire are depicted in **Table 4**. The high *n* indicated for teachers in the third column is due to the copying of teachers' data for each class according to the number of students, to match each student with his or her teacher. That is, teachers were not treated as single cases in the analysis, but their data were duplicated in accordance with the number of students in the class. More specifically, if a class had 30 students, for instance, these 30 students were treated as single cases each, while the teacher questionnaire data were matched 30 times to the students (30 comparisons, such as student A–teacher X, student B–teacher X, student C–teacher X, and so forth). As can be seen in **Table 4**, the numbers still differ slightly, which is because occasionally, items were left out by either teachers or students.

Inferential Statistics

In the next section, the results of our study are described in accordance with the research questions. To answer research questions 1a and 2a (whether and how students' answers in the questionnaire differ from the respective answers of their teachers), we conducted paired-sample t-tests for the overall sample as well as paired-sample t-tests separated for the grades. In this

Table 4. Mean scores & standard deviations for five scales of student & teacher versions of the questionnaire

	Student questionnaire	Teacher questionnaire
Learning with diagrams	2.43 (.730) & n=859	3.91 (1.200) & n=867
Learning with tables	2.58 (.670) & n=862	3.84 (1.130) & n=867
Learning with texts	2.61 (.810) & n=863	3.70 (.820) & n=867
Learning with formulas/calculations	2.28 (.910) & n=848	3.79 (1.510) & n=845
Change & transition between different forms of representations	2.10 (.800) & n=859	2.35 (1.020) & n=845

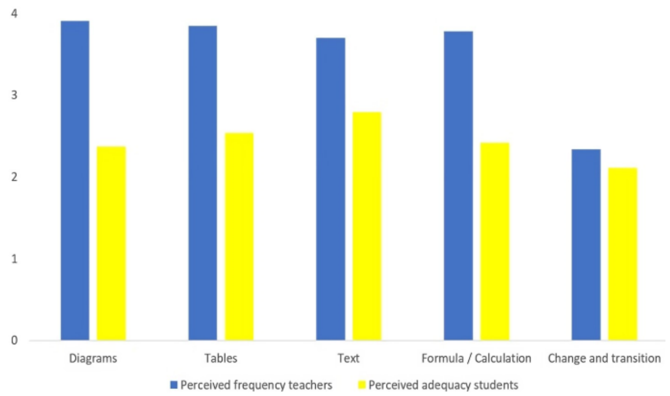

Figure 3. Perceived frequency of usage of representations by teachers & perceived adequacy of this usage by students for overall sample (Source: Authors' own elaboration)

case, paired samples t-tests are the method of choice as each student answer is paired with the respective answer of his or her teacher (Field, 2013). In other words, in the SPSS file, the single cases were the 867 students (thus, 867 rows in the file). For each of these students, respective variables were their own answers in the questionnaire as well as their teachers' answers. More explicitly, to give an example, for each student there were two variables for "we practice generating diagrams"–one showing the answer of the student and one showing the answer of the teacher, both on a 5-point Likert scale (statistically, this comparison between the two variables is the same as comparing the values of a pre- and a post-test, where two similar variables from an identical instrument are matched). In addition, univariate ANOVA with grade as a between subject factor were calculated to compare the students' and teachers' answers in dependence of the different grades (research questions 1b and 2b).

Comparison of Teachers' Estimated Frequency and Students' Perceived Adequacy

This analysis focuses on the first research question: how does teachers' estimated frequency regarding their usage of several types of representations in physics lessons differ from what the learners in their classes indicate to consider appropriate? Example items used in this analysis are shown in **Table 1** and **Table 2**. The mean scores for what teachers and students indicated are depicted in **Figure 3**.

Paired-sample t-tests show significant differences between teachers' estimated frequency and students' perceived adequacy for the four representation scales (all $p<.001$) and a marginally significant difference for the scale on change and transition between representations ($p=.087$). Focused on the research question mentioned above, this means that teachers indicate to use these representations and practice the transition between them on average occasionally too often, but that students do not perceive this as perfectly adequate (or in other words, students indicate they would like to work even more with the respective representation).

