DIAGNOSIS OF DIFFICULTY-GENERATING CHARACTERISTICS IN PHYSICAL PROBLEMS

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In general, physics is seen as one of the less favourite school subjects, which has been widely examined in the past. The lessons are perceived as difficult by many pupils, resulting in a deficient number of them choosing physics as an advanced course, or A Levels exam subject. Explaining the difficulty of physics lessons, essential features of physics are often suspected, such as experimental work, thinking in models, mathematization, dealing with different forms of representation, or just the scientific language. Although these individual features have been empirically referenced, their impact on pupils' perception of the difficulty has not been examined sufficiently. Based on four main categories established by Merzyn (2008), this project examined pupils' problems while solving physical tasks, each with an increased share of scientific language, mathematization, modelling or a lack of reference to everyday life. While solving the tasks, the method of thinking aloud was used to answer the following questions: What characteristics make physical problems difficult for pupils while solving a task? How do pupils perceive the problem's level of difficulty? Can pupils articulate a particular difficulty-generating characteristic to ask for targeted support? In an ensuing interview, the pupils were asked to rank the problems according to their level of difficulty and to reflect on the difficulties and individual hurdles during the solving process.

Keywords: Physics, Problem-solving, Task difficulty

THEORETICAL BACKGROUND

As so many pupils see physics as their least-liked school subject (Williams et al., 2003; Bennett & Hogarth, 2006; Fruböse, 2010; Caglar-Öztürk, 2015), it is interesting to explore the main reasons for this unpopularity. Especially its widely perceived difficulty has been stated many times (Ford, 1989; Angell et al., 2004; Ornek et al., 2008). This is also reflected in the alarming results of the PISA survey (OECD, 2016) which are worthy of improvement and brought problem-solving to public attention, as experts feared after those results, that pupils would not learn to deal with real problems in everyday life (Kühn, 2011). Daily and physical problems, as well as the problem-solving competence, will be explained hereafter.

In a previous work (Fareed & Winkelmann, 2019), several factors that are believed to make physics difficult have been examined. Most frequently mentioned, by both male and female pupils, are the following difficulty-generating characteristics: lack of relevance in the daily life, need of personal effort, use of technical terms, modelling and idealisation of physical problems. These factors coincide with the main categories by Merzyn (2008) and will be further explained in the following.

(Physical) Problems and Problem-solving

Although the two terms “problem” and “task” are mostly used synonymously, it is helpful to define them, as well as the process of problem-solving in cognitive psychology. While a task predominantly describes one single (part) of an exercise or question, a problem serves more as a collective term, from which related terms like problem-solving derive (cf. Brandenburger, 2016). Dörner (1976) defines a situation as a problem if a person strives to turn an unpleasant initial state into an opposite final state. A barrier in between prevents the person from doing so, which might be a lack of methods or the final state not being defined properly. Following Smith (1991), every item that needs analyses and conclusions (concluding knowledge of the relevant domain) is defined as a problem. In order to reach the desired final state, a person must make use of problem-solving strategies. Problem-solving is an essential condition to act in simple daily situations, in scientific questions, or in complex socially relevant political and economic problems (cf. Reif, 2008; Brandenburger, 2016). In school, problems need to be solved daily. The ability to do so is called problem-solving competence, which is defined as “an individual’s capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious […] in order to achieve one’s potential as a constructive and reflective citizen” (OECD, 2014). In school, it is also a key competence necessary in all subjects and fields (cf. Brandenburger, 2016) and required in national educational standards and curricula. Therefore, the focus of our research is on the problem-solving competence, which enables students to deal with the presented physical problems successfully. Those problems result from reality; in order to process them appropriately for pupils, they are represented by means of idealization and simplification. Physical models depict those phenomena of everyday life professionally in the form of representations, which are to be solved with mathematical tools. Thus, multiple characteristics are faced, which can generate difficulties during the problem-solving process.

Difficulty-generating Characteristics in Physical Problems

As mentioned at the beginning, Merzyn (2008) collected pupils’ impressions of difficulty and sorted them into four prominent categories. These are a) the technical jargon, b) the use of mathematics and quantitative calculations, c) physical statements that are inconsistent with expectations from everyday life, and d) a high degree of abstractness and modelling. These four main categories are difficult to separate in school, as they overlap a lot. They served as a basis for this study, which was conducted to examine the impact of the characteristics on task difficulty.

In school, it is useful to include everyday life phenomena as a context for solving physical problems. Those contexts also help in training scientific literacy (cf. Dorschu, 2013). By applying knowledge to other contexts, it is linked and transferred more strongly, as learning never happens in an isolated way. In this way, physics gets closer to the pupils’ lives and more problem-oriented, so authentic problems are needed in class. Furthermore, the higher motivation which comes with it helps create a better attitude of the pupils towards physics lessons (cf. Merzyn, 2008). The ideas of everyday life phenomena are retrievable like previous knowledge (cf. Lehner, 2012), whereas incorrect ideas and preconceptions need to be corrected.

