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Students' Difficulties in Applying the Law of Conservation of Mechanical Energy: Results of a Survey Research

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Abstract: The purpose of this study was to explore the effectiveness of the conventional high school instruction about conservation of mechanical energy in Canton Sarajevo. To that end we tested 441 high school students from six different schools in Sarajevo (Bosnia and Herzegovina) for their competence to apply the law of conservation of mechanical energy. Concretely, students were expected to solve 5 open-ended tasks that covered conceptually different situations. In each task we asked a set of sub-questions to check whether the students possess all the prerequisite sub-competencies for systematic reasoning about conservation of mechanical energy. In addition, we investigated how students' ideas about conservation of mechanical energy were affected by the choice of the physical system, as well as by the choice of the observed time interval. Data analysis was performed on the level of individual tasks. The students' written answers were analyzed and the frequencies of most prominent student responses were reported. Generally, it has been shown that most high school students from Sarajevo fail to identify and distinguish internal, external, conservative and non-conservative forces. Also, many students think that applicability of the conservation law does not depend on the chosen physical system and its evolution over time. We could conclude that high school students' use of the conservation law is mostly based on remembering similar problem solving experiences, rather than on relevant strategic knowledge.

Keywords: *Conservation of mechanical energy; Energy analysis; Systems approach; Survey research.*

Introduction

Nowadays, physics curricula are often built around so-called key physical concepts, i.e. concepts that are relevant for developing understanding in all areas of physics (Hertel & Grossmann, 2016). One such concept is energy, and an important aspect of the competence to use the energy concept is applying the law of conservation of energy (Chen, Eisenkraft, Fortus, Krajcik, Neumann, Nordine & Scheff, 2014). Becoming proficient in applying the law of conservation of mechanical energy can help students to solve problems easier that would be relatively difficult to solve if analyzed from the perspective of Newton's second law. Such problems often include time-dependent forces or motion along arbitrary trajectories, which makes their mathematical treatment rather complex. In these situations, if applicable, it is preferable to use the law of conservation of mechanical energy (LCME) to put into relation the variables that describe two chosen states of the observed physical system.

However, earlier research shows that students have many difficulties with understanding energy conservation (Duit & Häußler, 1994). Concretely, it has been shown that students often struggle with choosing a physical system for which the conservation law can be applied (Lindsey, Heron & Schaffer 2012; Van Huis & Van den Berg, 1993), as well as with understanding the notion of an isolated system (Grimellini-Tomasini, Pecori-Balandi, Pacca & Villani, 1993). In addition, for many students it is difficult to identify two states of the physical system that can be put into relation with each other through LCME (Van Heuvelen & Zou, 2001).

According to LCME, the mechanical energy of a system is conserved if the work done on the system by external forces, as well as the work done by internal non-conservative forces is zero. Therefore, the sub-competencies for successful application of the conservation law include reasoning about internal and external forces, as well as about conservative and non-conservative forces and work performed by these forces. Here, internal forces are defined as forces acting within the chosen physical system, and external forces are forces exerted by the surroundings on the system. In addition, a non-conservative force is defined as a force for which the work done depends on the path taken (Giordano, 2009). It should be noted that complexity of reasoning about these forces and their work largely depends on the choice of the physical system. Also, applicability of the conservation law highly depends on the choice of the initial and final state of the system. Fundamental condition that has to be met when describing the system in terms of energy conservation is isolation of a system (Grimellini-Tomasini et al., 1993). The physical system is isolated if it is possible to neglect external forces acting on the system or if the resultant work done by the external forces is zero.

Review of Relevant Literature

Although certain concepts in physics seem simple and well organized when viewed independently, students often struggle to apply them to situations from everyday life that require linking of multiple physical concepts (Chi, Feltovich, & Glaser, 1981). One of those key concepts in physics that students have difficulties with is energy (Herrmann-Abell & DeBoer, 2011).

In the study by Neumann, Viering, Boone and Fischer (2013), students' progression in understanding of the energy concept throughout Grades 6, 8 and 10 was investigated. The authors of this study could not confirm that conceptions of energy forms, transformation of energy, degradation and conservation of energy, represent distinct levels of the energy concept, even though a general progression in the understanding of the energy concept was detected. Results of this research also suggest that students have difficulties with some of more complex conceptions, like understanding of energy conservation until the end of the middle school, and even at Grade 10 only some students achieve a deeper understanding of it.

Herrmann-Abell and DeBoer (2011) investigated students’ understanding about energy transformation, energy transfer, and conservation of energy, based on a sample that included 9739 middle-school students, 5870 high school students and 176 university students. Although a progression in understanding about concept of energy has been detected, it has been also shown that some misconceptions about energy are prevalent at all educational levels. Concretely, students struggled mostly with items about conservation of energy, as percentage of correct responses about those items was 28% for the middle-school students, 37% for the high school students, and 73% for the university students. Students especially struggled when trying to apply the law of conservation of energy in the context of the examples from everyday life. Students’ misconceptions about conservation of mechanical energy in the context of rolling motion were investigated by Vidak, Erceg, Hasović, Odžak and Mešić (2018).

In the research by Goldring and Osborne (1994), 75 lower sixth form students were included and it was found that at least 50% of them exhibit significant difficulties with the concept of energy. Thereby, it was interesting to note that those students who were able to solve numerical tasks often could not correctly explain corresponding concepts when asked about examples from everyday life. Why students tend to do better with numerical tasks than when asked to explain concepts can be rooted in the way we teach energy and laws of conservation, and how these topics are treated in textbooks. Bryce and MacMillan (2009) explored treatment of concepts of momentum and kinetic energy in 44 textbooks used in UK secondary school courses. They have found that mathematical approach to the analysis of simple collision problems of isolated objects prevails in most of them, which contributes to students' confusion about real life situations where external forces usually exist, so students become unsure if law of conservation is applicable. In addition, earlier research shows that in traditional physics instruction numerical tasks often have a low pedagogical potential for developing students' conceptual understanding (Kim & Pak, 2002).

