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EXPLORING AI APPLICATIONS FOR ADDRESSING ALTERNATIVE CONCEPTIONS IN TEACHING PHYSICS: FOCUS ON ELECTRICAL CIRCUITS AT THE SECONDARY LEVEL

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ABSTRACT

This article introduces our initial foray into a comprehensive, long-term study on the learning practices of high school students using chatbots as educational tools. In this section, we explore the correlation between the logic underlying the responses generated by two chatbots for problems related to electrical circuits and the well-known alternative conceptions prevalent in the field of science education. To achieve this, we employed a methodology involving the presentation of ten questions to the chatbots, followed by an analysis of their answers in conjunction with established knowledge in physics and the Theory of Conceptual Fields. The objective was to bridge the gap between AI-generated responses and human responses. Our primary findings reveal a close resemblance between these two groups. This initial endeavor lays the foundation for developing an investigative methodology that will facilitate a comprehensive understanding and categorization of the various forms of interaction between students and chatbots.

KEYWORDS

science education; learning practices; theory of conceptual fields; AI-generated responses

1. INTRODUCTION

This article aims to initiate a discussion on the potential uses of generative artificial intelligence (GAI) applications as learning tools in physics, specifically focusing on electrical circuits at the secondary level. While the integration of GAI elements such as ChatGPT or Gemini in the didactics of Physics is relatively unexplored, this study recognizes the importance of exploring new teaching approaches to enhance student learning.

Despite initial reservations within the teaching community [1], it is crucial to emphasize the transformative potential of GAI technologies through research that highlights their possibilities. Notably, the OpenAI ChatGPT and Gemini applications, which generate textual responses to user questions [2], have prompted discussions about their applications in education [3]. By considering the ongoing discourse, this study explores « alternative conceptions » present in GAI tools within the field of physics and their impact on human learning. This groundbreaking research aims to address concerns outlined in previous studies [1] and contribute to the fields of physics education and artificial intelligence studies.

The emergence of constructivism as a philosophical and epistemological approach in understanding the origin and role of errors and alternative conceptions in the learning process [4][5] provides valuable insights into the field of physics education. All human beings make mistakes during the learning process, particularly in physics [6]. The research community in science education has made significant efforts to identify and understand the origins of these misconceptions and propose activities to overcome them, utilizing various methodologies [7-10]. As stated by [11], learners bring preconceptions formed through interactions within their physical and social environments, which subsequently influence their learning experiences. Despite these efforts, alternative conceptions persist among students [5], necessitating new research approaches to better comprehend the psychological mechanisms involved in constructing scientific concepts. This article focuses on two commonly reported alternative conceptions related to electrical circuits, identified in the existing literature. The first one involves learners viewing batteries as sources of constant current, independent of the circuit in which they are connected [12]. The second misconception revolves around learners perceiving current flow as unidirectional, gradually weakening as devices consume portions of the current [13]. Additionally, learners often exhibit local reasoning, focusing on changes at specific points in the circuit without recognizing the subsequent effects on other points [14].

We present a comparative exploratory activity involving the GAI tools ChatGPT and Gemini. The answers generated by these tools are compared with each other and with the existing research literature on alternative conceptions. This comparative analysis aims to identify potential equivalents to alternative conceptions within these GAI tools. To facilitate this exploration, we employ the concept-am-action and theorem-in-action formulations from the Theory of Conceptual Fields [15]. Concepts-in-action refer to concepts held as pertinent, while theorems-in-action represent propositions held as true to solve a given situation. These categories constitute the epistemic content underlying the actions of individuals¹.

This exploratory research serves as an initial step in a broader project focused on modeling interactions between humans and GAI tools. The overarching goal is to provide empirical and theoretical insights for implementing GAI as a learning practice in physics education. By shedding light on alternative conceptions and leveraging GAI tools, this research aims to enhance the effectiveness of teaching and learning processes in physics education.

2. ARTIFICIAL INTELLIGENCE TOOLS

Gemini and ChatGPT are language models developed by OpenAI and Google, respectively, designed to engage in conversations and interact with users on a wide range of topics. These models employ a process known as "natural language processing" to generate text that is relevant to user prompts or questions. Natural language processing is a field of computer science that focuses on the interaction between computers and humans using human language.

Both Gemini and ChatGPT utilize machine learning and neural networking techniques. Machine learning is a form of artificial intelligence that enables computers to learn from data without explicit programming. Neural networks, inspired by the human brain, are a type of machine learning algorithm used in these models.

It's worth noting that ChatGPT operates offline and relies on data available until September 2021, while Gemini can access current information through Google search.

