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# Misconceptions in mechanics and their elimination

**Imre KUCZMANN**

*Nádasi Ferenc Gimnázium Budapest, Hungary*

**Abstract.** Misconceptions are beliefs that contradict accepted scientific knowledge but they are seemingly supported by common-sense arguments. By testing misconceptions, we have deduced that they are also related to the structure of knowledge. Some basic elements of the incomplete knowledge structure have been identified, which promote the root of misconceptions to be persistent. Based on recognizing and eliminating these shortcomings, distinct guidance for the prevention or overcoming of misconceptions is proposed.

## 1. Introduction

Elimination of students' misconceptions is a very old question, which has been a crucial matter for teachers for a long time. There are a lot of excellent papers concerning this from the last century up till now [1], but the problem of treatment of misconceptions has already turned up at the time of Galilei [2]. Papers concerning misconceptions are continuously drawing attention to the influence of misconceptions on teaching and they are trying to seize their essential properties to help their overcoming. In the following, after viewing the theories of misconceptions, we report on our new theoretical model and our own results.

## 2. A theoretical background

The examination of the causes of misconceptions often starts from the psychological characteristics of the development of the student's conceptual system. We can read about the role of conceptual change e.g. in [3]. According to Eryilmaz [1], „the conceptual change discussion was an effective means of reducing the number of misconceptions”.

Abd Rahman [4] reports on strategies for conceptual change that can be observed in the classroom. He regards this method the most common in addition to the constructivist teaching model and considers the following four conditions for the success of the conceptual change model: the learner should be aware of the inaccuracy of his idea, the idea offered should be understandable, should be acceptable, and should be useful (intelligible, plausible, fruitful). To accept new knowledge, a cognitive conflict must be created or appropriate analogies should be used. The article also highlights the importance of introducing a teaching method based on conceptual change in teacher education.

According to Gülbin Özkan [5], "It has recently been observed that most studies discuss the process of the "Conceptual Change Approach" to eliminate the misconception problem and improve students' learning." His study analyses the effectiveness of the strategies listed there, e.g. the use of conceptual change texts, concept maps, mind maps. Concept maps are graphs that show the relationships between each concept within a given concept system. In the area of teaching physics, their practicality and reliability can be seen.



The constructivist teaching model does not consider students' misconceptions as such a big problem. According to the analysis [6] the constructivist approach to misconceptions does not acknowledge discontinuity between right and wrong knowledge, rather focuses on continuity. It does not accept that misconceptions should be considered a manifest error and suggests a deeper description of the development of knowledge systems. According to [7] mixed strategies can be useful to overcome misconceptions in physics:

- The „Hybridization Cognitive Strategy" guides students' process of concentration, observation, memorization, and thinking. Stresses the mnemonics, concept mapping, and analogies. By absorbing information, cognitive structures are formed in people's consciousness, under the model of conceptual change (pp 181 – 201).
- Constructivist-based hands-on activities, based on the importance of learning by doing. The method also encourages the development of students' critical thinking (pp 203-222).
- The Learning-cycle approach is one of the most commonly used conceptual change strategies. It breaks down the learning process into successive phases, e. g. exploration, concept development, and expansion (pp 223-242).
- Process-oriented guided inquiry learning is one of the constructivist-based learning approaches. Inquiry activities encourage active communication, which in turn leads to the development of thinking as well as problem-solving (pp 243-262).

The structure of knowledge is often discussed in terms of taking into account the local and global coherence of concepts. The study [8] is about the importance of creating a coherent knowledge structure. It illuminates the concept of a locally coherent and globally coherent knowledge system. He expounds that often only local coherence appears in students' knowledge systems. It filters out that teaching materials and exams should be designed to help students make the necessary connections between different physical concepts and qualitative and quantitative knowledge. However, according to [9], in the process of learning, more and more global knowledge structures are emerging, although initially knowledge structures covering a smaller area may compete when deciding on a particular issue. It defines well the structure of the knowledge system (particular concepts or procedures + the links correspond to connections between these concepts). In addition to the usual methods (e. g. problem solving, dimensional analysis, magnitude analysis) the author draws attention to the meaningful use of the basic principles such as of Newton's laws.