It is also very important to note, that students at all educational levels often do not understand the relationship between energy and work. For example, it has been found that undergraduates enrolled in introductory physics courses often do not interpret properly the meaning of the work-energy theorem and do not see the connection between doing work on a body and increase in its kinetic energy (Lawson & McDermott, 1987). Similar findings were obtained in a newer study that included a much larger sample of students, from introductory to the graduate level (Pride, Vokos & McDermott, 1998). Concretely, many students struggle with identifying forces doing work on the system, or with identification and categorization of the system as isolated or non-isolated (Jewett, 2008). In fact, many students enrolled in introductory physics courses do not recognize how choice of a system influences the applicability of conservation of mechanical energy (Lindsey, Heron & Shaffer, 2012). On the other hand, it seems that understanding the concept of a physical system and its surroundings is at the mere heart of successfully applying LCME. In fact, explorative research about systems approach to teaching energy has proven its usefulness and has inspired 15-16 year old students to think more in depth about work-energy processes (Van Huis & Van den Berg, 1993). Also, in the recent study by Halilovic et al. (2021) it was proven that only three hours of system-based teaching can significantly improve the high school students' understanding of conservation of mechanical energy. However, the study by Seeley, Vokos and Etkina (2019) showed that even high school physics teachers manifest significant difficulties when trying to use systems approach to energy analysis which indicates the necessity of reforming the initial education of physics teachers.

What might be further aggravating students' difficulties with understanding LCME is that it also requires good understanding of forces. For LCME to hold, the work done by external forces, as well as the work done by internal non-conservative forces has to be zero. It follows that identifying and categorizing forces that are acting on a physical system is of great importance for successful application of the conservation law. However, even university students struggle with identifying forces for relatively simple physical situations (Aviani, Erceg, Mešić, 2015). When it comes to students' competence to identify non-conservative forces within the context of applying the conservation law, we could not find any relevant earlier research related to that topic.

Based on the previously described findings from earlier research, as well as based on our teaching experience, we assert that the competence for effective application of the law of conservation of mechanical energy relies on following sub-competencies:

1) Distinguishing between physical system and its surroundings.

2) Analyzing work processes in the time interval between the two states of the system which we wish to put into relation via the conservation law; this analysis includes:

2a) Identifying all forces acting within the system (internal forces) and categorizing them as conservative or non-conservative.

2b) Determining whether or not the work done by the non-conservative forces is zero, if some non-conservative forces are identified in step 2a.

2c) Identifying all forces acting on the system (external forces).

2d) Determining whether or not the work done by the external forces is zero, if some external forces are identified in step 2a.

2e) Deciding whether or not the conservation of mechanical energy holds for a given system during the observed time interval (that connects the two states of interest). It holds if the work of external forces and internal non-conservative forces is equal to zero.

3) Depending on the decision in 2e:

3a) If LCME does not hold: Concluding that LCME is not applicable for the given system and time interval; attempting to use the work-energy theorem.

3b) If LCME holds: Applying LCME to the two given states (which correspond to two instants of time): summing the expressions for various energy forms (e.g., kinetic energy, gravitational potential energy, elastic potential energy) the system has in the state 1 and equating them with the sum of various energy forms in state 2. For both states of the system, the gravitational/elastic potential energy has to be calculated relative to the same level of reference.

4) Solving the equation from 3b for the unknown quantity.

In our opinion, students should have developed all these sub-competencies for successfully using the law of mechanical energy conservation in various contexts.

Research Aim and Significance of the Study

The aim of this study was to explore whether the existing high school curriculum in Canton Sarajevo helps students to develop the above mentioned sub-competencies that are crucial for applying the law of conservation of mechanical energy. The development of the competencies to solve equations for unknown quantities has not been explored because we aimed to focus our attention less on mathematical and more on conceptual issues.

The significance of this research is that it points out those sub-competencies that are not satisfactorily developed through implementation of the existing high school curriculum in Canton Sarajevo. Consequently, the findings from this study could serve as a good starting point for a curriculum revision not only in Canton Sarajevo, but also in other regions/countries with a similar curriculum. In addition, tasks we developed for the purposes of this research are potentially useful for diagnostic testing about law of conservation of mechanical energy, at the high school level, as well as in introductory physics courses at the university. Finally, it should be noted that most earlier research has been conducted with university students (Lindsey, Heron & Shaffer, 2012; Seeley, Vokos & Etkina, 2019), so this present research can provide valuable insight about the (in)effectiveness of traditional high school curricula when it comes to developing students' ability to apply LCME.

Methods

Research Design

For purposes of fulfilling our research aim, a written survey research was conducted in six high schools in Sarajevo, Bosnia and Herzegovina. Concretely, all third and fourth year students who on the day of testing attended the regular physics classes were included in our sample. In the survey, high school students were asked to solve different tasks that require the competence to apply LCME.

Students' answers to each of the survey items were entered into a database, and coded by two high school teachers who had over 10 years of experience in teaching high school physics. Then, the database has been recoded, and has been used for statistical analyses that were relevant for fulfilling the research aims.

Sample of Participants

In this study the sample of participants consisted of 441 high school students from six different schools in Sarajevo, Bosnia and Herzegovina. They were mostly 16, 17 and 18 year-olds. All participants were informed about the nature of the study and they gave their informed consent to participate in the study. The participants were assured that the principles of confidentiality and anonymity would be adhered to in the study.

Distribution of certain characteristics for our student sample is given in Table 1. On average, approximately 60 % of students were girls, and 40 % were boys. About 70 % of students were higher ability students, according to their previous physics grades (higher ability: grades above 4 on a scale from 1 to 5), and about 2% of the students are some of the most successful students in Sarajevo, as they stated that they were selected in their schools to take part in physics competitions, at different levels.

Taking into account that students from 6 out of 8 public high schools from Sarajevo participated in our study, as well as the size of our student sample, we can be relatively confident that our sample represented well the population of all third and fourth year high school students from Sarajevo. For purposes of strengthening the external validity of our study, in the sample of 441 students we also included 28 students from the Cambridge International School in Sarajevo. These students learned about energy and conservation laws in line with the AS/A level Physics Syllabus, and not the national curriculum. Taking into account that initial analyses showed similar answering patterns for students enrolled in these two curricula, in the *Results and Discussion* section we only provide a single analysis which holds equally for both curricula.