These tools can assist users in various tasks, including writing texts, generating ideas, crafting stories, answering questions, or providing advice. They are valuable resources for professionals, students, writers, and anyone seeking language assistance. However, it is important to

acknowledge that both ChatGPT and Gemini have limitations. When used as didactic aids, the answers generated may exhibit certain similarities to alternative conceptions identified in human beings, as there may be a degree of undifferentiation between common sense and scientific knowledge.

Despite their capabilities, these language models should be used with caution and critical thinking, especially in educational contexts where ensuring accurate scientific knowledge is crucial.

3. CONSTRUCTION OF THE QUESTIONS PROPOSED TO THE GAI TOOLS

To lay the groundwork for researching student learning practices with the assistance of GAI tools, we conducted an extensive review of research conducted since the 1990s on alternative conceptions in electricity. This review allowed us to establish the initial categories for the interaction sessions with the tools.

The primary objective is to compare the answers provided by the GAI tools with those documented in science education researches. This comparison will help us to determinate the extent to which the answers resemble or differ from alternative conceptions. This step is crucial as it reveals not only the quality of the answers but also the coherence within the virtual "chat" responses.

This initial phase will serve as the foundation for constructing research protocols that will accompany students throughout their study sessions, utilizing one or both of the investigated GAI tools. Over time, this will enable the development of a theoretical model that helps us understand how such interactions contribute to the learning of Physics. Furthermore, it will guide the identification of more suitable learning practices based on specific learning profiles.

Using the categories derived from the literature, we conducted interaction sessions with Gemini and ChatGPT. Ten questions were formulated, with the first five focusing on the alternative conception of progressive weakening of current [13], and the next five addressing the battery as a constant source of current [12].

Below we present the questions and a summary of the answers. Each question was posed to the chatbots daily for ten consecutive days in three different languages (English, French, and Portuguese) to ensure consistency across responses. While there were minor variations in wording, the essence of the answers remained the same. Italics have been added by us to highlight aspects that may align with alternative conceptions.

<p>Question 1: Consider a simple electrical circuit composed of an electrical resistor connected to an ideal battery. Let i_1 be the magnitude of the current before passing through the resistor, and i_2 be the magnitude of the current after passing through the resistor. Compare i_1 and i_2.</p> <p>Gemini: The intensity of the electric current is <i>lower after it has passed through an electric motor</i> because some of the electrical energy is converted into mechanical energy. The motor uses this energy to turn a shaft, which can then be used to power a machine or device. The amount of electrical energy that is converted into mechanical energy depends on the efficiency of the motor.</p> <p>ChatGPT: In a simple electrical circuit composed of an electrical resistor connected to an ideal battery, the magnitude of the current before passing through the resistor (i_1) <i>will be equal to the magnitude</i> of the current after passing through the resistor (i_2). This principle is known as the conservation of current.</p>

Question 2: Why is the intensity of the electric current lower after it has passed through an electric motor?

Gemini: The intensity of the electric current is lower after it has passed through an electric motor because *some of the electrical energy is converted into mechanical energy*. The motor uses this energy to turn a shaft, which can then be used to power a machine or device. The amount of electrical energy that is converted into mechanical energy depends on the efficiency of the motor.

ChatGPT: The intensity of the electric current is lower after it has passed through an electric motor *due to the presence of the motor's internal resistance*. When an electric current flows through a motor, it encounters resistance within the motor's coils, windings, and other components. According to Ohm's Law, the current (I) passing through a component is inversely proportional to the resistance (R) it encounters. In the case of an electric motor, the motor's internal resistance contributes to the overall resistance in the circuit. In summary, the internal resistance of an electric motor causes a voltage drop and reduces the current intensity as the current flows through the motor, leading to a lower intensity of the electric current after passing through the motor.

Question 3: Do you mean that an electric motor makes some of the current disappear?

Gemini: No, I don't mean that an electric motor makes some of the current disappear. *The current is still there, but it has been converted into other forms of energy*, such as mechanical energy and heat. The amount of current that is converted into other forms of energy depends on the efficiency of the motor.

ChatGPT: No, an electric motor does not make the current disappear. The current flowing into an electric motor is conserved according to the principle of the conservation of electric charge.

When an electric current passes through an electric motor, the motor converts electrical energy into mechanical energy, which allows it to perform work. *The motor's internal components, such as the coils and windings, have resistance that impedes the flow of current*. This resistance causes a voltage drop across the motor.

The voltage drop across the motor's internal resistance reduces the potential difference (voltage) across the motor. According to Ohm's Law ($V = I * R$), if the voltage decreases, and the resistance remains constant, the current passing through the motor will also decrease. This decrease in current is due to the conversion of electrical energy into mechanical energy within the motor, not because the current disappears.