Physics has a high level of abstract words which are used in a technical way (cf. Fruböse, 2010). This results in a contrast between physical language and everyday language (cf. Merzyn, 2008), and is especially difficult when terms are used in both domains with different meanings.

Mathematics plays an essential role in physics. On the one hand, it acts as a helpful tool for capturing physical correlations quantitatively. On the other hand, it helps with formulating precise statements about physics, making it a medium for communication (cf. Pospiech et al., 2015). Furthermore, numerous fundamental physical concepts consist of mathematical operators, making mathematics and physics closely linked and hard to separate. Moreover, mathematics is used for modelling, in order to predict and simplify phenomena (cf. Trump & Borowski, 2012). But transferring mathematical knowledge to physics is often problematic for pupils (cf. Taşar, 2010), as they cannot apply the right knowledge flexibly to physical problems and therefore use mathematical strategies which are inconsistent with the problem (cf. Uhden, 2012).

Scientific models are distinguished through two essential features. The illustrating feature means that a model is the projection of an object, while the reducing feature means that a model includes only a subset of all attributes of an object (cf. Kircher, 2010). Therefore, there are elements of an object which are not part of the model, resulting from the method of idealizing. Idealization means neglecting aspects of reality in a theoretical model which would complicate it (cf. Lehner, 2012). Furthermore, models are always linked to an issue and a purpose, thus they include the opinion of a person or a certain intention for formulating and analysing hypotheses about experiences (cf. Krüger et al., 2018). Another argument in favour of including models in physics class is the fact that they are a way of treating physical subjects like in real scientific research, which can be motivating for pupils (cf. Leisen, 1999).

STUDY DESIGN

Research Questions

In this project, based on the presented background, the following research questions are addressed:

1. Do pupils articulate the difficulty-generating characteristics suspected in the referred literature while trying to solve physical problems?

2. Can pupils use the detected characteristics to overcome difficulties in the solving process by purposefully asking for support?

Preliminary Study

In the preliminary study, experts (n = 25) on creating lesson material (active and retired teachers, scientific assistants, and university professors) were to evaluate, based on the problems we have created, what constitutes the difficulty-generating characteristic which is deliberately built into the task by us. Here, the experts were not required to solve the tasks, but only to find out what is the hurdle that makes the task difficult. The difficulty-generating characteristics that were incorporated are those mentioned before in the theoretical background and have been worked out by Fareed & Winkelmann (2019). This preliminary study was conducted as a validity check of whether experts can recognize the difficulty-generating characteristics in the problem.

Main Study

In the main study, a two-stage qualitative case study, two types of testing were performed. First, our group of pupils (n = 9), was presented with physical problems on four different worksheets. The group consisted of high school (Gymnasium) pupils in the German E-Phase (pre-A levels, year 10, or 11). All the problems dealt with the issue of freefall, which is part of the curriculum of that year. The pupils were asked to articulate their method of solving the freefall situations on each worksheet. Every single problem was designed consisting of a certain built-in characteristic that made the task difficult (cf. preliminary study, above). The pupils' statements were recorded, and they were supervised by one of the study leaders while solving the problems within a time span of 45 minutes, each pupil on his or her own. In their attempt to solve the tasks, they were motivated to use the method of thinking aloud (cf. measuring instruments, below) to explain their solving techniques.

At the end of the thinking aloud phase (second stage), the pupils were to reflect on what was difficult in the individual tasks, and the resulting interviews were then used to check whether the statements match our assumptions. A guideline-based interview supported the pupils' reflection on identifying individual hurdles in the different given problems. First, they had to rate the four worksheets with regard to the level of difficulty. Secondly, every worksheet was discussed regarding each intended characteristic, and the pupils were asked what exactly made the solving process difficult or impossible. In the end, the pupils' half-term marks in physics and their satisfaction with the subject were recorded.

The objectivity of the study was ensured by working with an observation sheet that provided a pre-structured guide to the analysis of the recordings, including keywords which point to the individual characteristics. The recordings were transcribed in order to analyse them qualitatively, according to Mayring (2015).

Measuring Instruments

1. Physical Problems and Rating Sheet

In the preliminary study, the experts received four different worksheets, each of which contained a physical problem with one individual difficulty-generating characteristic. By the experts, this characteristic only needed to be recognized and named without having to solve the problem. For this purpose, the experts received an additional rating sheet to help them to identify the corresponding difficulty-generating feature. Using a five-point rating system, they had to evaluate which feature occurs to what extent in the task. Additionally, we checked the inter-rater reliability.

In addition to the worksheet covering the technical jargon, an alternative one was prepared for the pupils to compare them in the reflection phase. On the alternative version, all technical terms were wiped out, and physical phenomena were explained in simple words.