The study [10] describes how to make connections between the concepts of different topics in physics in the period following the study of each topic. The method is illustrated by the concrete example of building connections between the concepts of mechanics and electromagnetism. Students carry out problem-solving activities, depicting the relationships between concepts with concept maps. He notes that learning materials should be designed to help develop the necessary knowledge structures. The program also supports that well-understood core concepts make knowledge truly usable.

The authors of [11] attempt to develop an understanding of the process of conceptual change in the larger context of a cognitive theory of learning. They define conceptual change "as the outcome of a very complex cognitive as well as social process thereby which an initial framework theory is restructured". They emphasize the correct order of necessary knowledge, which is related to the principle of essential information in our cognitive net, and also a lack of critical thinking in the emergence of misconceptions.

Additional suggestions also occur. John Clement suggests creating situations in which students can articulate their prejudices and then compare them with experimental facts, to eliminate misconceptions [12]. The role of practical activity is emphasized in the formation of misconceptions by S. Bayraktar [13]. Authors of [14] compare the effects of various remediation practices in reducing the number of students' misconceptions on physics concepts. They mention six forms of remedial misconceptions: re-

learning, feedback, integration of remediation in learning, physical activity, utilization of other learning resources, and interviews.

[15] analyses student misconceptions about the motions and efforts to remediate it, using cognitive conflict-based learning (CCBL) model through the application of real experimental video analysis.

According to Susan Gomez-Zwiep, many authors believe in creating a cognitive conflict to be created in students' minds that tensions between misconceptions and reality [16]. She reports on the opinions of teachers in grades 3, 4, and 5 who consider this method to be appropriate. She mentions that some teachers consider it sufficient to simply inform students.

### 3. Research

Mechanics can be regarded as the fundamental part of physics being able to introduce and substantiate the key concepts and methods of total physics. The concepts and laws of mechanics pervade the other areas of physics. This is also true for the wrong cognitive mechanisms. So, from studying misbeliefs of mechanics, we can conclude those in other fields of physics. Therefore, our research has been restricted to the field of mechanics. A special part of this is hydrostatics, which we tested by a separate test. The basic research question was how we can help students' conceptual understanding to get rid of misconceptions, but also what suggestions can be made to help the work of teachers.

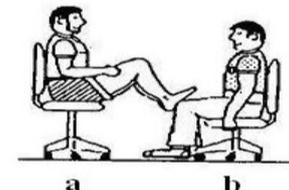
#### 3.1. Mechanics Baseline test

9<sup>th</sup>-grade physics teaching traditionally focuses on discussing mechanics, except the mechanics of fluids, which students essentially encounter only in the seventh grade. Students were tested in point mechanics and the mechanics of rigid bodies. In these topics the Mechanics Baseline test [17] was used.

The Mechanics Baseline test (29 questions) was taken electronically by 9th-grade students from three high-schools, from two secondary schools and one vocational school (age group of 15 years), 114 respondents altogether. The test results were obtained online in the spring period when the 9th grade was already familiar with Newton's laws. 67% of students misapply the law of action-reaction (question 13, 14) in the case of the collision of a truck and a car (figure 1). In the case of question 11 about the person sitting in office chairs (figure 2), 41% of the students believed that the "active" force is bigger than the "passive". 14% believed that person B exerts a bigger force. 9% believed that only person A exerts force. 35% answered correctly.



**Figure 1.** A collision of a truck and a car [17]



**Figure 2.** Persons in rolling chairs [17]

In the case of the towed box (question 28), 24% of students believed that doubling of pulling force lead to doubling of the speed of the box. 20% of students believed that pulling force must be greater than the weight of the box. 23% of students believed that pulling force must be greater than the force of friction. 10% of students believed that the friction is not real force. 19% answered correctly.