Table 1

Characteristics of the Student Sample

TASK 1

Year	Frequency	Percent	Gender	Frequency	Percent	Ability	Frequency	Percent
3	136	50.6	**M**	98	36.4	**higher**	191	71
4	133	49.4	**F**	171	63.6	**lower**	78	29
Total	269	100.0	Total	269	100.0	Total	269	100.0

TASK 2

Year	Frequency	Percent	Gender	Frequency	Percent	Ability	Frequency	Percent
3	140	53.4	**M**	101	38.5	**higher**	180	68.7
4	122	46.6	**F**	161	61.5	**lower**	82	31.3
Total	262	100.0	Total	262	100.0	Total	262	100.0

TASK 3

Year	Frequency	Percent	Gender	Frequency	Percent	Ability	Frequency	Percent
3	170	67.2	**M**	104	41.1	**higher**	188	74.3
4	83	32.8	**F**	149	58.9	**lower**	65	25.7
Total	253	100.0	Total	253	100.0	Total	253	100.0

TASK 4

Year	Frequency	Percent	Gender	Frequency	Percent	Ability	Frequency	Percent
3	135	50.4	**M**	96	35.8	**higher**	207	77.2
4	133	49.6	**F**	172	64.2	**lower**	61	22.8
Total	268	100.0	Total	268	100.0	Total	268	100.0

TASK 5

Year	Frequency	Percent	Gender	Frequency	Percent	Ability	Frequency	Percent
3	154	57.9	**M**	111	41.7	**higher**	184	69.2
4	112	42.1	**F**	155	58.3	**lower**	82	30.8
Total	266	100.0	Total	266	100.0	Total	266	100.0

Relevant Characteristics of the Physics Curriculum

Taking into account that the existing physics curriculum for the primary school in Canton Sarajevo only lists content to be covered in classes, but no expected learning outcomes, deeper insight into curricular practice can be gained by analysis of textbooks that are approved for use in Canton Sarajevo (e.g., Muratovic & Gabela, 2011).

In Canton Sarajevo, students start their formal physics education in Year 7 of primary school. However, they learn about the mechanical energy concept for the first time in Year 8 of primary school when they are on average 13 year-old. In Year 8, the focus of instruction is on forms and transformations of energy. Thereby, most attention is devoted to kinetic and gravitational potential energy which are described through verbal and mathematical representations. Relationships between mechanical energy, work and power are discussed, too, as well as the law of conservation of total energy. Although it is expected from the higher ability students to be able to apply LCME, the textbooks typically do not promote reasoning about physical systems and contain no strategies on how to apply the conservation law (Muratovic & Gabela, 2011). In Year 9, students merely extend their knowledge about forms and transformations of energy, within the contexts of electricity, sound waves and light waves.

After Year 9 of primary school students from our sample had entered high school education which lasts 4 years. Students are expected to deepen and extend their understanding of the mechanical energy concept in Year 1 of high school (15 year old students), and Year 3 if they take Physics as elective subject (equivalent would be AS level in UK). In Year 1 students learn to quantitatively apply LCME in cases when transformations of various forms of mechanical energy take place (Colic, 2001). The high school curriculum for Year 1 also explicitly foresees a demonstration experiment for showing that mechanical energy is conserved. In Year 3 students who choose physics as elective subject are supposed to learn the concepts that are important for applying LCME, e.g., isolated system, internal and external forces, conservative and non-conservative forces (Abasbegovic & Musemic, 1998). Students are expected to use these concepts for solving work-energy and conservation of mechanical energy problems. However, no explicit strategy for using the work-energy theorem or LCME is presented (Abasbegovic & Musemic, 1998). Consequently, the most common approach to teaching laws of conservation in Canton Sarajevo is the inductive approach, as it is implicitly assumed that by solving a series of numerical tasks students will get a "sense" of how LCME is applied. However, tasks that are most commonly used in high school physics classes about conservation of mechanical energy are related to situations that are designed *to allow* the application of LCME, resulting in students not knowing when that law *cannot* be applied. In other words, students most often do not develop relevant conditional knowledge related to the use of LCME.

Difficulties in developing high school students’ competence to use LCME are probably not limited to the curriculum of Canton Sarajevo. Useful insights about educational practices at the international level can be gained by inspecting some popular international study programs, such as the Cambridge program. Cambridge International AS/A Level Physics syllabus introduces the concept of energy and its conservation as useful accounting tools that help students to understand the behavior of physical systems. Students are expected to give examples, and explain transformation and conservation of energy, and apply the principle of conservation of energy to simple examples. LCME and its application is not named explicitly in the AS level syllabus. An inspection of two textbooks that are designed to facilitate implementation of the Cambridge program showed that treatment of work and energy concepts does not strictly follow a systems-based approach, although students are expected to know how to solve simple numerical tasks regarding the conservation of mechanical energy (Crundell, Goodwin & Mee, 2014; Sang, Jones, Woodside, & Chadha 2012). Concretely, one of these two textbooks does not mention the system concept at all, whereas the other explains in only one sentence the notion of a closed system. We can conclude that, like the curriculum for Canton Sarajevo, the Cambridge program falls short in promoting development of explicit strategic knowledge related to the use of LCME.

Assessment Instrument

For assessing the students' competence in applying LCME, five open-ended tasks were designed which covered conceptually different physical situations. Concretely, we attempted to design tasks which include: different forms of energy, situations for which different types of forces are acting over the time, situations were external forces are acting but the work done by these forces is zero (Task 4), situations which include dissipative non-conservative forces (Task 1, Task 5), situations which include non-dissipative non-conservative forces (Task 3).

Taking into account that it would not be reasonable to expect the students to solve all 5 tasks during one teaching class (45 minutes), we created 10 booklets, each containing only 3 tasks (see Table 2). In the end, each student who participated in our study has been administered one booklet consisting of 3 tasks. As a result of our testing design, each of 5 tasks has been administered to the nearly the same number of students, approximately 260 high school students (see Table 1).

Table 2

Testing Design

BOOKLET NUMBER	TASKS INCLUDED
1	1, 2, 3
2	1, 2, 4
3	1, 2, 5
4	2, 3, 4
5	2, 3, 5
6	3, 4, 5
7	1, 3, 4
8	2, 3, 5
9	1, 4, 5
10	2, 4, 5

In Tasks 1, 2 and 3 students' ideas about the applicability of LCME for different choices of observed physical system and time interval were investigated. Examples used were a falling apple, object on a compressed, massless spring, and two objects connected over a massless pulley, respectively (Table 3).

Taking into account that tasks 1-3 already provide sufficient insight into students' ideas about the influence of the observed time interval on applicability of LCME, in Task 4 and Task 5 we decided to only check students' ideas about how choice of the observed system affects the applicability of LCME for the given situation. Examples used were a pendulum, and motion of an object on an inclined plane, respectively (Table 4).