2. Recordings of the Thinking Aloud Phase

In the main study, the pupils were given the worksheets with the built-in difficulty-generating characteristics, and they were then encouraged to solve them. Successful solving was not required, which the pupils were told beforehand. While solving the problems, the pupils were asked to formulate their thoughts out loud, which was recorded via voice recorder. The voice recordings of the thinking aloud phase were transcribed and served for further analyses.

Qualitative research formed the approach of the study since the openness and flexibility of the qualitative method make it possible to freely and exploratively analyse the pupils' way of solving the tasks and generating hypotheses. Furthermore, the method of thinking aloud is used to capture insights into the mental part of the problem-solving process, which is very complex and sometimes unobservable. Thinking aloud always happens parallelly to the primary task (cf. Völzke, 2012).

3. Guideline-based Interview

The observations from the problem-solving phase were used to ask what the personal difficulty was specifically for each pupil. Also, all difficulty-generating characteristics were addressed, so that the pupils could connect each general difficulty with a concrete problem situation and sort these according to the perceived difficulty.

RESULTS

In the preliminary study, the validity of the material was checked. Unfortunately, only two of the expert questionnaires were sent back to the institute in time to analyse them for this study, so there cannot be drawn adequate conclusions. Moreover, there could be seen a big inter-rater discrepancy between those two questionnaires, so that the preliminary results were not used for the final evaluation.

The main study enabled in-depth structural analyses of problem situations. The pupils' statements during the thinking aloud phase and in the reflective interview suggest that they have issues formulating concrete difficulties and are not able to ask for targeted support concerning the difficulty.

Furthermore, the study should give a brief insight into the pupils' ability to solve physical problems in the sense of identifying the difficulty of the individual problem. Different difficulties can dominate different problems. The identification of those individual hurdles could help the pupils to solve the problem.

Regarding the four examined difficulty-generating characteristics, especially the modelling and idealising, get into the focus. The pupils agreed that exercises with models are rarely used in class. While solving the modelling worksheet, the pupils found it rather motivating that they did not have to calculate at first. They tended to idealize the wrong details, though, in order to approach their model. For example, some pupils thought about the constitution of the landing ground while modelling a suitable parachute situation.

Before pupils have to use advanced mathematics in a problem like the presented one (here: using the reduced quadratic equation), the sense of the problem has to be understood by modelling it. Most of the pupils already failed in this situation, which confirms earlier studies (cf. Angell et al., 2004).

Technical jargon in physical problems was perceived as both an advantage and a disadvantage. On the one hand, new physical terms first sounded difficult and confusing, but on a closer look, they helped in founding the right formula. In the reflection interview, the pupils had to compare it to the alternative version without the technical terms. They perceived that version as childish and not helpful in solving the problem. Last, the pupils expressed the wish for a higher level of everyday life references in all the worksheets.

SUMMARY & OUTLOOK

The results of the study show that it seems worthwhile to focus more on modelling in physics class. On the one hand, pupils express more interest in this kind of exercises, and on the other hand, they show big difficulties in solving the problems.

Almost all pupils complained that they were not able to solve the problems due to the lack of important formulas. The reason for this might be the long period between learning the subject in class and the study, as the issue of free fall had been discovered in the first half term of that year and thus had been a few weeks earlier. The required formulas could have been repeated in preparation for the study, but it would have distorted the results.

Contrary to the literature, the characteristic of the technical jargon was often not perceived as hindering, but as helpful for deriving the necessary formulas. Nonetheless, in future studies, the material should be designed more clearly and unambiguously with the required formulas given, in order to focus more strongly on the actual difficulty-generating characteristics.

Regarding the second research question, if pupils can use the detected characteristics to ask for targeted support, we can see that they were not able to do so. In conclusion, pupils should be sensitized more in class for difficulty-generating characteristics, to facilitate the search for support. One possibility might be the reflection about individual hurdles while trying to solve physical problems.

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REFERENCES

Angell, C., Guttersrud, Ø., Henriksen, E. K., & Isnes, A. (2004). Physics: Frightful, But Fun. Pupils' and Teachers' Views of Physics and Physics Teaching. *Wiley Periodicals Sci Ed*, *88*, 683–706.

Brandenburger, M. (2016). *Was beeinflusst den Erfolg beim Problemlösen in der Physik? Eine Untersuchung mit Studierenden*. Berlin: Logos.

Bennett, J. & Hogarth, S. (2009). Would YOU Want to Talk to a Scientist at a Party? High School Students' Attitudes to School Science and to Science. *Science Education*, *31*, 1975–1998.

Caglar-Öztürk, Y. (2015). Interessenforschung – Werden Naturwissenschaften und Mathematik immer unbeliebter? *Delta Phi B*, 1–9.

