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The determination of the learning curve on the concept of energy using the alternatives ideas

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ABSTRACT

In this study, alternative ideas of energy were evaluated for five different age groups. Research participants included primary school, middle school, and high school students, students of the department of primary education, and active teachers in primary education. The same questionnaire was used in all groups, indicating that age-related differences exist between answers. The sigmoid curve, which represents energy learning, is obtained by analyzing correct answers according to age. Correlations between age and all questions were statistically significant. An engaging perspective is imparted on energy education. According to our findings, misconceptions and preconceptions of students and teachers diminish with age or, more accurately, with educational attainment. In addition to improving science teaching classrooms and curriculum design, the results of our study may also benefit teachers' professional growth.

Keywords: alternative ideas, energy, learning curve, sigmoid learning curve, teaching physics

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INTRODUCTION

Physics concepts and phenomena are developed throughout students' and adults' lives (Kerr et al., 2006). Using these alternative ideas (AI), they explain what is happening around them, and their AI give them a better understanding of the world around them. Throughout the past 30 years, research has consistently demonstrated that a person's ideas and beliefs significantly impact his physics learning (Lin & Singh, 2015; Panagou et al., 2022).

Fundamental physics laws are complex for university students to comprehend and apply in real-life scenarios (Stylos et al., 2021). For students of the Physics Department, the conclusion can be drawn similarly. In studies on teachers, different viewpoints were found to be held compared to scientifically accepted beliefs (Wang & Back, 2016). The misconceptions about physics persist even among high school teachers (Taber & Tan, 2010).

It has been noted that alternative viewpoints of teachers are often similar to those of students (Beyer & Davis, 2008; Kotsis & Panagou, 2022; McNeill & Knight, 2013). Teachers' alternative perceptions tend to be a subset of students' perceptions. While teaching physical sciences, inadequate knowledge and non-identification of views with corresponding scientific ones (Sampson & Blanchard, 2012) affect various processes (organization of activities, presentation of content, nature of questions, understanding of student's pre-existing ideas).

The age of the respondents is one of the main characteristics of each research group. Although it is the only variable, there is a repetition of the concept of teaching at various levels of education. The mental development of students (Rapp, 2005), the experiential experience (Wallace & Brooks, 2014), how the concept method is taught (Sperandeo-Mineo et al., 2006), the teacher who teaches it, and other factors cannot be isolated for analysis in this study. There is no doubt that the respondents were of different ages when they answered the questionnaire.

According to the age of the respondents, it is interesting to examine the correlation between the correct answers to each question. Each of the six questions will undoubtedly have a mathematical relation describing the relationship, but the aim is to be the same for all of them.

LITERATURE REVIEW

A critical factor in effective teaching is students' understanding of concepts and natural phenomena. Observations that students bring to school different ideas about the natural world, which often deviate from scientific knowledge, have alarmingly been raised by the international scientific community (Ferreira et al., 2017; Kurnaz & Arslan, 2011; Villarino, 2018). This led to the development of new teaching strategies and curriculums, which served as a starting point, reference, and evaluation.

As students interact with the natural world and their social environment, they develop AI based on the cognitive constructs they are growing in their minds (Kotsis & Panagou, 2022). Consequently, they are not arbitrary constructs but incorporated into conceptual structures that allow a logical and consistent understanding of the world. They differ from scientific concepts because they are descriptive formulations of natural phenomena students interpret established on their experiences (Duit & Treagust, 2004).

Researchers have interpreted students' conceptions in two distinct ways. According to some researchers, students' conceptions are theory-like in that they are stable, coherent, rational persistent, and helpful in various tasks (Vosniadou, 2019). In addition, some scholars have characterized students' conceptions as unstable, fragmented, transient, and context-bound (Kurniawan et al., 2019; Marhadi et al., 2019).

Thus, students sometimes use multiple alternative conceptions (AC) simultaneously with scientific concepts. The context often prompted diverse and inconsistent explanations of scientific phenomena created in situ by operating various conceptual elements (Taber, 2008). In a few studies, students' perceptions of physical, chemical, and biological phenomena were examined across different age groups (Chu et al., 2012; Nieminen et al., 2017; Wang et al., 2017).

The findings of studies showed that few students used scientifically correct concepts when performing physics tasks, which contrasts with many students who responded to their assignments using alternative perceptions (Chu et al., 2012; Stylos et al., 2008). The AC or AI becomes a primary element in students' learning process (Driver & Easley, 1978). A notable finding is that AC is more persistent and diverse than expected, eventually affecting students' critical thinking (Taber, 2008). Moreover, students may hold differing views on scientific subjects, often contrary to well-established theories (Pulgar et al., 2021).