Table 3

Observed Physical Systems and Time Intervals in Tasks 1-3

Task 1: A falling apple		**Task 2: Object on a compressed, massless spring**		**Task 3: Two objects connected over a massless pulley**	
Observed system	**Observed time interval**	**Observed system**	**Observed time interval**	**Observed system**	**Observed time interval**
1. Earth and an apple	1.1. from the moment the apple is separated from the branch until the moment just before it hits the ground	**1.Earth, object and a massless spring**	1.1. from the moment the object is released on a compressed spring until the moment just before it leaves the spring	**1. Earth and two masses**	1.1. from the moment the larger mass is released to free fall until the moment just before it hits the ground
	1.2. from the moment the apple is separated from the branch until the apple stops completely on the ground		1.2. from the moment the object is separated from the spring until it reaches the maximum height above the ground		1.2. from the moment the larger mass just hits the ground, until the smaller mass reaches the maximum height above the ground
2. Apple	2.1. from the moment the apple is separated from the branch until the moment just before it hits the ground	**2. Object**	2.1. from the moment the object is released on a compressed spring until the moment just before it leaves the spring	**2. Earth and smaller mass**	2.1. from the moment the larger mass is released to free fall until the moment just before it hits the ground
	2.2. from the moment the apple is separated from the branch until the apple stops completely on the ground		2.2. from the moment the object is separated from the spring until it reaches the maximum height above the ground		2.2. from the moment the larger mass just hits the ground, until the smaller mass reaches the maximum height above the ground

Table 4

Observed Physical Systems in Task 4 and Task 5

Task 4: A pendulum	*Task 5: An object moving on an inclined plane*
Observed physical system	
1.Earth and a pendulum bob	1.Earth, wooden box and a rough inclined plane
2.Pendulum bob	2. Earth, wooden box and a smooth inclined plane

In order to more clearly illustrate our tasks' design we provide here the complete text for Task 1 (***falling apple)***.

TASK 1*:* *Imagine sitting on a bench and watching an apple tree with lots of ripe apples. At one point your attention is drawn to an apple that separates from the branch and falls to the ground. You begin to think about the following questions regarding different physical systems. In all the situations bellow, ignore the air resistance.*

1. Let us choose the system that consists of the Earth and the falling apple. Let's analyze this system during the following time intervals.

1.1. ***The first time interval to observe is from the moment the apple is separated from the branch until the moment just before it hits the ground.*** For the above time interval, answer the questions about the system consisting of Earth and apple.

Set of subtasks 1.1.1. - 1.1.6.

1.2. ***The second time interval is from the moment the apple is separated from the branch until the apple stops completely on the ground.*** For the above time interval, answer the questions about the system consisting of Earth and apple.

Set of subtasks 1.2.1. - 1.2.6.

2. Let us choose the system that consists of the **falling apple only**. Let's analyze this system during the following time intervals.

2.1. ***The first time interval to observe is from the moment the apple is separated from the branch until the moment just before it hits the ground.*** For the above time interval, answer the questions about the system consisting of apple only.

Set of subtasks 2.1.1. - 2.1.6.

2.2. ***The second time interval is from the moment the apple is separated from the branch until the apple stops completely on the ground.*** For the above time interval, answer the questions about the system consisting of the apple only.

Set of questions 2.2.1. – 2.2.6.

For each of the chosen systems and chosen time intervals, students were asked to solve the same set of subtasks:

- Identify external forces
- Identify internal forces
- Identify non-conservative forces acting within the chosen system if any exist
- If the law of conservation of mechanical energy can be applied for the given time interval, write it in mathematical form! The law should be applied to associate any two arbitrary moments within a given time interval, such as for example, at the start and at the end of a time interval.

Results and Discussion

Taking into account that focus of our research was on identifying various types of students' difficulties with applying LCME, we decided that it is appropriate to report the results at the level of individual tasks. In Table 5 and Table 6, results for Task 1 (falling apple) are provided.

Table 5

Most Frequent Responses for Task 1 When Observed System is Earth and an Apple

Task 1: A falling apple (system: Earth and an apple)	
Observed time interval	
1.1. *from the moment the apple is separated from the branch until the moment just before it hits the ground*	***1.2.*** *from the moment the apple is separated from the branch until the apple stops completely on the ground*
Most frequent responses: **1.1.1.** Identify internal forces acting Gravitational force 14.9% Weight 1.1% Missing 80.3 % **1.1.2.** Identify external forces acting Gravitational force 3.0% Weight 2.6% Missing 87.7 % **1.1.3.** Are there non-conservative forces acting No 53.9% Yes 37.9% Missing 8.2 % **1.1.4.** Identify non-conservative forces acting Gravitational force 10.0% Weight 0.4% Elastic force 1.1% Missing 87.4 % **1.1.5.** Is LCME applicable in this example Yes 63.2% No 32.0% Missing 4.8 % **1.1.6.** Apply LCME E=Ep+Ek 23.4% Ep=Ek 10.4% Missing 64.3 %	Most frequent responses: **1.2.1.** Identify internal forces acting Gravitational force 6.3% Normal force 1.5% Weight 0.7% Gravitational force and normal force 0.4% Missing 87.4 % **1.2.2.** Identify external forces acting Gravitational force 1.8% Weight 2.2% Gravitational force and weight 1.1% Gravitational force and normal force 0.4% Missing 91.1 % **1.2.3.** Are there non-conservative forces acting Yes 38.3% No 49.8% Missing 11.9 % **1.2.4.** Identify non-conservative forces acting if said yes Gravitational force 9.3% Force of friction 4.1% Normal force 1.1% Missing 84.0 % **1.2.5.** Is LCME applicable in this example Yes 56.9% No 32.3% Missing 10.8 % **1.2.6.** Apply LCME E=Ep+Ek 13.0% Ep=Ek 4.5% Missing 80.7 %

As the number of different combinations of named forces was large, not all the forces students named are presented in the tables, but rather the most frequent responses are described. Please do also note that for the "applying the LCME" subtask the calculation of percentages included only those students who in the previous subtask answered that LCME is applicable for the (whole) observed time interval.

