Students' misconceptions in physics

Theses of the PhD dissertation

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Introduction

We call the beliefs, emerging among students, which contradict scientifically accepted knowledge [1] but seemingly supported by some argument, student misconceptions. We may encounter them while teaching science subjects (Physics, Chemistry, Biology) [2] and Mathematics [3]. The misconceptions belonging to the scope of Physics seemingly explain natural correlations or phenomena in an illustrative way, however, they are only based on superficial everyday observation and speculation.

A simple example of student misconceptions is that most of the students think the proportion of colliding bodies' mass is decisive in regard of the forces applied, although the law of action and reaction teaches them otherwise. Another characteristic misconception is the consideration of the total volume of liquid against the dependence on depth. In certain cases, the students rely on external but not decisive signs and not the subject matter.

The source of misconceptions is often some kind of practical experience. Mostly students in lower years rely on these. The misconceptions emerging in upper years may arise in a more abstract way, by logical reflection. They may make up a part of a more extended philosophy. During the time of my research, I also contemplated the possibility of the emergence of misconceptions in a logical way and I also included it my thesis involving the definition of misconceptions.

Academic literature also describes such misconceptions that were widespread in the past, as well. Newton's First Law of Motion was not a part of Aristotelian thinking, thus it reflected a lack of recognition of a nowadays basic principle. Aristotle's school had an impact on how people think. This warns us that even widely accepted, but only authority-based knowledge may also be faulty. There is no generally acceptable definition of misconceptions in academic literature. There are several phenomena similar to misconceptions and surely, we cannot draw a sharp boundary between them. In a general sense, misconceptions mean a lack of understanding of any given phenomena [4]. The things that may lead to a lack of understanding are reviewed in my thesis and in the part of my dissertation concerning the causes of misconceptions.

The main directions of the research

The most general aim of my research was to get to know the significant characteristic feature of misconceptions and develop a method to overcome them.

I gained direct date for the examination of misconceptions from mechanics and hydrostatics. In addition, I studied the questions of electromagnetism and modern physics, since the specific forms of misconceptions arising in a logical way can be connected to the more abstract chapters of physics [S1] [S2]. In respect of modern physics, I assessed how academic literature relates to the misconceptions arising among those studying the area. Uncovering the causes of misconceptions was in the centre of my attention.

By examining the general cause of arising misconceptions, we may conclude that certain factors such as the internet have an impact on the students' knowledge. This fact underlines the importance of school education and the work of teachers. One cannot ignore the question of quality in case of the textbooks used in schools. My aim was to form an opinion on the quality of the sources used by students in the light of preventing misconceptions.

The most common way of arranging the topics in physics education is discussing each sub-area in succession (e.g. mechanics, molecular physics and thermodynamics, electricity and magnetism, etc.) and revising all the areas in an older age. Cyclicality brings a deepening and strengthening of knowledge. My work contains conclusions relate to this fact.

The methods of research

An essential tool of the research of misconception is data collection and the observation of students. The students chose from pre-formulated answers in the mechanics tests to draw the outlines of their way of thinking. In the hydrostatics test, however, I asked the students for a short explanation, so I had the chance to directly get to know the structure of student misconceptions [S3]. The answers made it clear for me that the structural relationships of the knowledge system to be acquired fundamentally define the misconceptions. The characteristic features of human thinking also play a role [5].

In the mechanics test, I relied on Hestenes mechanics test containing 29 questions [6] [S4]. There were figures to help understanding the respective questions. The questions were aimed at Newton's First Law of Motion, projections, the law of action and reaction, and the general characteristic feature of forces. I also involved three secondary school classes from different schools and a first year college group of 22 students in the work. The responses to the entire test were registered via the internet [S5].

The test on fluid mechanics was paper-based and 186 students took part in it from three different secondary schools (from year nine to year twelve). The tasks were introduced by simple figures and a short description. Beside my own questions, I also used ones that appeared in an earlier research [S3] [7].

Theses

Based on the logical relationships of the mistakes while analysing the tests, I made theses concerning the nature and ways of overcoming misconceptions, which I am describing below in bullet points. The first four bullet points contain the insights related to the structure of knowledge and makes a net of thought, which may be used to base strategies against misconceptions. In bullet points 5 and 6, I raise awareness to early prevention and the necessity of critical thinking. In bullet point 7, I introduce devices that help refute misconceptions through virtual experiments. In bullet point 8, I make a comprehensive proposal for the definition of misconceptions. In bullet point 9, I shed light on the significance of illustration and the appropriate choice of technical terms.