Through empirical understanding, the AC is formed in a child's attempt to make sense of the world through daily life experiences. In some cases, they are so deeply ingrained that they cannot be abandoned or even slightly affected by the educational process (Driver, 1989). For this reason, teachers and other education professionals need to understand the different AC characteristics of their students to prepare appropriate teaching interventions for them. Thus, they can recant or critically confront these crucial aspects of children's considerations (Kotsis & Panagou, 2022).

Thus, as a reader can discern, there is an enormous body of literature that examines students' AI (Liu & Fang, 2016; Resbiantoro & Setiani, 2022; Wells et al., 2020), as well as teachers' misunderstanding of energy concepts (Narjaikaew, 2013; Topalsan & Bayram, 2019). As evident from the Greek educational reality, similar research studies examine the concept of energy and AI from students and teachers. Nevertheless, we take it a step further and investigate the concept of energy and the possible misunderstandings that students and teachers may have based on their age to create a sigmoidal learning curve.

Every process in life is powered by energy, one of the most critical topics in physics. Despite its crosscutting importance, the point is essential in the field of energy and other disciplines (Nordine et al., 2018). Students' interest in learning may be enhanced by energy issues that have personal, social, and environmental implications (Domenech et al., 2007).

According to many studies on energy teaching and learning (Duit & Treagust, 2004; Fortus et al., 2019), students need more clarification about its concept (Dega & Govender, 2016; Lemmer, 2011; Meiring & Webb, 2012). This study identifies scientifically incorrect conceptions as "AC", according to Chi (2013) and Fernandez (2017). Students' thoughts about energy come from different origins, i.e., ordinary written or spoken discourse, science texts and lectures, economics and politics, and their interpretation of nature (Millar, 2014).

In our study, we investigate students' and teachers' AI in classical mechanics and how they change with age in the context of our research. It would be impractical to provide a questionnaire covering all areas of physics, so the concept of energy was chosen. The concept of energy is one fundamental yet the most misunderstood in physics. Students across different age levels (primary, middle, high, and university) have various vague and undifferentiated ideas about energy (Yuruk, 2007). Therefore, we examined the concept of energy in Greek educational literature for the age groups of our research.

In the field of learning, a well-known concept is the learning curve. The learning curve correlates an individual's performance on a task and the number of trials, or the time required to make mistakes or successful trials. The learning curve proposes that a learner's efficiency in a task improves as much as that learner performs the task (Morrison, 2008). A model used to describe this concept is known as the "S"-curve model (Leibowitz et al., 2010).

Our research measures the respondents' performance on the concept of energy according to their age to determine at what age students should ideally teach energy concepts based on a sigmoid curve. As a consequence, in the Greek educational reality context, this study intended to examine how the progression and consistency of students' and teachers' understanding of physics concepts in everyday contexts changed over the years. The main objective of this paper is to highlight the possible AI of students and teachers regarding the concept of energy, which will contribute to the broader research carried out in the field of didactics of science on the design of curricula and the professional development of teachers in primary and secondary education in Greece. The focus of this paper is persons that are involved with all levels of the educational system and are studying physics. Of course, there is an increase in correct answers, since the persons as they grow up and continue their studies, they are learning more about everything, so another objective is to find out, how the steep increase in the frequency of correct answers is changing with age, in other words, what is the learning curve for the concept of energy.

RESEARCH DESIGN

The present study attempts to determine whether there is a relationship between the perceptions of the concept of energy for primary school students, middle school students, high school students, student candidates of the department of primary education, and primary school teachers. The purpose of this study is not to detect new AI but to see if and how much they change depending on age.

Research Questions

The purpose of this research was to investigate the following fundamental questions:

1. Is there a consistency among students and teachers in their understanding of the energy concept from the perspective of the scientific and non-scientific (alternative) understandings?