For a system consisting of Earth and a falling apple, when the time interval does not include the moment apple hitting the ground, the only internal force acting is gravitational force. There are no external and non-conservative forces acting in the observed time interval which means that LCME is applicable. It has been found that only 14.9 % of students correctly identified the internal force. When it comes to this subtask, only 1 out of 8 students who placed in top 10 in physics competitions in Sarajevo gave a correct answer which makes their rate of success below average. It is also useful to note that one of students who participated in physics competitions named the nuclear force as the internal force, which indicates that he/she had the misconception that internal forces are forces that act within a body. If we compare lower and higher ability students, 9 out of 78 “lower ability” students identified gravitational force as internal force, and 31 out of 191 higher ability students gave the same answer. In other words, it seems that physics instruction in Canton Sarajevo even fails to prepare the highest-achieving students to effectively identify internal forces, which indicates a serious shortcoming of the curriculum. Although the percentage of missing answers on questions that assess sub-competencies relevant for applying LCME is huge, the same cannot be said for questions that require the students to answer whether or not LCME is applicable to the given situation. Also, the percentage of missing answers for the “apply LCME” subtask is much lower than for the “identify forces” subtasks. This finding reinforces our hypothesis, that current teaching practice does not help students to acquire the required sub-competencies for applying LCME, but students are expected to inductively develop “a sense” for solving problems that involve conservation of mechanical energy.

When it comes to the time interval which included apple hitting the ground, the two interval forces acting are gravitational force and normal force which appears during the collision. Taking into account that normal force is non-conservative and leads to non-elastic deformation of the apple, LCME does not hold for the whole time interval. It has been found that only 1 out of 269 students correctly identified both internal forces (i.e. gravitational force and normal force) in this situation. It is also interesting to note that for both observed time intervals a similar percentage of students answered that LCME is applicable. In fact, 113 out of 170 students who answered that LCME is applicable for the time interval before apple hits the ground, also answered that LCME is applicable for the time interval that includes collision of the apple with the ground, although here mechanical energy is transformed to thermal energy. This could indicate that some students do not understand that for an observed physical system it can happen that LCME is applicable for one set of states (two chosen instants of time), but not for another set of states (another two instants of time). In other words, it seems that some students do not understand that applicability of LCME may depend on the evolution of the physical system over time.

When the system consists only of an apple, LCME cannot be applied because the external, gravitational force performs the work on the apple. When asked about identifying external forces when the chosen system consists only of the falling apple, for the time interval that does not include apple hitting the ground, 92.6% of the students did not answer at all and only about 1.9% of the students correctly recognized that the gravitational force is now external force. It is interesting to note that there was a moderate association between students’ answers about the applicability of LCME for the two observed systems (apple and Earth-apple) and the time interval before apple hits the ground. Concretely, 93 out of 170 students who answered that LCME is applicable for the Earth-apple system answered that it is also applicable for the apple system. In other words, some students believe that for a falling apple *situation* the law of conservation holds, no matter what *physical system* we observe. However, it is true that LCME is applicable only for the “apple – Earth” system, whereas for the “apple” system the work-energy theorem can be applied (Etkina, Gentile & Van Heuvelen, 2013). It is not very surprising that secondary school students struggle to understand how system choice affects applicability of LCME, if we know that most secondary school textbooks do not promote a systems approach to learning and teaching about energy (Colic, 2001; Crundell, Goodwin & Mee, 2014; Sang, Jones, Woodside & Chadha 2012). As a result, students enroll introductory physics courses at universities with a very weak foreknowledge about LCME which often limits development of deep understanding about LCME in these courses (Lindsey, Heron & Shaffer, 2012).

Table 6

Most Frequent Responses for Task 1 When Chosen System is Just the Apple

Task 1: A falling apple (system: apple)	
Observed time interval	
2.1. *from the moment the apple is separated from the branch until the moment just before it hits the ground*	***2.2.*** *from the moment the apple is separated from the branch until the apple stops completely on the ground*
Most frequent responses:	Most frequent responses:
2.1.1. Identify internal forces acting Gravitational force 8.5% Gravitational force and air resistance 1.1% Missing 88.1 %	**2.2.1** Identify internal forces acting Gravitational force 3.7% Gravitational force and normal force 2.2% Missing 91.4 %
2.1.2. Identify external forces acting Weight 3.7% Gravitational force 1.9% Normal force 0.4% Missing 92.6 %	**2.2.2.** Identify external forces acting Weight 3.0% Gravitational force 1.9% Normal force 0.4% Missing 92.6 %
2.1.3. Are there non-conservative forces acting Yes 37.2% No 53.2% Missing 9.7 %	**2.2.3.** Are there non-conservative forces acting Yes 44.2% No 43.9% Missing 11.9 %
2.1.4. Identify non-conservative forces acting if said yes Gravitational force 7.8% Friction 0.4% Weight 0.4% Missing 90.7 %	**2.2.4.** Identify non-conservative forces acting if said yes Gravitational force 5.9% Friction 2.6% Gravitational force and normal force 1.5% Weight 1.1% Normal force 0.7% Missing 86.6 %
2.1.5. Is LCME applicable in this example Yes 41.3% No 51.3% Missing 7.4 %	**2.2.5.** Is LCME applicable in this example Yes 47.6% No 40.9% Missing 11.5 %
2.1.6. Apply LCME E=Ep+Ek 10.0% Ep=Ek 3.7% E=Ek 0.7% Missing 84.4 %	**2.2.6.** Apply LCME E=Ep+Ek 7.1% Ep=Ek 3.7% Missing 88.5 %

When it comes to the time interval which includes apple's collision with the ground it should be noted that besides gravitational force there is also contact force (normal force) acting on the apple. However, none of the students correctly named both external forces for this time interval. This could be related to the fact that secondary school curricula devote most attention to studying isolated systems which does not promote development of the sub-competence related to identifying external forces (Bryce and MacMillan, 2009). Moreover, we could say that the high school students from our sample had difficulties with identifying forces in general which is not surprising if we know that in the study by Aviani, Erceg & Mesic (2015) even university students struggled to identify forces in given free-body diagrams.

Similarly as in Task 1, a large percentage of missing and wrong answers on subtasks related to identifying forces combined with a relatively low percentage of missing answers related to assessing applicability of LCME has been observed on all remaining tasks. For that reason, the presentation of results for the remaining tasks includes only the most prominent students' answers on some of the subtasks.