To answer research question 1b and to investigate the differences between 6th, 8th, and 10th grades the t-tests were also calculated for the grades separately. Again, significant differences were found for all scales. In 6th grade the largest difference between students' and teachers' perceptions refers to the scale *learning with diagrams* ($M=1.65$, $SD=1.540$) whereas in 8th and 10th grade the largest difference was found with regard to *learning with formulas/calculations* with $M=1.63$ ($SD=1.260$) in 8th and $M=1.56$ ($SD=1.170$) in 10th grade (**Table 5**).

To confirm these results, repeated measures ANOVA with grade as the between subjects factor were conducted. These analyses show the differences between the teachers' estimated frequency and the students perceived adequacies for all five scales in accordance with the paired-sample t-tests. The amount of these differences does not differ as a function of grade regarding the scale *learning with diagrams* ($F<1$).

For the other four scales, the (always significant) differences between teachers' and students' perceptions vary as a function of grade ($10.480\leq F\leq 36.750$; all $p<.001$; $.024\leq \eta^2\leq .081$). Regarding *learning with tables*, this means that the difference between teachers' and students' perception decreases in higher grades. Regarding

Table 5. Average differences between teachers' perceived frequency of usage & students' perceived adequacy as a function of grade

Grade	Diagram		Table		Text		Formula/calculation		Change & transition	
	M	SD	M	SD	M	SD	M	SD	M	SD
6th	1.65	1.540	1.52	1.460	0.98	1.230	1.09	2.100	0.34	1.350
8th	1.57	1.480	1.35	1.330	0.65	1.360	1.63	1.260	0.40	1.450
10th	1.33	1.270	0.89	1.470	1.05	1.220	1.56	1.170	0.45	1.120

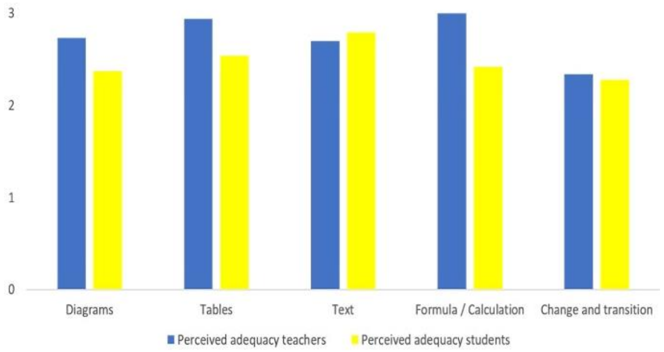

Figure 4. Perceived adequacy of usage of representations by teachers & perceived adequacy of this usage by students for overall sample (Source: Authors' own elaboration)

learning with formulas/calculations and *change and transition*, the difference is smaller in 6th grades and larger in 8th and 10th grades, whereas the latter two do not differ.

Finally, for text, the difference between teachers' and students' perceptions is the smallest in 8th grades and larger in 6th and 10th grades, and the latter two again do not differ.

Comparison of Perceived Adequacy Between Students and Teachers

To answer research question 2a about the comparison of the perceived adequacy of teachers and students, the five overall-items of the two respective scales were paired to calculate five paired-sample t-tests. The mean scores for what teachers and students indicated are depicted in **Figure 4**.

The teachers' perceived adequacy of their overall usage of representations differs significantly from their students' perceived adequacy for each scale ($p<.001$ for diagrams, tables, and formula, $p=.002$ for change and transition, $p=.007$ for text). The average differences, however, are small, as can be seen in **Figure 4**. For example, the average difference for *change and transition between different forms of representations* is M=.12 (SD=1.150). The maximum average difference is M=.58 (SD=1.120). In short, this means that teachers perceive the usage of the respective representations in their lessons as slightly more adequate compared to how students perceive this offer. In other words, both teachers and students perceive the frequency in which the respective representations are used in their physics lessons as *rather too little* to *just right*. Interestingly in this analysis and as can be seen in **Figure 4**, differences are mostly in the way that students would like to work more with the respective representations than what teachers perceive as being adequate, except for text, where this difference is just the other way round (and still significant, although the difference itself is rather small).