So, while the current intensity may be lower after passing through an electric motor, it is due to the motor's internal resistance and the conversion of energy, rather than the current simply disappearing.

Question 4: So you're saying that the motor makes some of the electrons stop moving?

Gemini: Yes, that's correct. When an electric current passes through an electric motor, *the motor's internal resistance and components impede the flow of electrons*. This resistance causes collisions and interactions between electrons and the motor's internal structure, resulting in the conversion of electrical energy into mechanical energy. As the electrons encounter resistance within the motor, their motion is impeded, and some of their kinetic energy is converted into other forms of energy, such as heat or mechanical work. This conversion process slows down the movement of electrons within the motor.

ChatGPT : Well, not exactly. The electrons in a current do not actually stop moving. *They simply lose some of their energy as they flow through the motor*. This is because the current flowing through the motor creates a resistance, which causes heat to be produced. The heat is dissipated into the environment, which further reduces the amount of electrical energy available to turn the shaft.

Question 5: Does this mean that the internal resistance of the motor decreases the speed of the electrons in the electric current?

Gemini: Yes, that's correct. *The internal resistance of the motor acts as a resistor in the circuit, which causes the electrons to lose energy as they flow through the motor.* This energy loss manifests itself as heat, which is why electric motors get hot when they are running. The amount of energy that is lost as heat depends on the internal resistance of the motor and the current that is flowing through it. The higher the current, the more heat is produced. This is why the intensity of the current is lower after it has passed through the motor.

ChatGPT: Yes, that's correct. The internal resistance of an electric motor hinders the flow of electrons in the electric current, which in turn decreases the speed of the electrons. *When electrons encounter resistance within the motor's internal components, such as coils, windings, and brushes, they experience collisions and interactions that impede their movement.* These collisions result in a decrease in the average speed of the electrons as they navigate through the motor.

Question 6: An ideal battery would always provide the same intensity of current, no matter what circuit it is connected to?

Gemini: Yes, an ideal battery would always provide the same intensity of current, no matter what circuit it is connected to. This is because an ideal battery has no internal resistance, so the current that flows through it is determined only by the resistance of the circuit. In a real battery, there is some internal resistance, so the current that flows through it will be less than the current that would flow through an ideal battery with the same voltage. The amount of current that flows through a real battery will also depend on the size of the battery and the rate at which it is being discharged.

ChatGPT: No, that statement is not accurate. The current provided by a battery depends on the circuit it is connected to. In an ideal scenario, where the internal resistance of the battery is negligible and the battery voltage remains constant, the current drawn from the battery would depend on the resistance of the circuit according to Ohm's Law ($I = V/R$).

Question 7: So, if this ideal battery is connected to a resistance R or to two resistances R in series, will the intensity of the electric current supplied be equal in both cases?

Gemini: No, the intensity of the electric current supplied will not be equal in both cases. When an ideal battery is connected to a resistance R , the current that flows through the circuit is given by Ohm's law: $I = V / R$

where I is the current, V is the voltage of the battery, and R is the resistance of the circuit.

If the same ideal battery is connected to two resistances R in series, the current that flows through the circuit is given by:

$$I = V / (2R)$$

In this case, the current is half of what it would be if the battery were connected to a single resistance R . This is because the two resistances in series effectively create a larger resistance, which reduces the current that flows through the circuit. Therefore, the intensity of the electric current supplied by an ideal battery will be half as much when it is connected to two resistances R in series than when it is connected to a single resistance R .

ChatGPT: Yes, if an ideal battery is connected to a single resistance (R) or to two resistances (R) in series, the intensity of the electric current supplied will be the same in both cases. In an ideal scenario, the ideal battery has zero internal resistance and a constant voltage output. When connected to a single resistance (R), the current flowing through the circuit is determined by Ohm's Law ($I = V/R$), where V is the constant voltage of the ideal battery. Similarly, when two resistances (R) are connected in series, the total resistance in the circuit is $2R$. Therefore, the current flowing through the circuit will be $I = V/(2R)$.

Since the voltage output of the ideal battery remains constant, the current flowing through the circuit in both cases will be the same. Whether the resistance (R) is connected as a single component or in series with another resistance (R), the ideal battery will provide a consistent intensity of electric current.

Question 8: Consider three different situations. Situation 1: An ideal battery is connected to a single incandescent bulb. Situation 2: Two batteries identical to the one in situation 1 are connected in series and this set connected to a single bulb (identical to the bulb in situation 1). Situation 3: The same two batteries from situation 2 are connected in parallel and the set is connected to the same bulb from situation 1. Compare the power dissipated by the bulb in the three situations.