Table 7

Most Frequent Responses for Task 2 and Task 3 (applying LCME)

Task 2: Object on a compressed spring (system: Earth, object and massless spring)	**Task 3: Two objects connected over a pulley (system: Earth and two connected objects)**
Observed time interval Before the object leaves the spring	**Observed time interval** Before larger mass hits the ground
Most frequent responses: 2.5. Is LCME applicable in this example Yes 59.5% No 36.6% Missing 3.8 % 2.6. Apply LCME E=Ep+Ek 12.2% Ep=Ek 1.9% Missing 82.8 %	Most frequent responses: 3.5. Is LCME applicable in this example Yes 47.0% No 45.5% Missing 7.1 % 3.6. Apply LCME E=Ep+Ek 8.7% Ep=Ek 2.8% Ep+Ek=const. 1.2% Missing 78.3 %

Students' answers for Task 2 and 3 provide a good context for discussing students' difficulties with estimating the applicability of LCME, and students' use of LCME in the given situations. Table 7 provides the most frequent responses about LCME for an object on a compressed, massless spring (Task 2) and two objects connected over a massless pulley (Task 3).

Before the object leaves the spring in Task 2, as well as before the larger mass hits the ground in Task 3, no external forces are doing work and work done by the non-conservative (tension) force in Task 3 is zero, which means that LCME is applicable to these situations. Although many students recognized that LCME is applicable in the given situations, a large percentage of these same students missed to apply the LCME for purposes of putting into relation two states for each of the observed physical systems. Students who attempted to apply LCME mostly wrote the general form of LCME, and some common variations of it. We rarely saw answers were students tried to use expressions for the specific energy forms relevant for the given situation. Similar pattern was observed in a research conducted in the context of an introductory calculus-based physics course (Lindsey, Heron & Shaffer, 2009). Concretely, in that study students had difficulties to correctly interpret the statement that energy is conserved, and they used general form of equation $(Ep+Ek)_{initial} = (Ep+Ek)_{final}$ when explaining how the energy of a system does not change.

Table 8

Most Frequent Responses for Task 3 (identifying non-conservative forces)

Task 3: Two connected masses over a pulley (system: Earth and two connected objects)	
Observed time interval	
1.from the moment the larger mass is released to free fall until the moment just before it hits the ground	2. from the moment the larger mass just touches the ground, until the smaller mass reaches the maximum height above the ground
Most frequent responses: 1.3. Are there non-conservative forces acting Yes 41.1% No 50.2% Missing 8.7 % 1.4. Identify non-conservative forces acting if said yes Gravitational force 5.9% Force of friction 2.0% Force of tension 1.2% Missing 86.6 %	Most frequent responses: 2.3. Are there non-conservative forces acting Yes 39.1% No 50.6% Missing 10.3 % 2.4. Identify non-conservative forces acting if said yes Gravitational force 7.1% Gravitational force and normal force 0.8% Force of friction 0.8% Force of tension 0.4% Missing 88.5 %

Answers in Task 3 may also provide additional insight into students' ideas about the role of non-conservative forces in conservation of mechanical energy. Table 8 shows the most frequent responses about non-conservative forces named for Task 3. It is evident that most students in our study were not able to correctly name non-conservative forces. Before the large mass hits the ground, the only non-conservative force acting is tension force. However, because the two masses undergo same displacement and Newton's third law holds, the net work done by the tension force is zero and LCME holds. Just after the large mass hits/touches the ground, the only non-conservative force acting is normal force that performs deformation work during the short interval in which non-elastic collision happens. For that reason LCME is not applicable for this time interval. A large majority of students missed to identify the non-conservative forces acting in the two time intervals. Concretely, 1.2 % of students provided a correct answer for the first time interval, and none student for the second time interval. Consequently, the results from Task 3 show that besides having difficulties with identifying internal and external forces, students also exhibit substantial difficulties with understanding the concept of non-conservative forces.

Task 4 has been designed with the purpose to investigate whether students understand that sometimes we can have external forces acting on a system, but doing no work on the system in which case it is correct to apply LCME. Concretely, the students were expected to analyze the motion of a simple pendulum for two different choices of observed physical system (Earth and pendulum bob vs pendulum bob only). Most frequent responses for Task 4 are presented in Table 9.

Table 9

Most Frequent Responses for Task 4 (internal, external forces, applicability of LCME)

1. Earth and a pendulum bob	**2. Pendulum bob**
Most frequent responses:	Most frequent responses:
1.1. Identify internal forces acting Gravitational force 1.8% Tension force 2.6% Weight 2.2% Gravitational force and weight 1.1% Missing 89.9 %	**2.1.** Identify internal forces acting Gravitational force 0.7% Tension force 2.6% Weight 4.1% Missing 91.4 %
1.2. Identify external forces acting Gravitational force 8.2% Tension force 0.4 % Missing 88.1 %	**2.2.** Identify external forces acting Gravitational force 4.9% Weight 0.4% Gravitational force and normal force 0.4% Missing 91.4 %
1.5. Is LCME applicable in this example Yes 42.5% No 44.5% Missing 13.1 %	**2.5.** Is LCME applicable in this example Yes 32.8% No 50.4% Missing 16.8 %

When the physical system consists of Earth and pendulum *bob*, then tension force in the string represents an external force. Taking into account that displacement of the pendulum bob is always perpendicular on the tension force, as well as the fact that air resistance is taken to be negligible, LCME can be applied for this system. On the other hand, if the system consisted only of a pendulum bob, the gravitational force would represent an external force that does work on the pendulum bob, and LCME would not be applicable. It is particularly interesting to note that there was larger percentage of students who considered gravitational force to be external force when the chosen system was pendulum bob-Earth, than when the chosen system was the pendulum bob. Probably, the mere mentioning of Earth influenced the students to more frequently name gravitational force as an internal or external force. This indicates once again that students' answers often were not a result of systematic reasoning about LCME, but an "intuitive act". Our finding is in line with the hypothesis that the existing high school curriculum in Canton Sarajevo is not effective in developing systematic reasoning about LCME. Instead, it is expected that students inductively, through solving many problems (which from the start allow for application of LCME), develop "a sense" for applying LCME. When faced with new problems, students then simply try to tackle them based on superficial similarities with problems they had solved in the past (Chi, Feltovich, & Glaser, 1981).

Finally, we also wanted to include a task which covers the concept of frictional forces and the important context of motion along an inclined plane. Concretely, in Task 5 students were asked about motion of a wooden box on a rough and smooth inclined plane, respectively (Table 10).