1 The question of possessing relevant information

Based on the results of the tests aiming at misconceptions of mechanics among students, I showed that their misconceptions are often related to their lack of essential information to entirely understand the given situation. Presumably, if the students had all the essential information related to the given question in due time, certain misconceptions would not be formed. By knowledge, we mean knowing the facts and knowing the relationships between different facts.

The fact that a high number of students believe that the force of the blow impacts a golf ball hit throughout the entire time of flight shows that a significant part of the students does not know the law of inertia at all or know it in such a formal way that they cannot recognize or use it in a direct situation.

The mistakes made in connection with the law of action and reaction also refer to similar serious deficiencies, which sign an incomplete knowledge of the concept of force.

To avoid this problem, it helps if the teacher considers the question of the completeness of information while planning the topics.

Related literature: [S1] [S2] [S6] [S7]

2 The question of closely connected knowledges

While studying the results of the hydrostatics test, I came to the observation that between certain knowledges of a topic, the relationship is so close that in this case, we have to introduce the idea of a knowledge group making up an organic whole. In this case, the lack of *any link of the chain may lead to questioning the other knowledges. We refer to these cases as the question of closely connected knowledges.*

The statement is supported by the fact that the students did not account for the significance of hydrostatic pressure depending on depth. They did not employ the principle of communicating vessels in case of a pipe of varying cross-section and they did not reflect on Pascal's law concerning the impact of external atmospheric pressure. This means that their parts of knowledge connected to the concept of pressure were not connected in a way that they support each other in a more complex situation. The teacher has to be aware of the existence of these connections and they have to observe it while imparting knowledge.

Related literature: [S3] [S4] [S5] [S6]

3 The role of full arcs of thought found in the subject matter

While studying the results of the hydrostatics test, I came to the conclusion that the emergence of misconceptions can be connected to fact whether the students were able to pull through the individual arcs of thought in the subject matter or not. If we observe that pressure does not depend on the amount of the liquid (hydrostatic paradox), while discussing the topic of the principle of communicating vessels, then the students will have a more secure knowledge of hydrostatic pressure.

For the sake of the successful teaching of the principle of communicating vessels, it is necessary to understand the correlation of hydrostatic pressure and the hydrostatic paradox. To think it over, one needs to travel the entire arc of thought. If this does not happen, it means that given topic does not get to the phase where it can be considered entirely and securely processed. In some cases, decreasing the subject matter may not make it easier for the student, because curbing the arcs of thought can make reaching any aims doubtful. The teacher can help by thinking over the arcs of thought, which students have to be led to.

Related literature: [S3] [S6] [S8]

4 The confirmative role of basic principles

Understanding has a tight connection with the knowledge of basic principles. Based on the results of the study done among students, I came to the conclusion that discussing the basic principles in the systematization phase can be looked at as one of the tools of excluding *misconceptions. By stating the basic principles, not only is the process completed but the possibility of recurring misconceptions is also impeded.*

Disciplines arrive at stating their basic principles by natural development. However, education must purposefully move toward the stating of basic principles, the teacher has to validate the guiding role of basic principles even in the planning phase of the teaching process.

The students have to be thought about the basic principles in an age-appropriate way.

Related literature: [S6]

5 The early prevention of forming misconceptions

During my research, I came to the conclusion that there are simple introductory forms of key knowledge whose introduction in the appropriate age may prevent the development of misconceptions. It is practical to deliberately look for and shape their age-appropriate forms. Presumably, several misconceptions would not form if students received related information in due time.

In my experience, for example, in year six, we can talk about such principles that movement in nature is relative, mechanical and other experiments give the same result in a moving train just as in stillness; that without friction, the movement of objects would not cease; that no electricity is engendered in electrical conductors if we move it simultaneously with a magnet, etc. These knowledges must be planned, the method of their delivery must be formed purposefully. The difficulty of the task is in limiting the complexity of the knowledges.