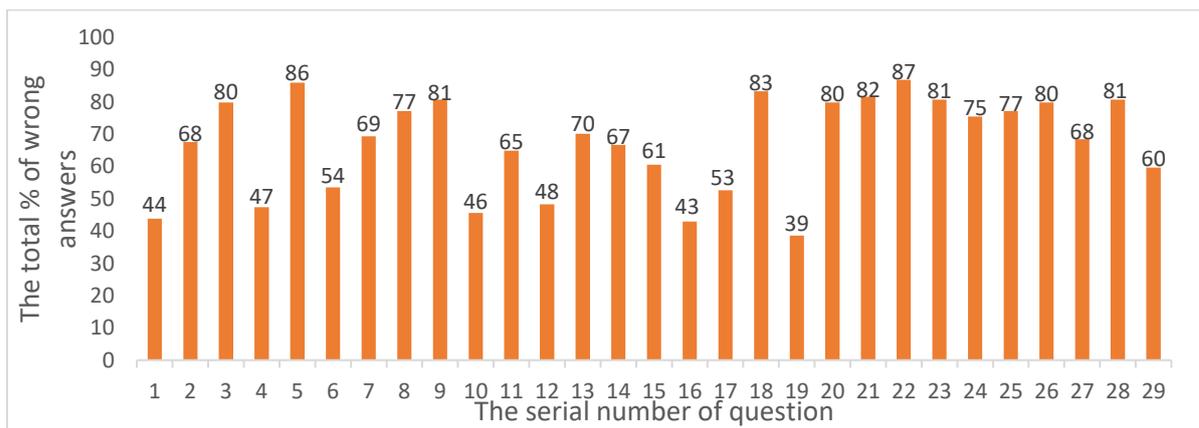
In our opinion, these errors have been perpetuated as a consequence of the Aristotelian physics, according to which the cause of motion is the so-called impetus (the property of the bodies that results in motion). It is about ignoring the law of inertia and the friction force.

The success of each group is shown in table 1.

**Table 1.** Data on the correct answers in the mechanics-test

	Number of students	The average-point	Successfulness %
<b>High school 1</b>	25	11.8	40.7
<b>High school 2</b>	22	11.5	39.8
<b>High school 3</b>	15	10.7	37.0
<b>Secondary school 1</b>	21	7.7	26.8
<b>Vocational school</b>	15	7.1	24.4
<b>Secondary school 2</b>	16	6.6	22.6
<b>Total</b>	114	9.5	32.8

Figure 3 shows the total % of students *wrong* answers. The least successful they were in questions 5 and 22, which are related to the concept of impetus (the issue of the tossed ball or flying golf ball).



**Figure 3.** The total % of wrong answers

### 3.2. Hydrostatics test

The hydrostatics test involved 186 students, from grade 9 to grade 12. For testing hydrostatics, our autonomously elaborated questions were combined with some chosen from questionnaires, which can be found in the literature [18]. It is worth mentioning that for testing hydrostatics we did not use a multiple-choice questionnaire. It contained relatively simple questions, which were directed to check the students' conceptual knowledge. The tasks mainly required a comparison of pressure in certain points, e.g. in "N" shaped and "L" shaped vessel, in Torricelli's experiment, in communicating vessels and the "U" shaped vessel with two liquids (water and mercury). In the case of these questions, the short explanation of the answers was also asked, therefore it was very useful for following students' cognitive processes [19]. It should be noted, that students have previously only encountered the topic of hydrostatics in 7th grade, in subsequent grades, this is not a compulsory part of the curriculum.

The test consisted of 11 questions. The last two questions come from the more complex questions in [18]. According to our findings, some typical misbeliefs are related to the concept of hydrostatic pressure, Torricelli's problem, and communicating vessels. Concerning U-shaped vessels with a variable cross-section (question 4) a very high rate of the students (57%) believed that in case of balance the

level of the liquid in the thicker stem should be lower (figure 4). In the case of the „L" shaped vessel, our students made a wrong comparison of the water pressure in the horizontal part of the vessel (figure 5). 17% of students have thought, that the pressure at the point „B" is higher as at the point „A" –  $p(B) > p(A)$ . Similar bad answers have been given for the relations between pressures at other points:  $P(B) < p(A)$  – 22%,  $P(E) > p(C)$  – 9%,  $P(C) > p(D)$  – 15%. Only 31% of students answered correctly.