Again, these paired-sample t-tests were calculated separately for each grade to answer research question 2b. The differences between students' and teachers' scores are significant for all scales in 6th and 10th grade, and for all scales except *change and transition* in 8th grade (**Table 6**). In line with the results for the overall sample, this means that teachers perceive their usage of and learning with the respective representations in their lessons as more adequate than students do. Like the previous analyses, a repeated measures ANOVA (with grade as the between subject factor) was conducted to confirm the results. The differences between the scores of students and teachers are significant for all overall items, that is, for the respective representations as well as for *change and transition*. Interaction between paired comparison of students' and teachers' perceived adequacy is significant as a function of grade. In other words, the perceived adequacy of students and the perceived adequacy of teachers differ differently in each grade. For example, the average difference for *learning with tables* in 6th grade is M=.51 (SD=1.070) and M=.47 (SD=.920) in 8th grade, whereas in 10th grade it is M=.14 (SD=.890). That is, although perceptions of teachers and students always seem to differ, these differences become smaller and the perceptions more homogeneous with increasing grades.

DISCUSSION

The aim of the study was to investigate, how students in 6th, 8th, and 10th grade perceive the usage of multiple representations in their physics lessons, in particular their frequency and adequacy and how this relates to the frequency and adequacy that teachers indicate for the usage of representations regarding their physics lessons in the respective classes. To our knowledge, this has not been in the focus of research so far, and we aimed to fill this gap to better understand the relationship of both, teachers' and students' perception of how external representations are used in their physics lessons. Such understanding is crucial from our point of view because it could help to explain how and why students process (or do not process) and profit from the representations that their teachers offer to them while trying to increase their physics knowledge.

A questionnaire was developed for this purpose. The scales are reliable with acceptable to excellent internal consistencies. Results of a factor analysis show that

Table 6. Average differences between teachers' & students' perceived adequacy as a function of grade

Grade	Diagram		Table		Text		Formula/calculation		Change & transition	
	M	SD	M	SD	M	SD	M	SD	M	SD
6th	0.49	1.120	0.51	1.070	0.11	1.020	0.96	1.050	0.13	1.140
8th	0.23	1.230	0.47	0.920	0.30	1.020	0.24	1.250	0.08	1.290
10th	0.28	0.870	0.14	0.890	0.17	0.960	0.27	0.880	0.28	0.990

especially younger students do not yet differentiate between different forms of representations but only between *text* on the one hand and other forms of representations on the other hand. Items containing the words "text" or "writing" show more homogeneous results (e.g., factor loadings) than all other forms of representations.

An explanation might be that the less experience students have, the more they probably "only" differentiate between *text* as a verbal form of representation and other pictorial forms of representations like *diagrams, tables,* and formulas/calculations, considering *formulas/calculations* as very abstract. The scale *change and transition between different forms of representations* contains more than one representation, which might be the reason why students do not perceive the scale separately. One reason could be that learners might not be able to assign different functions to different representations because of their missing methodic and professional knowledge as mentioned in the theoretical background (Treagust et al., 2017). The questionnaire with its initial five scales seems to work better for teachers because they differentiate between different forms of representations, especially *diagrams, texts,* and *formulas/calculations*. Furthermore, as mentioned above, teachers combine items that can be related to a more general construct that we would call "working independently" (that is, items that contain phrases like students are able to create diagrams (tables, texts, etc.). Additionally, they do not perceive the *change and transition between different forms of representations* separately but rather seem to focus on one of the representations contained in the item. In general, teachers seem to perceive forms of representations more individually than their students do. This could be related with their experience and background knowledge in learning and teaching. But the *change and transition* must be practiced explicitly in physics lessons so that learners can understand multiple representations and integrate them into a coherent model. Otherwise, the use of multiple representations might become a hard-to-solve challenge for them that can be linked to the DeFT model (Ainsworth, 2006).

The same scales as written in *development of the questionnaire* above, are used for every grade. Although, the scales work better in the teachers' than in the students' questionnaire, this procedure increases the comparability of students' and teachers' scores in each grade. Based on the questionnaire, teachers especially differentiate visual forms of representation more clearly than students. This finding is an important aspect to be able to interpret results and learning successes. Furthermore, the scales are separated in terms of content for the different forms of representations.

The first part of the results is about the teachers' estimated frequency of their educational offer and the students' perceived adequacy of this offer (research question 1a). Teachers estimate the frequency of their offer in every case as often. This is not surprising because teachers create and thus are responsible for their own offer in physics lessons. It would thus be more counterintuitive if they indicated (or *admitted*; cf. social desirability; Edwards, 1957) that their teaching including instructional materials is rather inadequate. Students, on the other hand, would like to learn more and with diverse representations. This was surprising, as we rather expected that students would indicate that learning with representations in their physics classes as being too much, which would be in line with findings that instructional materials are often very demanding for learners and impose a high amount of cognitive load (e.g., Opfermann et al., 2017). An explanation for this finding might be that students do not perceive every situation as learning with those representations. For example, they only differentiate between texts and other representations because they do not perceive the adequacy of learning with representations in general as sufficient. This could be the reason, why they want to learn more with different representations in physics.