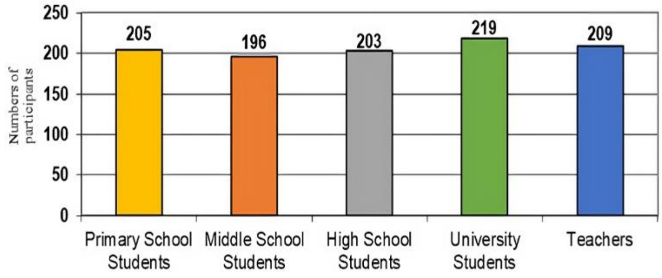

Figure 1. The distribution of the research population (Source: Authors)

2. Is there a statistically significant difference between students and teachers' performance depending on their age?

Research Instrument

Frequently, multiple-choice questionnaires are employed to investigate students' AI. Usually, multiple-choice questions require students to choose the best answer from an array of alternatives. The benefits of questionnaires are their flexibility, practicality, objective nature, ease of use, and less influence from people's tendency to react a certain way (Brancato et al., 2004). It was considered appropriate to use a multiple-choice questionnaire for research purposes–questions in the questionnaire about conceptual understanding, which all research groups can answer.

Therefore, a multiple-choice questionnaire was used for research purposes. The questionnaire addressed all research age groups and included simple conceptual understanding questions that can be answered even by primary school students. All candidates were provided with a multiple-choice questionnaire, which included questions about the concept of energy. The same questionnaire was used for data collection for all candidates.

The questionnaire was distributed to students and teachers of primary and secondary education to check the clarity of the questions. Teachers at the high school and primary school considered it passable and within the capability of their students (Kotsis, 2011).

The questionnaire has been used again in studies conducted in Greek schools (Kotsis et al., 2002). A scenario from a familiar everyday environment is presented in each question, followed by a statement that includes a scientific explanation and alternatives.

This study used the revised closed-type multiple-choice questionnaire of six items regarding the energy concept. Each question is based on an example from a school textbook. The questionnaire did not include graphic or pictorial representations to avoid unwanted misinterpretations. Students could easily read the scripts given on the objects without using or knowing scientific terms.

Participants

Samples were selected from the prefecture of Ioannina for all research groups. Our sample contains 1,032 students and teachers from several public education facilities in Ioannina, whose ages range from 27 to 50 years old. **Figure 1** shows the sample distribution. Random sampling has been used to select the schools to avoid bias in the research.

Each survey group corresponded to a specific education class: the primary school students were in the 5th grade (11 years old), the middle school students in the 3rd grade (15 years old), and the high school students in the 2nd grade (17 years old). We used primary education students in their third year after they had completed a mechanics course in their first year and their age was about 21 years old.

Table 1. Q1-Two athletes with the same weight and same height run 100 meters. Who consumes more energy?

	A (%)	B (%)	C (%)
Primary school	48.5	9.3	42.2
Middle school	50.5	4.1	45.4
High school	38.4	3.0	58.6
University students	23.7	9.1	67.1
Teachers	26.0	1.5	72.5

Note. A: The one who finishes first; B: The one who finishes second; & C: They consume the same energy

Data Analysis

The statistical program SPSS V26 was used to process the questionnaire responses for the research questions (Landau & Everitt, 2004). We utilized the χ^2-test as a statistical control criterion to examine whether responses to survey items vary with age. One can notice a statistically significant difference in the respondents' ages from the statistical analysis of the data.

A χ^2-test and IBM SPSS statistics 26 computer software were used for statistical analysis based on their answers (Field, 2013; Wagner, 2019). This study adopted a quantitative methodology. Survey data were collected simultaneously from students and teachers without any intervention or changing the learning environment.

Additionally, the questionnaire was tested with 823 students and 209 teachers, and the reliability of the Cronbach's alpha coefficient was 0.6. According to Ekolu and Quainoo (2019), a Cronbach's alpha reliability coefficient greater than 0.7 indicates high reliability, while values in the range of 0.5-0.7 indicate moderate reliability and are acceptable in cognitive nature studies.

To investigate the sigmoid curve and extract the data that we will evaluate, the age of the respondents was selected as an independent indicator as a function of the idea of energy. As the index rises, the percentages of respondents' correct responses will be examined, and a sigmoid curve will be generated as a function of age and the respondents' correct responses. All six questions showed a statistically significant correlation between age and the proportion of correct answers.

The first question has to do with the separation of the concepts of energy and power and is, as follows: "Two athletes with the same weight and same height run 100 meters. Who consumes more energy?" The primary school students state the correct answer that both athletes consume the same energy at a rate of 42.2%. In middle school, the percentage becomes 45.4%, and in high school, it increases to 58.6%. 67.1% of university students answered correctly, and 72.5% of teachers. Those who responded that the one who finishes first consumes more energy have probably identified the concept of energy with power (**Table 1**).