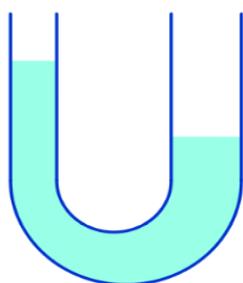


Figure 4. Vessel with a variable cross-section

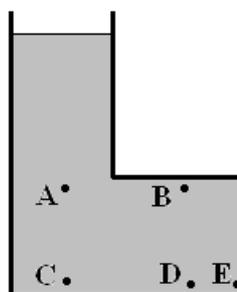


Figure 5. "L-shaped" vessel

It can be concluded that the students are not aware of the connection between Pascal's law and the principle of communicating vessels and the depth-dependence of hydrostatic pressure. The results achieved in each grade are shown in table 2.

Table 2. Data on the correct answers in the hydrostatics-test

	Number of students	The average-point	Success ratio%
<b>Grade 9</b>	93	3.5	32.3
<b>Grade 10</b>	19	3.7	33.5
<b>Grade 11</b>	69	3.0	26.9
<b>Grade 12</b>	5	6.4	58.2
<b>Total</b>	186	3.4	31.1

Figure 6 shows the total number of *correct* answers for each question. The fourth question about the U-shaped vessels with a variable cross-section was a simple one about communicating vessels.

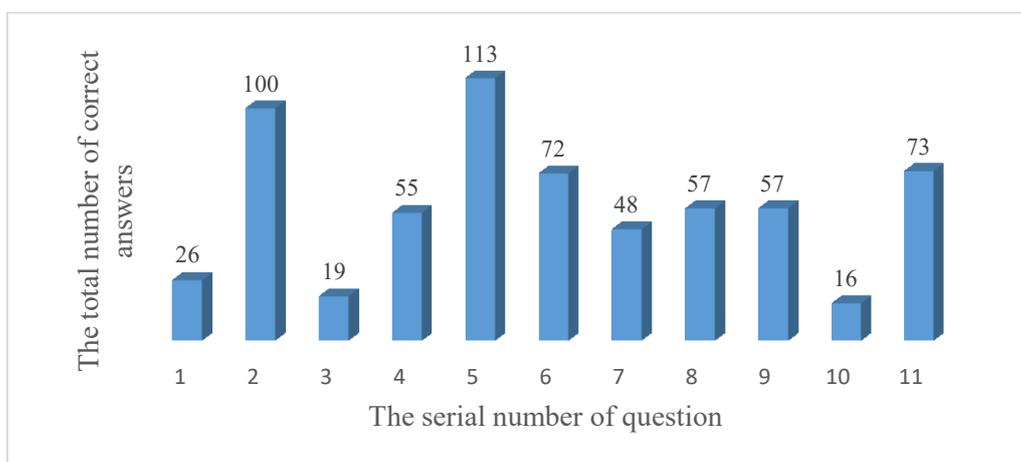


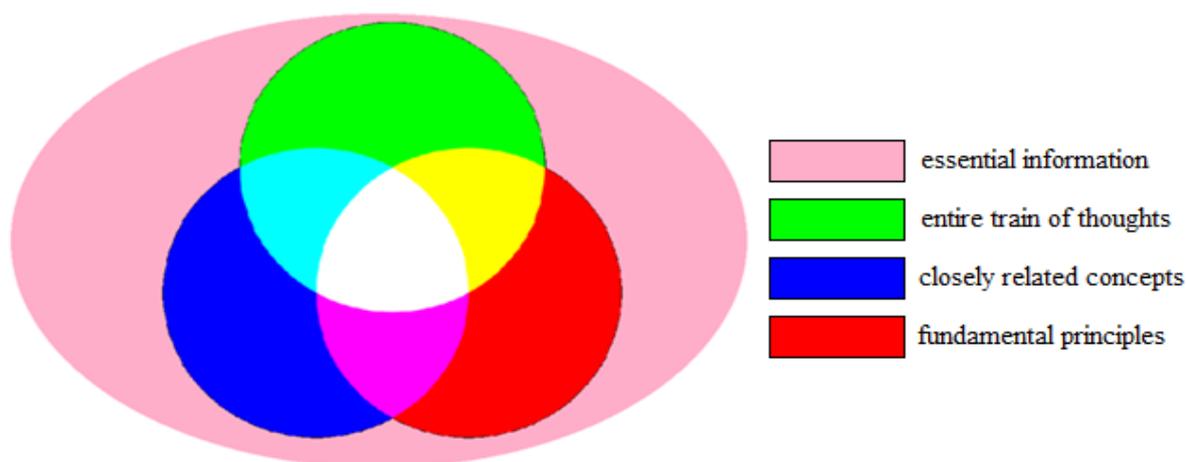
Figure 6. The number of correct answers in the hydrostatics test

#### 4. A new interpretation of the research results

We would like to emphasize that in this respect our approach to misconceptions differs from the usual one [19].