The research question 1b focuses on the differential effects of teachers' estimated frequency and students' perceived adequacy in 6th, 8th, and 10th grades. The results show differences between the three grades. In 6th grade teachers indicate *learning with tables* and *texts* as taking place significantly more often than their students perceive this offer as appropriate. In contrary, in 8th grade we only found differences between students and teachers in *learning with formulas/calculations*. In 10th grade the perceived adequacy and estimated frequency differ about *learning with diagrams, tables, texts,* and *formulas/calculations*. In all cases teachers estimate the frequency of their learning offers for these representations as "often to almost always" whereas students perceive the offer as rather "just right." In 6th grade the use of *formulas/calculations* is not very present in German high schools, it often only starts in higher grades. It is connected to the technical content taught in 6th grade and the professional requirement of the representation. Although, all the used representations are descriptive there are differences in detail. *Formulas/calculations* have mathematical and abstract characteristics, and they describe correlations compactly. *Diagrams* and *tables* are also symbolic but less abstract than *formulas/calculations*. As mentioned in the theory, *texts* can describe the relations linguistically adapted to the reader, in more detail and with some examples (Bruner, 1967; Schnotz, 2005). This might be why students in 6th grade perceive the *learning with formulas/calculations* as too much at this point. They compare *learning with formulas/calculations* with *learning with tables* and *texts* that is more present. In 8th and 10th grade the use of *formulas/calculations* increases. Students of higher classes must use, form, and interpret this form of representation, which is also one central goal in current learning standards. Thus, they might perceive the learning offer as too little. Students of these grades want to learn more with *formulas/calculations* to use them correctly. The *change and transition between different forms of representations* seems not to be used very often, this is how the teachers estimate the frequency of their offer. Accordingly, in the students' opinions in all grades, this is not enough yet. That is, in this case, there is no difference between the estimated frequency of the teachers' and the students' perceived adequacy in learning the *change and transition*. Both indicate that this is not used or practiced enough but could be more focused on in their physics classes.

Regarding research question 2a and thus the perceived adequacy of learning with diverse representations in physics lessons in general, the students' results are like the results mentioned before. They perceive the adequacy of the overall offer for representations as too little to just right. Although teachers indicate a similar perception, they perceive the offer as more adequate. The significant differences show that students would like to work more with all these representations whereas teachers rather claim it to be just right. Again, the students' results were unexpected for the same reason as mentioned above, whereas the teachers' results did so because they might have reflected their own teaching and educational offer, which again are part of their professional perception as described in the theoretical section (Könings et al., 2014).

The results regarding the perceived adequacy of teachers and students show differences between the grades as well (research question 2b). There are significant differences for the perceived adequacy of learning with all representations in all grades but only for the perceived adequacy of *change and transition between different forms of representations* in 6th and 10th grade. In 6th grade the differences between teachers' and students' perceived adequacy regarding *learning with diagrams, tables*, and *formulas/calculations* are the largest compared to the other grades. This finding comes close to what we expected because this can be related to students' understanding of representations. As mentioned at the beginning of this section, they differentiate between *text* and other representations. Especially in 6th grade these other representations (such as formulas or diagrams) seem to be more abstract for students than the term *text*. That might explain why they want to learn even more with these representations although the teachers think that their currently usage is just right. In 8th grade the difference in *learning with tables* is close to the difference of 6th graders. In physics in 8th grade the use of *formulas/calculations* and *diagrams* increases. This could be a reason for students' perceived adequacy compared to the teachers' perceptions. Even more surprising is the major difference between teachers' and students' perceived adequacy of *learning with texts* in 8th grade. In this case and even in 6th grade, students perceive the *learning with texts* as almost just right whereas the teachers indicate it being not enough. Initially, this would have been what we expected but looking at the other results, this finding does not fit to the other findings related to the other representations. This could be explained by a predominant use of texts (which, in all grades and even throughout university courses, still seem to be the main form of representation to convey information) compared to the other representations. On the other hand, in 10th grade, all other representations and the *change and transition* of these are focused on. Students have to learn to connect different forms of representations to make use of the benefits of the different representations as mentioned in the theory (Ainsworth, 1999). This can be seen as a learning process and that is one reason for the necessity of learning with different representations at school. At least the differences can be justified by the various levels of students in learning and experience in school and by the different requirements in these grades.