Question 2 reads: "in an orange tree, one orange is on the tree, and another is falling; which of the two oranges has the energy?" In this question, the primary school students' correct answer, that both have energy, is stated by only 5%. In middle school, where they have been taught about dynamic and kinetic energy, the correct answers reached 51%, while in high school, they reached 58.6%. The university students declare the correct answer at 61.2%, and the teachers at a rate of 66.7%.

Table 2. Q2-In an orange tree, one orange is on the tree, and another is falling. Which of the two oranges has the energy?

	A (%)	B (%)	C (%)
Primary school	61.9	33.2	5.0
Middle school	45.9	3.1	51.0
High school	41.4	0.0	58.6
University students	35.2	3.7	61.2
Teachers	30.3	3.0	66.7

Note. A: The orange that falls; B: The orange that is on the tree; & C: Both oranges have energy

Table 3. Q3-You are on the roof of your block flat & looking at sunset. Where do you have the most energy regarding the level of the earth?

	A (%)	B (%)	C (%)	D (%)
Primary school	9.3	19.0	41.5	30.2
Middle school	1.0	15.3	49.0	34.7
High school	0.0	23.6	38.4	37.9
University students	0.9	20.5	54.8	23.7
Teachers	2.1	57.7	29.9	10.3

Note. A: When you are on the first floor; B: When you are on the roof; C: You have the same energy everywhere; & D: You have no energy anywhere

Table 4.Q4-Why do long jumpers gain momentum & run before jump?

	A (%)	B (%)	C (%)
Primary school	31.8	61.7	6.5
Middle school	30.9	66.0	3.1
High school	23.2	68.0	8.9
University students	30.6	67.6	1.8
Teachers	22.7	75.8	1.5

Note. A: To overcome air resistance; B: To gain more energy; & C: I do not know

Those who answered that the falling orange has energy have associated energy with movement, but as the age group rises, the percentages of this alternative idea weaken (**Table 2**).

Question 3 has to do with the concept of potential energy and is as follows: ″you are on the roof of your block flat and looking at the sunset. Where do you have the most energy regarding the level of the earth?″ The correct answer that a body has greater energy (dynamics) when it is at a higher height than the ground and consequently when it is on the roof is stated by only 19% of primary school students. In middle school, the percentage is only 15.5%, and in high school, 23.6%. University students followed them at 20.5% and teachers at 57.7%. Many of the respondents, in all age groups, state either that they have no energy at all or that they have the same energy everywhere since it is a static situation and without movement, as a result of which they do not adequately understand scientific concept of dynamic energy (**Table 3**).

Question 4 explores the concept of kinetic energy and reads as follows: "why do long jumpers gain momentum and run before the jump?" From the responses of the respondents, it appears that the correct answer ″to gain more energy″ is stated by 61.7% of primary school students. The correct answers do not change much in high school and high school, reaching 66% and 68%, respectively. University students get the same correct answers at 67.6%, while teachers have the highest percentage at 75.8%. The answer ″to overcome the air resistance" seems to influence a significant number of research subjects since it is known that the speed of the air during the jump is considered in this sport (**Table 4**).

Table 5. Q5-When does a truck have more energy?

	A (%)	B (%)	C (%)
Primary school	79.3	11.3	9.4
Middle school	82.5	3.1	11.4
High school	82.3	5.9	11.8
University students	68.9	10.0	21.0
Teachers	89.7	3.6	6.7

Note. A: When it moves; B: When it is stationary; & C: It always has the same

Table 6. Q6-Two weightlifters lift the same weight. Who spends more energy?

	A (%)	B (%)	C (%)
Primary school	29.4	37.3	33.3
Middle school	53.6	30.1	16.3
High school	65.0	14.3	20.7
University students	52.1	18.3	29.7
Teachers	62.1	22.3	15.5

Note. A: The taller one; B: The shorter one; & C: They both spend same energy

Question 5 has to do with the connection of energy and motion and is, as follows: ″when does a truck have more energy?″ In all the age groups of the research, the correct answer is expressed in large percentages, that the truck has more energy when moving. In primary school, the percentage is 79.3%; in middle school, 82.5%; in high school, 82.3%. University students state the lowest correct answer rate at 68.9%, which is remarkable, and teachers with 89.7% have the highest rate (**Table 5**).

The last question, 6, is as follows: ″Two weightlifters lift the same weight. Who spends more energy?″ From the answers, 29.4% of the primary school students gave the correct answer, i.e., the taller spends more energy. The answers of the primary school students are almost equally divided in all three answers. They reach 53.6% in middle school and 65% in high school: university students 52.1% and teachers 62.1% (**Table 6**).