From the nature of the students' mistakes, we concluded that misconceptions reflect a specific lack of information. This lack may mean a deficiency of the knowledge of facts and a deficiency of the knowledge of relationships between some knowledge. We examined what kind of relation exists between misconceptions and the structure of knowledge. We relied on the assumption that if a student has got all essential information and he/she knows important relations of factual knowledge, the emergence of misconceptions is mostly excluded. Some features of the knowledge content may increase the probability of the development of misconceptions. Certain errors exist basically due to the logical structure of the knowledge itself, which is an objective circumstance. These result in errors that appear and persist almost unchanged over and over again.

According to us, misconceptions are often not the consequence of incorrect thinking or making bad conclusions, but they might come from the bad fit of the curriculum with the intrinsic structure of the subject. So we have mapped the core elements of the knowledge system including the essential connections between them (figure 7).



**Figure 7.** Core elements of the knowledge system

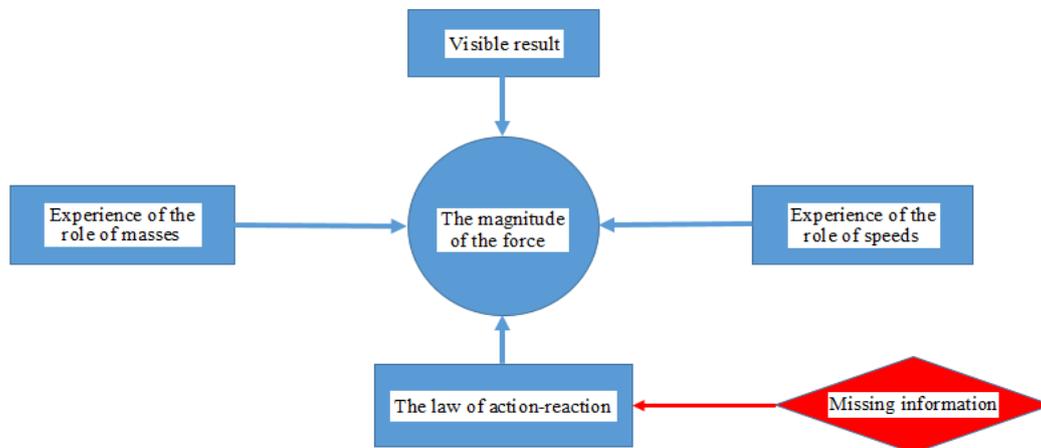
Comparing the key concepts and relations of the subject with the misconceptions revealed by the tests a cognitive net was created, which helps teachers to find the methods of excluding misconceptions. This net includes, besides the main concepts, some guidance concerning the knowledge of students and the teaching, namely that teaching should be focused:

- to provide all essential information on the subject,
- to facilitate the recognition of the entire train of thoughts and to provide their comprehension
- to ensure a well-organized transfer of closely related concepts
- to exploit the guiding and controlling role of the Fundamental Principles.

The rule of completeness of information, the knowledge of closely related ideas, the existence of entire trains of thought, and the thorough knowledge of basic principles were identified as a tool for the elimination of the students' misconceptions. We propose distinct guidance for the prevention or elimination of misconceptions based on this idea. In the following, we focus on the elements of this cognitive net.