Table 10

Most Frequent Responses for Task 5 (internal, non-conservative forces, applicability of LCME)

1. Earth, wooden box and a rough inclined plane	2. Earth, wooden box and a smooth inclined plane
Most frequent responses:	Most frequent responses:
1.1. Identify internal forces acting Gravitational force 1.9% Weight 3.8% Gravitational force and friction 0.8% Gravitational force and weight 0.8% Gravitational force, friction and normal force 0.8% Force of friction 2.6% Normal force 1.1% Missing 86.5 %	**2.1.** Identify internal forces acting Gravitational force 2.7% Weight 1.5% Normal force 1.5% Missing 92.1 %
1.2. Identify non-conservative forces acting Gravitational force 4.2% Gravitational force and friction 1.5% Gravitational force and normal force 0.8% Force of friction 10.2% Normal force 0.4% Missing 81.6 %	**2.2.** Identify non-conservative forces acting Gravitational force 5.3% Gravitational force and friction 0.8% Missing 91.4 %
1.3. Is LCME applicable in this example Yes 43.6% No 44.0% Missing 12.4 %	**2.3.** Is LCME applicable in this example Yes 47.0% No 42.5% Missing 10.5 %

If we take our system to consist of Earth, wooden box and inclined plane, then internal forces are the gravitational force and normal force. For a rough inclined plane, there is also a frictional force which is internal, non-conservative and dissipative. First interesting finding for Task 5 is that students much more often named gravitational force than normal force as one of the internal forces. This could be related to the fact that textbook authors and teachers often tend to oversimplify some physical situations, and omitting to draw the normal force acting on an object on an inclined plane represents a typical didaktikogenic misconception (Wiesner, Schecker & Hopf, 2015). When it comes to identification of non-conservative forces, it was surprising to see that even for motion of a wooden box on a rough inclined plane only 10.2 % of students identified the friction force as a non-conservative force. More detailed analyses show that 15 out of 27 students who correctly recognized the friction force as a non-conservative force believe that LCME can be applied to this system, although the friction force performs negative work and mechanical energy is transformed to thermal energy. This once more reinforces the finding that students from Canton Sarajevo very often struggle with understanding non-conservative forces. It should be noted that for both observed systems the normal force is non-conservative. However, this force does no work on the box, because it is always perpendicular on object's displacement vector.

The students' answers for the smooth inclined plane are very similar to answers for the rough inclined plane. Main difference is related to the fact that for the smooth plane friction force is significantly less often mentioned as one of acting forces. However, this did not change the fact that for both situations approximately the same number of students considered the LCME to be applicable which is only correct for the smooth inclined plane.

Conclusions and Limitations

Earlier research shows that students at all educational levels struggle with applying LCME (Neumann et al., 2013; Herrmann-Abell, DeBoer, 2011). In this study we attempted to investigate to what extent high school students from Canton Sarajevo develop sub-competencies that are prerequisite for applying LCME. It has been found that most high school students from Canton Sarajevo do not effectively distinguish internal, external, conservative and non-conservative forces. This, in combination with generally low developed competencies for identifying forces, could probably explain the dramatically weak learning outcomes observed in this study. This could be, at least partly, related to corresponding shortcomings in initial education of teachers. In fact, in a study from Cyprus which included 198 pre-service elementary school teachers, participants failed to recognize the importance of a system choice when asked to apply the energy conservation law in an example about an electric system (Papadouris, Hadjigeorgiou & Constantinou, 2014). Besides that, the systems approach to teaching about energy is also neglected in many upper-secondary school textbooks, although students are expected to apply the LCME in solving problems (Crundell, Goodwin & Mee, 2014). These problems are often deliberately designed in a way which from the start allows for application of LCME. Consequently, students develop the habit to tackle LCME problems by remembering superficially similar problems they had solved in the past. In other words, it seems that high school students are expected to inductively develop an "intuition" for applying LCME, instead of being provided with corresponding strategic knowledge. However, this study shows that intuitive knowledge about LCME cannot help the students to identify for which systems and time intervals LCME is *not* applicable. Therefore, students more often *distinguish situations* for which LCME can or cannot be applied, instead of *distinguishing systems* for which it can or cannot be applied. In addition, findings from this study show that many students do not realize that applicability of LCME may depend on evolution of the physical system over time.

Missing to teach about energy through a system-based approach may have far-reaching negative consequences for learning high school physics in general. In fact, some consider the concept of a system to be a key physical concept which is not only relevant for learning about mechanical energy, but also many other topics such as fluid dynamics and thermodynamics (Krause, 2013). Moreover, the fact that many high school students enter university education without having learned about energy through a systems approach could partly explain why even university students struggle with use of LCME or work-energy theorem (Herrmann-Abell & DeBoer, 2011; Lindsey, Heron & Shaffer, 2009).

The findings from this research show that conventional teaching does not promote the systems approach to teaching about energy and is very limited when it comes to developing understanding about conservation of mechanical energy in general. These findings could be interesting to science teachers at different educational levels, as well as to physics textbook writers.

A significant limitation of this study is related to the fact that a large percentage of students missed to provide answers. However, taking into account that even the intrinsically motivated high-achievers exhibited substantial difficulties with our test, the missing responses can be interpreted as a result of missing strategic knowledge about LCME, rather than a result of low motivation to solve the test. Taking into account that students from our sample exhibited difficulties even with basic aspects of using LCME, we could not completely exploit the diagnostic potential of our tasks for discussing about sophisticated aspects of the competence to use LCME (e.g., analyzing what percentage of students who recognize tension force as external force for the pendulum bob recognize that it does no work on pendulum bob and LCME can be applied). The external validity of our findings is strengthened by the fact that students who were taught in line with Cambridge International Program had similar difficulties as students who were taught in line with the national program for Canton Sarajevo. Furthermore, textbooks for both above mentioned programs do not provide sufficient strategic knowledge for systematic applying of LCME.

This research has important implications for the practice, as it provides an instrument, which may be used for identifying students' difficulties with conservation of mechanical energy, as well as for starting productive classroom discussions about conservation of energy in general. The instrument is composed of original test items which cover conceptually different physical situations.

In the next phase of our research, we plan to conduct oral interviews for purposes of further increasing our understanding of high school students' ideas about LCME. Finally, the findings from our written survey, as well as the findings from oral interviews, will be used as a starting point in developing a systems-based approach to teaching about the energy concept in high school.

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References

Abasbegović, N., & Musemić, R. (1998). *Fizika za 1. razred gimnazije* [Physics textbook for the 1st year of secondary school]. Svjetlost.