Across different levels of education, **Table 7** shows a mixture of statistical differences and random variations. According to the above, a physics concept's correct scientific answer depends on education and what that entails (age, experiential experience, and repetition). The existence of such a relationship, and the information it may provide, is of particular interest.

We isolated the percentage of correct answers from the research data for each research group to address the research question (2). A graph was made based on the age of respondents from each educational level. Students belong to the same class, and teachers have stated their ages, so calculating age for all levels of education is straightforward (except for teachers). Based on this definition of variables, the survey data (correct responses by age) are shown in **Table 8**.

Table 8 illustrates a statistical difference between students aged 11 to 17 and the six energy-related questions. This indicates that students' correct answers are influenced by their age and what it contains (experiential experience, education level, gender, and socioeconomic status, which were not examined in this study).

Nevertheless, in the age groups 21, 27, 32, 39, 45, and 50, there is a variation in the correct answers of future and active teachers, although not as much as with students. However, this does not negate a statistically significant difference in these age groups.

Table 7. Statistical analysis of the results using χ^2 criterion for pairs of groups for the levels of education

Question	Primary school/Middle school	Middle school/High school	High school/University students	University students/Teachers
1	RV	SD	SD	SD
2	SD	SD	SD	RV
3	SD	SD	SD	S.
4	RV	SD	SD	RV
5	SD	RV	SD	SD
6	SD	SD	SD	SD

Note. SD: Statistical difference & RV: Random variation

Table 8. The percentage of correct answers per question and age

Age	Q1	Q2	Q3	Q4	Q5	Q6
11	52.0	83.8	32.2	61.7	79.3	29.4
15	68.4	88.8	45.2	66.0	82.5	53.6
17	82.3	91.6	53.2	68.0	82.3	65.0
21	76.7	95.4	50.2	67.6	68.9	52.1
27	80.0	98.6	60.0	62.0	94.6	60.0
32	84.4	100.0	57.4	79.3	82.8	55.6
39	87.9	98.6	64.9	75.8	89.7	62.1
45	93.0	98.3	61.5	75.4	90.7	68.4
50	81.4	100.0	69.0	83.3	90.2	83.7

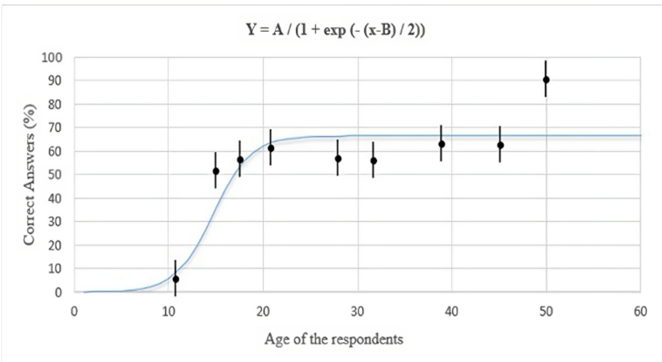

Figure 2. Research data for question 2 & curve that describes them (Source: Authors)

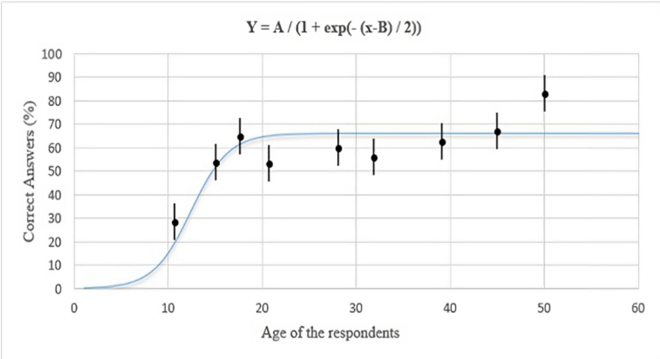

Figure 3. Research data for question 6 & curve that describes them (Source: Authors)

Based on the graphs generated for all six questions, it appears that percentages of correct answers depending on age can be described by a mathematical function (straight, exaggerated). Nonetheless, it is interesting that all curves must be characterized by a single mathematical function, which may provide an empirical rule for how scientific conception of physics changes with age and educational level.

According to da Silva and da Silva (2010), using LAB fit curve fitting software for all data in the questionnaire produced those two mathematical functions. A mathematical function that satisfied all the data for all six questions was the second-order exponential: $Y=A/X^2+B$ and a sigmoid curve (logistic function) of the form: $Y= A/(1+exp(-(X-B)/C))$, where X represents the age and Y represent the percentage correct answers.