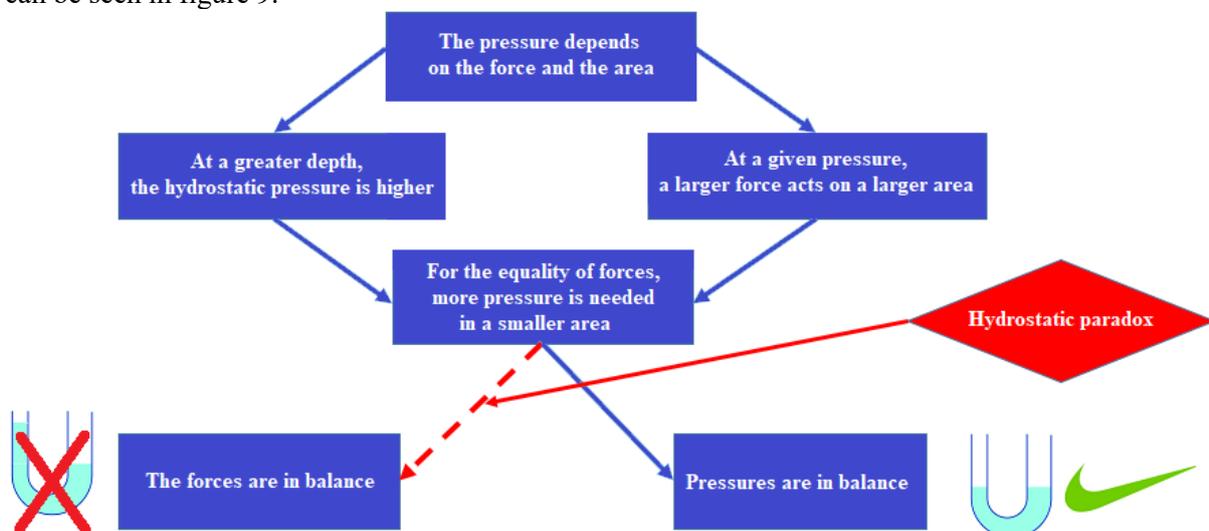
The effect of essential information on misconceptions regarding the law of action-reaction is demonstrated in figure 8.

Students judge the magnitude of forces in the collision based on the sizes of the masses, speeds, and based on some visible results of a collision, but they ignore the law of action-reaction.



**Figure 8.** Effect of essential information regarding forces in a collision

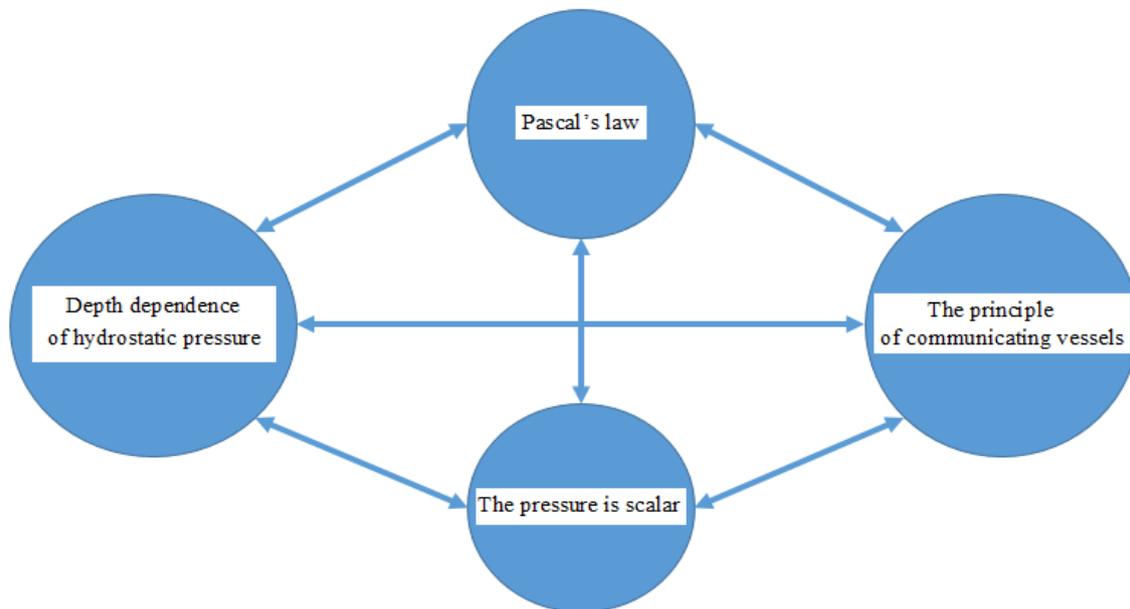
The mistake illustrated in figure 4 suggests that students connect the pressure of the liquid to the whole amount of liquid and based on this, they imagine a kind of balance. The possibility of arising misconceptions is influenced by the fact of whether students can get through certain critical points of the thoughts. According to this, the entire train of thoughts must be used in the investigation of communicating vessels and the role of pressure and hydrostatic paradox must be stressed. This effect can be seen in figure 9.