Of course, the perceptions of teachers and students does not have to be identical (which would be the biggest of all surprises). But the results of this study can contribute to a better perception of teachers in a more comprehensive way, and they can help develop themselves further. With these results teachers can compare the frequency and adequacy that they indicate for their usage of different forms of representations (or instructional scenarios in general) to how adequate their students perceive them to be. It might be a way to learn more about the perceived gaps, the wishes, and the needs of their students. The questionnaire enables the participation of students regarding learning with representations in physics. With some adjustments it is possible to use this questionnaire in other lessons to investigate the perceived learning with different representations for different domains. In sum, teachers can overthink and thus change and improve their teaching and support for learning with representations depending on the results of their students. For example, if teachers compare their perceptions of how representations are used with students' perceptions, they can ensure that the target can be appropriately achieved by students. Only in this way, students can learn and work from learning with representational forms without cognitive overload.

Limitations

As mentioned, results from the factor analysis first lead to a six-factor solution. With respect to factor loadings and our theoretical assumptions we interpreted only five of these six factors. An in-depth analysis accompanied by e.g., interviews would be needed to further investigate the sixth factor. This is also true for the fact that especially for younger students the several forms of representations do not split into several factors. This might influence their perception in this kind of retrospective approach. However, it would be much more difficult comparing teachers' and students' perspective without differentiating. It would be of interest, when and how students' recognition of different forms of representations gets more elaborate and in which way this is influenced by teaching. A longitudinal approach with analysis of learning content might provide important insights. Furthermore, regarding students' perception as explicated above even in the same grade students' abilities will differ and thereby influence their understanding up to an expertise reversal effect. As we did not assess individual students' prior knowledge (scientific knowledge, knowledge about diagrams, spatial abilities, …) no detailed regression analyses could be provided.

This also limits the validity of teachers' answers. With respect to our approach, teachers were forced thinking of a 'typical class in its whole. One would assume that teachers indeed might differentiate between different students and their individual needs. In consequence two students in the same class might be provided with different forms or different number of presentations. Also, there might be differences between two classes in the same grade. Both will lead to an uncertainty in our results as teachers were not allowed giving a range or making distinctions between separate groups or types of students. Especially as already mentioned above, *learning with formulas/calculations* is not very present in 6th grade for example. So, this could be left out in the questionnaire to focus on the other representations. It could be interesting to add other representations instead, like drawings or pictures with a physical content relevant in 6th grade. In 10th grade *formulas/calculations* should be included because of the increased relevance and importance of these representations in upper grades. Furthermore, in this study the subject content is not investigated. This can also be a part of further research because the usage and relevance of different forms of representations can depend on the subject content regarding the functions like mentioned in a section above. Another limitation is frequency as a purely visual structure of science education.

Finally, these are answers from teachers and students about how the remind what happened in the past. Thereby it might be influenced by other aspects (for example the intentions or beliefs of the teachers or motivation and interest of students). A further step regarding validation would be a combination of analyzing a series of (videotaped) lessons and our questionnaire with an idea of triangulation.

CONCLUSIONS AND IMPLICATIONS

In advance of answering the research question, it was found that students seem to not differentiate clearly between different forms of representations, meanwhile their teachers do. Therefore, in general one might assume that students' knowledge about the use a meaning of a specific representation is limited–or so to say they do not mind whether drawing a diagram or writing down a table. Based on this result, it would be a next step finding a way to promote and support students in learning not only with but about different forms of representations. This would also force teachers thinking about a specific learning progression regarding a meaningful use of representations in science class throughout lower and upper secondary education. As some of the results show, that especially students do not perceive their learning with different forms of representations as being adequate, they might themselves implicitly recognize their lack of knowledge. Teachers themselves are experts regarding content. It might be interesting to get to know to which degree they differentiate between forms of representations and their unique adequateness regarding specific conclusions. Few is known about the question how and why experts decide to use specific forms of representation, thereby it is questionable whether teachers plan the usage of a specific form despite some general assumptions ("when you perform an experiment you have to write down a table and draw a diagram"). Meanwhile the knowledge about how to use multiple representations from a psychological perspective, the scientific, content driven perspective is kind of underrepresented. However difficulties in learning with different representations can influence the learning of physical content and in some cases both could be much closer connected as assumed so far. Thus, it is necessary finding a method of support from both perspectives–psychological and scientific–to promote students and to avoid difficulties. For example in creating experiment protocols as it could be shown that language as well as cognitive abilities influence experimental success (Stender et al., 2018).