Related literature: [S6]

6 The development of the critical analysis of information

In my experience, in some cases, students may have access to all essential knowledge but they do not realize the error in their concept. In other cases, on the contrary, they overrule their original opinion in possession of inadequate information. Mainly it can be observed in processing information arriving from outside school, but it may also happen in a school environment. These errors may be fought off by teaching critical thinking. Critical thinking may be considered as a tool against misconceptions.

The amount of information flow is inconceivable, and as a result, its quality is surprisingly low. There is a vast amount of unchecked information with a negative impact. It also has an effect on relaying scientific information. The ability to assort information is key, however, in many cases the recipient is left to their own means. In such cases, independent, critical thinking may help.

Teaching science subjects is a suitable way to develop critical thinking, since the consequences of faulty decisions can be experienced objectively. Students have to be led towards the need for a full understanding [8] because it is a secure basis against the misconceptions.

Related literature: [S6]

7 Using ITC in fighting misconceptions

Parallel to my research, I was creating such electronic study aids that both give students the opportunity to perform activities and align with the principles, which I consider decisive, phrased in my theses. I proved that the electronic study aids may help both the unassisted learning process of the students and class work.

Experiments may be an effective means of disproving misconceptions. In an ideal case, students can make real experiments and gain direct experience. In case of inadequate laboratory equipment, the advantages of real experiments may be transitioned into a simulated experiment. My electronic study aids target the key knowledges of mechanics and hydrostatics but I also dealt with some questions from the field of optics and nuclear physics, for instance the correlation of Fermat's principle with the Snell-Descartes Law. I created an alternative electronic test in mechanics. I also introduced the electronic study aid in lessons and I also recommended it to complement at-home learning. It has a positive feedback among students.

Related literature: [S3] [S4] [S5] [S8]

8 The significance of illustration and the proper choice of terms

Illustration and the proper choice of terms while giving information has a role in what kind of concept a student establishes for themselves about a circle of phenomena. One can find characteristic examples in quantum theory. Those, who study quantum theory need interpretable physical pictures behind the words, a logically consistent and full form of *reality. If these do not exist, one cannot say that the theory gives a comprehensible picture about the given field; this may lead to serious errors, mainly from a pedagogical point of view.*

Regarding the misconceptions arising in a theoretical way, I had a look at the questions of interpretation in quantum theory. The question is closely related to illustration and choosing the right terms with the exact content. If we fill the words ‘particle’ and ‘wave’ with the content taken from classical physics, the wave properties and the particle properties cannot be accommodated. The wave property of electrons does not conflict with its concept of doses; the sources [9] [10] I quoted also point to this direction. Therefore, we have to strive for the illustrative understanding of quantum theory’s underlying reality and the proper choice of terms.

Related literature: [S1] [S7] [S8]

9 The definition of misconceptions

While analysing misconceptions, I realized that misconceptions are not always supported by an activity but they sometimes are pure theoretical deductions. In my opinion, it is also necessary to highlight this duality in the definition of misconceptions. Misconceptions have to be considered such faulty theories contrary to scientific principles that seem viable either based on some practical experience or logical deduction.

The general definition proposed by me makes it possible to uniformly incorporate a wide variety of misconceptions in the field of modern physics. The misconceptions of modern physics are typically far removed from everyday experience and they may be purely categorized among theoretical deductions.

Related literature: [S1] [S2]

Summary, the utilization of results

The results discussed above, come from the structural correlation of the knowledge system to be taught. In my opinion, the recommended methods originate from the essence of misconceptions and they can also be validated as viewpoints of subject matter organization. In the first three points of the thesis I point out what prerequisites must be realized when planning to transfer knowledge. Considering these may abolish the main causes of misconceptions. Point 4, 5, and 6 of the thesis may be regarded as a system of means to counteract false illustration. Point 9 of the thesis belongs here to a certain extent. In my recommendation for early prevention I draw attention to the fact that one may found some general educational objectives that have a positive impact on fighting such characteristic phenomena as misconceptions. My suggestion for a definition was motivated by the fact that the two main factors leading to the emergence of misconceptions should be included in the definition. Besides employing the advantage of illustration, the electronic study aids I created help immediately answer the questions arising from the student's viewpoint in an experimental way. The possibility of setting different parameters encourage students to be active and keeps their curiosity awake.