**Figure 9.** The entire train of thoughts regarding communicating vessel

In figure10 an explaining diagram of closely related concepts is shown. Pascal's law, the depth-dependence of hydrostatic pressure, the principle of communicating vessel and scalar character of pressure are tightly bonded concepts. Their interdependence plays a role in mistakes experienced concerning the question on L-shaped vessels.

The essential basic set of knowledge in a given knowledge-system is represented by its basic principles. The knowledge of basic principles excludes the formation of misconceptions or their repeated emergence.



**Figure 10.** Closely related concepts

In the traditional argumentations provided in the section 2, elements of our thought network emerge one by one, always embedded in a different theoretical environment. So neither approach coincides with ours, it's essentially always different.

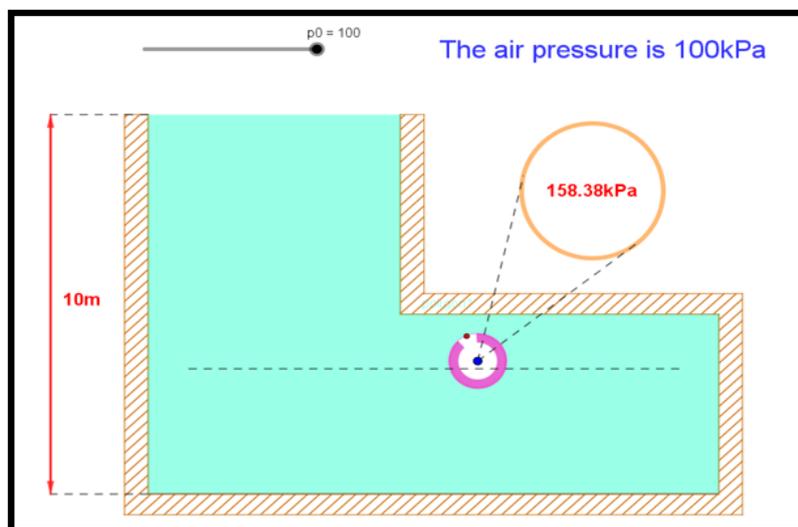
For example, [9] supports the importance of comparison with principles in our cognitive net, but does not suggest starting from the structure of knowledge and does not attempt to identify additional structural features of the knowledge system that may be important in overcoming misconceptions (e.g., entire train of thoughts, essential information, closely related concepts).

The conceptual change model puts at the centre the processes taking place in the students' world of thought, it starts from these and bases its proposals on this. So this is a psychological approach that is not based on the objective structure and logical context of the knowledge, although one of the tools it uses (conceptual map) has an obvious connection to the structure of knowledge. It keeps in mind the long-term process of students' intellectual development, where different stages are characterized by different psychic structures [11]. Mind maps and other similar tools appear in this approach as aids to help processes in students' minds. More fundamental, however, is the recognition that their usefulness is based on objective contexts between the concepts that describe nature, rather than on some subjective, psychological background. From this perspective, it is necessary to search and find as many structural features of the knowledge system as possible. The proposals formulated in the field of conceptual change, on the other hand, provide only a tactical, not a strategic proposal to overcome misconceptions. Due to the difference between the two approaches (subjective and objective), each of the proposed tools is completed by different tools.

## 5. Overcoming the misconceptions

We are convinced that the presented new theoretical approach may help the work of those who are trying to avoid misconceptions that occur during teaching. In line with the theme of the conference, we present below some of the elements of IT tools developed by us [20]. These tools, keeping in mind the ideas of the cognitive net, help to eliminate or prevent misconceptions. They pay special regard to the elimination of misconceptions and provide an opportunity for virtual experimentation and the interactive learning of mechanics and hydrostatics. These IT tools can be well applied in regular school teaching, but also for interactive individual learning. There is no doubt, however, that they are no substitute for real experiments, which are the most convincing means of overcoming misconceptions.