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A

Table A1. An overview of the sample's descriptive characteristics

	Students	Teachers
Number overall	867	23
Number in 6th grade	401	
Number in 8th grade	235	
Number in 10th grade	231	
Gender	48.8% male; 48.6% female; 2.2% diverse; .5% without indication	60.90% male & 39.10% female
Average age (years)	M=13.10 & SD=1.870	M=45.00 & SD=11.320
Age in 6th grade (years)	M=11.42 & SD=.610	
Age in 8th grade (years)	M=13.5 & SD=.660	
Age in 10th grade (years)	M=15.62 & SD=.740	

APPENDIX B: QUESTIONNAIRE

Dear Teacher,

With this questionnaire I investigate how students perceive the support in dealing with types of representation. Types of representation are for example tables, diagrams, texts or formulas or calculations. We refer only to physics classes in this questionnaire. The aim is to compare the teachers' perception with the students' perception. When filling out the questionnaire, it is only important how you personally feel about working with types of representations in the classroom. Your participation in the survey is voluntary. Your name will not be recorded in the process. Your students will not know what you have ticked. The questionnaire will be used and kept for scientific purposes only.

Once you have finished reading the introduction, you can start with the short introduction on the next page. Then read through the statements one by one and check off what you feel is appropriate: *never* to *always* or *too little* to *too much*. Please place the crosses in the center of the boxes and please do not place them next to each other, in the margins, or between two boxes. If you are not sure about a statement, please mark the answer that fits you best. If you change your mind and want to put your cross in a different box, color in the box with the first cross and put a cross in the new answer. Here is an example: you *never* checked first, but then you changed your mind.

never ⟶ ever

■ ☒ ☐ ☐ ☐

Read through everything at your leisure and tick the statements honestly. Thank you for your participation!

Table B1.

Statement	Every time				Never
1. I use different types of representation (e.g., diagrams, texts, or tables) together.	☐	☐	☐	☐	☐
Diagram					
2. We will discuss how to read charts before working with them.	☐	☐	☐	☐	☐
3. We discuss important properties of diagrams.	☐	☐	☐	☐	☐
4. We will learn about different types of diagrams (e.g., scatter plot, bar chart, & pie chart).	☐	☐	☐	☐	☐
5. We discuss what we learn from the diagram.	☐	☐	☐	☐	☐
6. Students draw diagrams on their own.	☐	☐	☐	☐	☐
7. We discuss the labeling of the axes of diagrams.	☐	☐	☐	☐	☐
8. We discuss during an experiment whether it makes sense to draw a graph in the diagram based on the points entered.	☐	☐	☐	☐	☐
9. We will practice drawing diagrams.	☐	☐	☐	☐	☐
10. We draw diagrams to show relationships between different to be able to recognize sizes better.	☐	☐	☐	☐	☐
11. If a student is having difficulty with plotting data from a chart, I will support him/her.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
12. Overall, from my point of view we work with diagrams in physics lessons …	☐	☐	☐	☐	☐
Table					
Statement	Every time				Never
13. Students make tables independently.	☐	☐	☐	☐	☐
14. We will discuss how to read tables before working with them.	☐	☐	☐	☐	☐
15. We discuss important properties of tables.	☐	☐	☐	☐	☐
16. We will practice making tables.	☐	☐	☐	☐	☐
17. We will discuss labeling of rows & columns in a table.	☐	☐	☐	☐	☐
18. We discuss what we learn from the table.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
19. Overall, from my point of view we work with diagrams in physics lessons …	☐	☐	☐	☐	☐

Table B1 (Continued).