Dörner, D. (1976). *Problemlösen als Informationsverarbeitung*. Stuttgart: Kohlhammer.

Dorschu, A. (2013). *Die Wirkung von Kontexten in Physikkompetenztestaufgaben*. Berlin: Logos.

Fareed, B. & Winkelmann, J. (2019). Schülerwahrnehmung von Schwierigkeit des Physikunterrichts und der kognitiven Aktivierung durch die Lehrkraft. In H. Grötzebauch & V. Nordmeier (Hrsg.). *PhyDid B – Didaktik der Physik, Beiträge zur DPG-Frühjahrstagung des Fachverbands Didaktik der Physik in Aachen 2019*. Beitrag DD. 02.11.

Ford, K. W. (1989). Is physics difficult? *American Journal of Physics*, *57*, 871–872.

Fruböse, C. (2010). Der ungeliebte Physikunterricht. Ein Blick in die Fachliteratur und einige Anmerkungen aus der Praxis. *Der mathematische und naturwissenschaftliche Unterricht*, *63*(7), 388–392.

Kircher, E. (2010). Modellbegriff und Modellbildung in der Physikdidaktik. In: Kircher, E., Girwidz, R. & Häußler, P. (Hrsg.). *Physikdidaktik. Theorie und Praxis*. 2. Aufl. Berlin, Heidelberg: Springer, 735–762.

Krüger, D., Kauertz, A. & Upmeier zu Belzen, A. (2018). Modelle und das Modellieren in den Naturwissenschaften. In: Krüger, D., Parchmann, I. & Schecker, H. (Hrsg.). *Theorien in der naturwissenschaftsdidaktischen Forschung*. Berlin: Springer, 141–157.

Kühn, S. M. (2011). Weiterentwicklung der Aufgabenkultur im naturwissenschaftlichen Unterricht der gymnasialen Oberstufe und im Abitur. *Zeitschrift für Didaktik der Naturwissenschaften, 17*, 35–55.

Lehner, M. (2012). *Didaktische Reduktion*. Bern: Haupt.

Leisen, J. (1999). Modellbildungssysteme. Didaktische und methodische Aspekte. *Praxis der Naturwissenschaften Physik, 48*(2), 1–3.

Mayring, P. (2015). *Qualitative Inhaltsanalyse. Grundlagen und Techniken.* 12., überarb. Aufl. Weinheim, Basel: Beltz.

Merzyn, G. (2008). *Naturwissenschaften, Mathematik, Technik – immer unbeliebter? Die Konkurrenz von Schulfächern um das Interesse der Jugend im Spiegel vielfältiger Untersuchungen*. Baltmannsweiler: Schneider Verlag Hohengehren, 5–96.

OECD (2014). *PISA 2012 Results (Volume V). Creative Problem Solving: Students' Skills in Tackling Real-Life Problems*. Paris: OECD Publishing.

OECD (2016). *PISA 2015 Results (Volume I). Excellence and Equity in Education*. Paris: OECD Publishing.

Ornek, F., Robinson, W. R., & Haugan, M. P. (2008). What makes physics difficult? *International Journal of Environmental & Science Education, 3,* 30–34.

Pospiech, G., Uhden, O. & Geyer, M.-A. (2015). Modell der mathematischen Modellierung in der Physik. In: Bernholt, S. (Hrsg.). *Heterogenität und Diversität – Vielfalt der Voraussetzungen im naturwissenschaftlichen Unterricht*. Gesellschaft für Didaktik der Chemie und Physik, Jahrestagung in Bremen 2014. Kiel: IPN, 199–201.

Reif, F. (2008). *Applying cognitive science to education: Thinking and learning in scientific or other domains*. MIT, Cambridge MA.

Smith, M. U. (1991). *Toward a unified theory of problem solving: Views from the content domains*. Lawrence Erlbaum Associates, Hillsdale NJ.

Taşar, M. F. (2010). What part of the concept of acceleration is difficult to understand: the mathematics, the physics, or both? *ZDM Mathematics Education, 42,* 469–482.

Trump, S. & Borowski, A. (2012). Mathematikkompetenz beim Lösen von Physikaufgaben. Evaluierung und Elaboration eines Kompetenzmodells der Mathematik für die Physik der Sekundarstufe II. *phydid B Beiträge zur DPG-Frühjahrstagung*.

Uhden, O. (2012). *Mathematisches Denken im Physikunterricht. Theorieentwicklung und Problemanalyse*. Dissertation, Universität Dresden.

Völzke, K. (2012). *Lautes Denken bei kompetenzorientierten Diagnoseaufgaben zur naturwissenschaftlichen Erkenntnisgewinnung*. Kassel: kassel university press.

Williams, C., Stanisstreet, M., Spall, K., & Boyes, E. (2003). Why aren't secondary students interested in physics? *Physics Education*, 38, 324–329.