Those sources (textbooks, the content of the lesson) where the students get information during their studies must meet strict requirements and one must reckon with the possibility of misconceptions. The quality of the sources is greatly influenced by the accuracy of the wording and striving for being illustrative.

The results detailed here may help the work of those who are striving to transfer knowledge and are trying to avoid those traps that inevitably occur during teaching.

LITERATURE

[1] Gomez-Zwiep, S.: Elementary Teachers' Understanding of Students' Science Misconceptions: Implications for Practice and Teacher Education. Journal of Science Teacher Education 19, 2008, pp. 437–454.

[2] Stein, M., Larrabee, T. G., Barman, Ch. R.: A Study of Common Beliefs and Misconceptions in Physical Science. Journal of Elementary Science Education, Vol. 20, No. 2 (Spring 2008), pp. 1-11

[3] Stephens, A. C.: Equivalence and relational thinking: preservice elementary teachers' awareness of opportunities and misconceptions. Journal of Mathematics Teacher Education 2006, 9: pp. 249–278

[4] Korom Erzsébet: A naiv elméletektől a tudományos nézetekig (in Hungarian) Iskolakultúra 1999/10

[5] Tóth Zoltán: Kémiai tévképzetek ((in Hungarian). Természet Világa 140 (1), 2009

[6] Hestenes, D., Wells, M., Swackhamer, G.: Force Concept Inventory, The Physics Teacher, Vol. 30, March 1992, 141-158

[7] Loverude, M. E., Heron, P. R. L., Kautz, C. H.: Identifying and addressing student difficulties with hydrostatic pressure. Am. J. Phys. 78 1, January 2010

[8] Clement, J.: Students' preconceptions in introductory mechanics. Am. J. Phys. 50 (1), 1982, pp. 66-71.

[9] Hobson, A.: There are no particles, there are only fields. American Journal of Physics 81 (3), 2013, pp. 211-223.

[10] Carroll, S.: Particles, Fields and The Future of Particle Physics. Lecture, see: https://www.youtube.com/watch?v=gEKSpZPByD0

Own publications:

[S1] Kuczmann Imre: Miből származhatnak tévképzetek a modern fizikában? in: A fizika, matematika és művészet találkozása az oktatásban, kutatásban. Conference Proceedings, Editors: A. Juhász and T. Tél, ELTE TTK, pp201–206, 2013. ISBN 978-963-284-346-9

[S2] Kuczmann Imre: Tévképzetek a mechanika és elektromágnesesség határán. in Sokszínű pedagógiai kultúra. Conference Proceedings, Editor: Torgyik Judit, Komárom, International Research Institute s. r. o. pp172-179, 2014. ISBN 978-80-89691-05-0

[S3] Kuczmann Imre: A diákok hidrosztatikai nyomással kapcsolatos tudásszintje és tévképzetei (in Hungarian). Fizikai Szemle 7-8, pp267-271, 2014.

[S4] Kuczmann Imre: Tanulói tévképzetek a mechanikában. in Természettudomány tanítása korszerűen és vonzóan. Conference Proceedings, Editor: Tasnádi Péter, Budapest, ELTE TTK, pp375-379, 2011. ISBN: 978-963-284-224-0

[S5] Kuczmann Imre: Student's Misconceptions in Mechanics and their Manifestation in a Survey. Physics Competitions 15, Issue 1-2, pp76-85, 2013.

[S6] Kuczmann Imre: The Structure of Knowledge and Students' Misconceptions in Physics. in TIM 2017 - AIP Conference Proceedings 1916, Editors: D. Vizman and A. Popescu. American Institute of Physics, doi: 10.1063/1.5017454, 2017.

[S7] Kuczmann Imre: Coordinate transformation in description of physical phenomena. in: Teaching Physics Innovatively -15, Conference Proceedings, editors: A Király, T. Tél, Budapest, pp373−378, 2016.

[S8] Kuczmann Imre: A kvantumszámok szemléletes jelentése az atomburokban. in: Matematikát, Fizikát és Informatikát Oktatók 41. Országos Konferenciája, Editor: I. Talata, Budapest, Szent István Egyetem Ybl Miklós Építéstudományi Kar, pp. 155-160, 2017. ISBN 978-963-269-662-1