Text					
Statement	Every time				Never
20. We work with professional texts.	☐	☐	☐	☐	☐
21. After reading a text, we answer questions about the text.	☐	☐	☐	☐	☐
22. When we experiment, we write down our observations.	☐	☐	☐	☐	☐
23. Students independently write instructions for experiments.	☐	☐	☐	☐	☐
24. The students write independently texts to describe findings from an experiment.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
25. Overall, from my point of view we work with diagrams in physics lessons …	☐	☐	☐	☐	☐
Formulas or calculations					
Statement	Every time				Never
26. We practice writing formulas or calculations.	☐	☐	☐	☐	☐
27. We discuss the meaning of the individual letters in the formulas or calculations.	☐	☐	☐	☐	☐
28. We discuss how to express relationships between quantities in formulas or calculations.	☐	☐	☐	☐	☐
29. We discuss the interrelationships of quantities used in formulas or calculations.	☐	☐	☐	☐	☐
30. We transfer formulas or calculations to our experiments.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
31. Overall, from my point of view we work with diagrams in physics lessons …	☐	☐	☐	☐	☐
Switching between types of representation					
Statement	Every time				Never
32. We describe measured values in tables by writing texts for them.	☐	☐	☐	☐	☐
33. We transfer measured values from tables to a diagram.	☐	☐	☐	☐	☐
34. Using tables, we develop formulas or calculations.	☐	☐	☐	☐	☐
35. We derive formulas and calculations from the relationships in diagrams.	☐	☐	☐	☐	☐
36. We describe diagrams by writing a text about them.	☐	☐	☐	☐	☐
Switching between types of representation					
37. We transfer measured values from a diagram to a table.	☐	☐	☐	☐	☐
38. We make tables of important information in the text.	☐	☐	☐	☐	☐
39. We draw diagrams of important information in the text.	☐	☐	☐	☐	☐
40. We write formulas or calculations from information in a text.	☐	☐	☐	☐	☐
41. We describe formulas or calculations in the form of a text.	☐	☐	☐	☐	☐
42. We draw diagrams using formulas or calculations.	☐	☐	☐	☐	☐
43. We make tables using formulas or calculations.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
44. Overall, from my point of view, we are working with alternation between types of representation in physics education …	☐	☐	☐	☐	☐

In the following, there is no longer a subdivision into "too little" to "too much". Here you can tick everything that applies in your opinion. You can therefore also tick more than one answer here.

If a student has problems regarding understanding following presentation, …	Diagram	Table	Text	Formula or calculation
… I will explain it again.	☐	☐	☐	☐
… Other students will help.	☐	☐	☐	☐
… I will provide examples.	☐	☐	☐	☐
… I will present additional material.	☐	☐	☐	☐
… I will …	☐	☐	☐	☐

Thank you for your support!

Dear Student,

With this questionnaire I investigate how students perceive the support in dealing with types of representation. Types of representation are for example tables, diagrams, texts or formulas or calculations. In this questionnaire, we refer only to physics classes. I would like to investigate how you work with such types of representation in your opinion in class. It is only important how you personally feel about it. You can also see it differently than your classmates or your teacher. Your participation in the survey is voluntary. Your name will not be recorded. The information you provide cannot be traced back to you. Your teachers will not know what you have marked. The questionnaire will be used and kept for scientific purposes only.

Once you have finished reading the introduction, you can start with the short introduction on the next page. Then read through the statements one by one and tick what you think is appropriate: *too little* to *too much*. Please put the crosses in the middle of the boxes and not next to them, at the edge or between two boxes. If you are not sure about a statement, please mark the answer that fits best for you. If you change your mind and want to put your cross in a different box, color in the box with the first cross and put a cross in the new answer. Here is an example: you first checked *too little,* but then you changed your mind.

Table B2. Example

Too little		Just right		Too much
■	☐	☒	☐	☐

Read through everything at your leisure and check off the statements honestly. Be a part of this investigation and support me in my research project to improve the use of types of representations in physics education.

Thank you for your participation!

Table B3.