In contrast, the second-order exponential curve gives negative values for ages below seven (about seven years), which has no logical significance. Thus, the sigmoid curve is the only mathematical function describing all six questions. According to a recent paper, learning curves take the form of sigmoidal curves when a person is interested in the subject (Leibowitz et al., 2010). The present study confirms those findings in line with the previous study's findings. Throughout education, the concept of energy is taught, resulting in a person's frequent encounters with it as they age.

The constant C was calculated for almost all questions at a value close to two, which simplifies the original function in the form: $Y=A/(1+exp(-(X-B)/2))$. An individual's education level and age determine the maximum percentage of correct answers they can give to a question, referred to as the constant A. Assume that constant A has a significant value (maximum 100). Consequently, most respondents perceive physics concepts as scientifically accurate. Having a small value of constant A does not mean that a concept cannot be understood scientifically, but there are still several alternative solid ideas.

The constant B represents the maximum derivative of the function in years. At this point, there is a significant increase in correct answers, and the slope of the sigmoid curve changes. The value of constant B is for the value of $Y=A/2$. The higher the value of constant B, the older age, the more correct answers appear. The application of the function, which describes the research data for questions 1 and 4, is shown in **Figure 2** and **Figure 3**. The Y-axis is the percentage (%) of the correct answers to the question, and the axis-X (X-axis) is that of age.

The constants A and B, their errors σA and σB, respectively, and the correlation coefficient R2, as calculated by the software, are presented in **Table 9**.

Table 9. The constants A and B of the sigmoidal curve describe the research data for each question

Question	Concept	A	±σA	B	±σB	Correlation factor (R^2)
1	Energy	70.4	3.2	11.2	0.9	0.89
2	Energy	66.4	4.2	13.7	1.2	0.87
3	Energy (potential)	60.8	5.0	20.8	1.2	0.89
4	Energy (kinetic)	72.6	2.4	7.8	1.4	0.93
5	Energy (kinetic)	85.6	2.7	6.5	2.0	0.94
6	Energy	64.1	3.4	11.4	1.1	0.87

DISCUSSION AND CONCLUSIONS

This study demonstrates how students and teachers conceptualize classical mechanics concepts across different age groups and how their conceptions are consistent. In the Greek educational system, few longitudinal studies interpret students' understanding of such concepts from primary (11) to high school (17) or even university students (21) to primary school teachers (27-50).

According to **Table 9**, there are questions where the value of constant A indicates that they can achieve a percentage of 70% correct answers over all age groups. The following questions can be considered more straightforward for obtaining a scientifically accurate understanding: 1, 4, and 5. On the other hand, there are questions where the value of constant A indicates that they cannot reach a large percentage of correct answers after all the age groups. Such questions are 2, 3, and 6, which could be described as challenging to obtain a scientifically accurate understanding.

The abstract concept of energy (questions 1, 2, and 3) is correctly understood by about 66% of all age groups. Therefore, from the results, we conclude that it is a concept that needs more depth in its teaching.

On the other hand, the concept of kinetic energy (questions 4 and 5) are easier to understand since about 8 out of 10 give the correct answer in all the age groups of our research.

Finally, question 3, which has to do with the concept of dynamic energy, turns out to be a complicated concept since 4 out of 10 cannot give the correct scientific answer to all age groups.

Our analysis shows a correlation between AC and all age groups of students and teachers regarding energy. Each person has created their mental model and AI to explain the natural phenomena they observe and related to physics concepts. Research has shown AI for energy in all age groups.

The large or small reduction in the percentage of AI depends on characteristics related to the concept of energy and the age of the respondents. Other factors mentioned above (gender, experiential experiences, socioeconomic status, religion, etc.), which are not analyzed in our research, may play a role in the correct answers. It would be interesting to study in future research together with other studies in this field.

The sigmoidal curve, which describes the increase in the correct answers concerning age, makes it possible to attribute whether the concept is difficult or not, depending on its ceiling value. Also, the result is obtained at what age the correct answers start to be given by the students, which means when the concept can start to be taught. This curve is the learning curve for the specific concept of physics.

Admittedly, the result of the research needs further investigation and even at the ages of 7 to 15 years, to become stronger. Other factors not studied in this research and related to the provided education, such as teaching methods, quality of education, technology infrastructure, or factors related to the students, such as social environment and religious background, need to be examined further. In conjunction with other studies on this subject, the results presented here are anticipated to help teachers develop more effective educational methods, construct analytical programs, and design improved curricula programs.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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