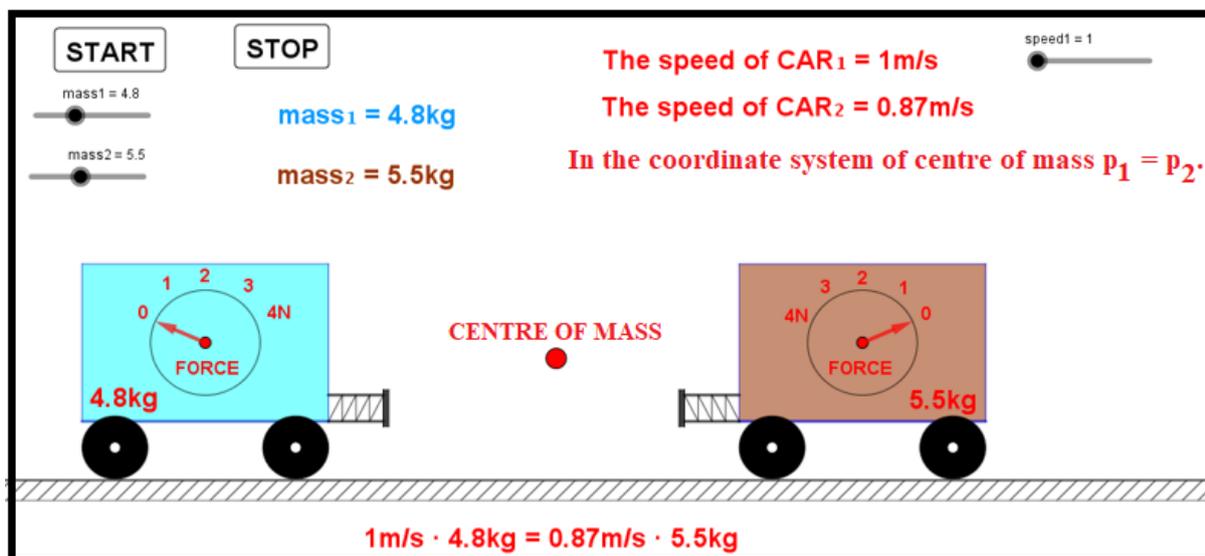
The tool for the "L" shaped vessel is demonstrated in figure 11.



**Figure 11.** A GeoGebra-tool for studying features of pressure in "L" shaped vessel

It is designed to allow the measurement of pressure in various places and directions in the liquid. The air pressure around the container is an adjustable parameter.

Another example of teaching aids is demonstrated in figure 12 for the case of the action-reaction principle. The collision of two bodies is simulated in the coordinate system of their centre of mass. In this system the magnitudes of the momentum of the two cars are equal.



**Figure 12.** A GeoGebra tool for studying the law of action-reaction

The masses of cars and the speed of the first vehicle is adjustable. Dynamometers on cars show equal forces throughout a collision. At the bottom of the picture, you can see the proof of the equality of the two momentums.

Experimentation is an efficient means of controlling and acquiring knowledge. The whole set of our GeoGebra – tools is available on the internet-sites of GeoGebra [20]. Presented tools are organized in Geogebra-books (mechanics, hydrostatics, optics, and physics of atoms). These tools allow students to

formulate their questions interactively because the parameters of each virtual experiment are freely chosen.

## 6. Summary

In the present paper, the properties of students' misconceptions are investigated and a new theoretical approach is proposed, which facilitates the overcoming of these. Interactive teaching material is also presented, which was developed relying on the results of studying the reasons and development of misconceptions.

With the presented analysis, we tried to point out the role of the structure of the knowledge to be taught as an important tool for overcoming misconceptions. The objective nature of student error possibilities is, in our view, mainly based on this. Careful consideration of the structure of knowledge is a necessary condition for the effective transfer of curriculum and should be made aware by the teacher. Based on the outlined principles, theoretical suggestions against misconceptions can be constructed. The IT aids presented and available on the Internet also help the work in the classroom or the students' learning alone. We are convinced that the results detailed here help to address and avoid misconceptions.

## Acknowledgments

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<https://www.geogebra.org/m/wrd2dUJf> (hydrostatics)  
<https://www.geogebra.org/m/W3JSsfsF> (optics and physics of atoms)