Statement	Too little		Just right		Too much
1. My teacher uses different types of representation (e.g., diagrams, texts, or tables) together.	☐	☐	☐	☐	☐
Diagram					
2. We will discuss how to read charts before working with them.	☐	☐	☐	☐	☐
3. We discuss important properties of diagrams.	☐	☐	☐	☐	☐
4. We will learn about different types of diagrams (e.g., scatter plot, bar chart, & pie chart).	☐	☐	☐	☐	☐
5. We discuss what we learn from the diagram.	☐	☐	☐	☐	☐
6. Students draw diagrams on their own.	☐	☐	☐	☐	☐
7. We discuss the labeling of the axes of diagrams.	☐	☐	☐	☐	☐
8. We discuss during an experiment whether it makes sense to draw a graph in the diagram based on the points entered.	☐	☐	☐	☐	☐
9. We will practice drawing diagrams.	☐	☐	☐	☐	☐
10. We draw diagrams to show relationships between different to be able to recognize sizes better.	☐	☐	☐	☐	☐
11. If I am having difficulty with plotting data from a chart, my teacher will support me.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
12. Overall, from my point of view we work with diagrams in physics classes …	☐	☐	☐	☐	☐
Table					
Statement	Too little		Just right		Too much
13. We make tables independently.	☐	☐	☐	☐	☐
14. We will discuss how to read tables before working with them.	☐	☐	☐	☐	☐
15. We discuss important properties of tables.	☐	☐	☐	☐	☐
16. We will practice making tables.	☐	☐	☐	☐	☐
17. We will discuss labeling of rows & columns in a table.	☐	☐	☐	☐	☐
18. We discuss what we learn from the table.	☐	☐	☐	☐	☐
Statement	Too little		Just right		Too much
19. Overall, from my point of view, we work with tables in physics classes …	☐	☐	☐	☐	☐

Table B3 (Continued).

Statement	Too little		Just right		Too much
Text					
20. We work with professional texts.	☐	☐	☐	☐	☐
21. After reading a text, we answer questions about the text.	☐	☐	☐	☐	☐
22. When we experiment, we write down our observations.	☐	☐	☐	☐	☐
23. We independently write instructions for experiments.	☐	☐	☐	☐	☐
24. We write independently texts to describe findings from an experiment.	☐	☐	☐	☐	☐
25. Overall, from my point of view, we work with diagrams in physics classes …	☐	☐	☐	☐	☐
Formulas or calculations					
26. We practice writing formulas or calculations.	☐	☐	☐	☐	☐
27. We discuss the meaning of the individual letters in the formulas or calculations.	☐	☐	☐	☐	☐
28. We discuss how to express relationships between quantities in formulas or calculations.	☐	☐	☐	☐	☐
29. We discuss the interrelationships of quantities used in formulas or calculations.	☐	☐	☐	☐	☐
30. We transfer formulas or calculations to our experiments.	☐	☐	☐	☐	☐
31. Overall, from my point of view, we work with diagrams in physics classes …	☐	☐	☐	☐	☐
Switching between types of representation					
32. We describe measured values in tables by writing texts for them.	☐	☐	☐	☐	☐
33. We transfer measured values from tables to a diagram.	☐	☐	☐	☐	☐
34. Using tables, we develop formulas or calculations.	☐	☐	☐	☐	☐
35. We derive formulas and calculations from the relationships in diagrams.	☐	☐	☐	☐	☐
36. We describe diagrams by writing a text about them.	☐	☐	☐	☐	☐
Switching between types of representation					
37. We transfer measured values from a diagram to a table.	☐	☐	☐	☐	☐
38. We make tables of important information in the text.	☐	☐	☐	☐	☐
39. We draw diagrams of important information in the text.	☐	☐	☐	☐	☐
40. We write formulas or calculations from information in a text.	☐	☐	☐	☐	☐
41. We describe formulas or calculations in the form of a text.	☐	☐	☐	☐	☐
42. We draw diagrams using formulas or calculations.	☐	☐	☐	☐	☐
43. We make tables using formulas or calculations.	☐	☐	☐	☐	☐
44. Overall, from my point of view, we are working with alternation between types of representation in physics education …	☐	☐	☐	☐	☐

In the following, we no longer divide it into “too little” & “too much”. Here you can tick everything that applies in your opinion. For example, if your classmates help you with several representations, you can put several crosses in the row.

If I have problems regarding understanding following presentation, …	Diagram	Table	Text	Formula or calculation
… My teacher will explain it again.	☐	☐	☐	☐
… Other students will help.	☐	☐	☐	☐
… My teacher provide examples.	☐	☐	☐	☐
… My teacher present additional material.	☐	☐	☐	☐
… My teacher will give me some cards with little hints.	☐	☐	☐	☐
… I will …	☐	☐	☐	☐

Thank you for your support!