Aviani, I., Erceg, N., & Mešić, V. (2015). Drawing and using free body diagrams: Why it may be better not to decompose forces. *Physical Review Special Topics-Physics Education Research*, *11*(2), Article 020137. https://doi.org/10.1103/PhysRevSTPER.11.020137

Bryce, T. G. K., & MacMillan, K. (2009). Momentum and kinetic energy: Confusable concepts in secondary school physics. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *46*(7), 739-761. https://doi.org/10.1002/tea.20274

Chen, R. F., Eisenkraft, A., Fortus, D., Krajcik, J., Neumann, K., Nordine, J., & Scheff, A. (Eds.). (2014). *Teaching and learning of energy in K-12 education*. Cham: Springer International Publishing.

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive science*, *5*(2), 121-152. https://doi.org/10.1207/s15516709cog0502_2

Čolić, A. (2001). *Fizika za 1. razred srednjih škola* [Physics textbook for the 1st year of secondary school]. Harfograf.

Crundell, M, Goodwin, G., & Mee, C. (2014). *Cambridge International AS and A Level Physics*. Hodder Education.

Duit, R., & Häußler, P. (1994). Learning and teaching energy. In P. Fensham, R. Gunstone, & R. White (Eds.), *The content of science* (pp. 185–200). The Falmer Press.

Etkina, E., Gentile, M., & Van Heuvelen, A. (2013). *College physics*. London: Pearson Higher Ed.

Giordano, N. (2009). *College Physics: Reasoning and Relationships*. Cengage.

Goldring, H., & Osborne, J. (1994). Students' difficulties with energy and related concepts. *Physics education*, *29*(1), 26-31. https://doi.org/10.1088/0031-9120/29/1/006

Grimellini-Tomasini, N., Pecori-Balandi, B., Pacca, J. L., & Villani, A. (1993). Understanding conservation laws in mechanics: Students' conceptual change in learning about collisions. *Science Education*, 77, 169-189. https://doi.org/10.1002/sce.3730770206

Halilović, A., Mešić, V., Hasović, E., & Vidak, A. (2021). Teaching upper-secondary students about conservation of mechanical energy: Two variants of the system approach to energy analysis. *Journal of Baltic Science Education, 20(2), 223-236.* https://doi.org/10.33225/jbse/21.20.223

Herrmann-Abell, C. F., & DeBoer, G. E. (2011). Investigating students' understanding of energy transformation, energy transfer, and conservation of energy using standards-based assessment tasks. In *NARST Annual Conference/Orlando,FL*. Retrieved from: https://www.researchgate.net/publication/265148820_Investigating_Students%27_Understanding_of_Energy_Transformation_Energy_Transfer_and_Conservation_of_Energy_Using_Standards-Based_Assessment_Items

Hertel, I. V., & Großmann, S. (2016). *Physik in der Schule: Hauptteil mit Anlage Basiskonzepte*. Bad Honnef: Deutsche Physikalische Gesellschaft.

Jewett Jr, J. W. (2008). Energy and the confused student II: Systems. *The Physics Teacher*, *46*(2), 81-86. https://doi.org/10.1119/1.2834527

Jewett Jr, J. W. (2008). Energy and the confused student IV: A global approach to energy. *The Physics Teacher*, *46*(4), 210-217. https://doi.org/10.1119/1.2895670

Kim, E., & Pak, S. J. (2002). Students do not overcome conceptual difficulties after solving 1000 traditional problems. *American Journal of Physics*, *70*(7), 759-765. https://doi.org/10.1119/1.1484151

Krause, E. (2013). *Das Erhaltungsprinzip in der Physik und seine Anwendung im Physikunterricht* (Unpublished doctoral dissertation). Universitaet Siegen, Siegen, Germany.

Lawson, R. A., & McDermott, L. C. (1987). Student understanding of the work-energy and impulse-momentum theorems. *American Journal of Physics*, *55*(9), 811-817. https://doi.org/10.1119/1.14994

Lindsey, B. A., Heron, P. R., & Shaffer, P. S. (2009). Student ability to apply the concepts of work and energy to extended systems. *American Journal of Physics*, *77*(11), 999-1009. https://doi.org/10.1119/1.3183889

Lindsey, B. A., Heron, P. R., & Shaffer, P. S. (2012). Student understanding of energy: Difficulties related to systems. *American Journal of Physics*, *80*(2), 154-163. https://doi.org/10.1119/1.3660661

Muratović, H., & Gabela, N. (2011). *Fizika VIII: za osmi razred osnovne škole* [Physics textbook for the 8th grade of elementary school]. Grafex.

Neumann, K., Viering, T., Boone, W. J., & Fischer, H. E. (2013). Towards a learning progression of energy. *Journal of research in science teaching*, *50*(2), 162-188. https://doi.org/10.1002/tea.21061

Papadouris, N., Hadjigeorgiou, A., & Constantinou, C. P. (2014). Pre-service elementary school teachers' ability to account for the operation of simple physical systems using the energy conservation law. *Journal of Science Teacher Education*, *25*(8), 911-933. https://doi.org/10.1007/s10972-014-9407-y

Pride, T. O. B., Vokos, S., & McDermott, L. C. (1998). The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems. *American Journal of Physics*, *66*(2), 147-157. https://doi.org/10.1119/1.18836

Sang, D., Jones, G., Woodside, R., Chadha, G. (2012). *Cambridge International AS and A level Physics*. Cambridge University Press.

Seeley, L., Vokos, S., & Etkina, E. (2019). Examining physics teacher understanding of systems and the role it plays in supporting student energy reasoning. *American Journal of Physics*, *87*(7), 510-519. https://doi.org/10.1119/1.5110663

Van Heuvelen, A., & Zou, X. (2001). Multiple representations of work–energy processes. *American Journal of Physics*, *69*(2), 184-194. https://doi.org/10.1119/1.1286662

Van Huis, C., & Van den Berg, E. (1993). Teaching energy: a systems approach. *Physics Education*, *28*(3), 146-153. https://doi.org/10.1088/0031-9120/28/3/003

Vidak, A., Erceg, N., Hasović, E., Odžak, S., & Mešić, V. (2018). Teaching About Rolling Motion: Exploring The Effectiveness Of An Extreme Case Reasoning Approach. *Journal of Baltic Science Education*, *17*(3), 511. https://doi.org/10.33225/jbse/18.17.511

Wiesner, H., Schecker, H., & Hopf, M. (2015). *Physikdidaktik kompakt*. Hallbergmoos: Aulis.

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