Gemini: The power dissipated by the bulb in the three situations is equal. This is because the power dissipated by a bulb is directly proportional to the voltage applied to the bulb and the current flowing through the bulb. The voltage applied to the bulb is the same in the three situations, since the two batteries in situation 2 have the same voltage as the battery in situation 1. The current flowing through the bulb is also the same in the three situations, since the bulb is the same in the three situations. Therefore, the power dissipated by the bulb is equal in the three situations.

ChatGPT: Situation 1: In this case, a single ideal battery is connected to a single incandescent bulb. Let's assume the battery voltage is V and the current flowing through the bulb is I . The power dissipated by the bulb can be calculated using the formula: $P = V * I$

Situation 2: In this situation, two identical batteries are connected in series, and this combination is connected to the same bulb as in situation 1. When batteries are connected in series, their voltages add up. So the total voltage across the bulb in situation 2 is $2V$ (assuming each battery has a voltage of V). However, the current flowing through the circuit remains the same as in situation 1. $P = (2V) * I$

Situation 3: Here, the same two batteries from situation 2 are connected in parallel, and the combination is connected to the same bulb as in situations 1 and 2. When batteries are connected in parallel, their voltages remain the same, but their currents add up. Therefore, the voltage across the bulb is still $2V$, but the current flowing through the bulb is now $2I$ (assuming each battery supplies a current of I).

$$P = (2V) * (2I) = 4VI$$

Comparing the three situations, the power dissipated by the bulb is the highest in Situation 3, followed by Situation 2, and the lowest in Situation 1.

Question 9: Consider three different situations. Situation 1: An ideal battery is connected to a single incandescent bulb. Situation 2: Two bulbs identical to the bulb in situation 1 are connected in series and this set is connected to an ideal battery identical to the one in situation 1. Situation 3: Two bulbs identical to the bulb in situation 1 are connected in parallel to each other and this set is connected to an ideal battery identical to the one in situation 1. Compare the power dissipated by the circuits in the three situations.

Gemini: The power dissipated by the circuit is the same in situations 1 and 3, and is twice the power dissipated by the circuit in situation 2.

In situation 1, the voltage is equal to the battery voltage and the resistance is equal to the lamp resistance. Therefore, the power dissipated is equal to the lamp resistance times the battery voltage.

In situation 3, the voltage is equal to the battery voltage and the resistance is equal to half the lamp resistance, since the two lamps are in parallel. Therefore, the power dissipated is equal to half the lamp resistance times the battery voltage.

As the total resistance of the circuit is the same in both situations, the power dissipated by the circuit is also the same in both situations. This is because the total resistance of the circuit is

equal to the sum of the resistances of the two lamps in situation 2, and is equal to the lamp resistance in situation 1.

The power dissipated by the circuit in situation 2 is twice the power dissipated by the circuit in situation 1. This is because the total resistance of the circuit in situation 2 is twice the total resistance of the circuit in situation 1.

In conclusion, the power dissipated by the circuit is the same in situations 1 and 3, and is twice the power dissipated by the circuit in situation 2.

ChatGPT:

Situation 1: In this case, a single ideal battery is connected to a single incandescent bulb. Let's assume the battery voltage is V and the current flowing through the bulb is I . The power dissipated by the bulb can be calculated using the formula:

$$P_1 = V * I$$

Situation 2: In this situation, two identical bulbs are connected in series, and this combination is connected to an ideal battery identical to the one in Situation 1. When bulbs are connected in series, the current flowing through each bulb remains the same, but the total voltage across the series combination is the sum of the individual bulb voltages. Therefore, the voltage across each bulb in Situation 2 is $V/2$ (assuming the battery voltage is V). Since the current is the same for both bulbs, the power dissipated by each bulb can be calculated using the formula:

$$P_2 = (V/2) * I$$

The total power dissipated by the series combination of bulbs in Situation 2 is:

$$P_{total2} = 2 * P_2 = 2 * [(V/2) * I] = V * I$$

Situation 3: Here, two identical bulbs are connected in parallel, and this combination is connected to an ideal battery identical to the one in Situation 1. When bulbs are connected in parallel, the voltage across each bulb remains the same, but the current flowing through the parallel combination is the sum of the currents through each bulb. Therefore, the current passing through each bulb in Situation 3 is $I/2$ (assuming the battery current is I). The power dissipated by each bulb can be calculated using the formula: $P_3 = V * (I/2) = (V * I) / 2$

The total power dissipated by the parallel combination of bulbs in Situation 3 is:

$$P_{total3} = 2 * P_3 = 2 * [(V * I) / 2] = V * I$$

Comparing the three situations, we observe that the power dissipated by the circuits is the same in all three cases. This is because the battery voltage and the total current passing through the bulbs remain the same in all situations, regardless of how the bulbs are connected.

Question 10: Consider three incandescent bulbs with the following nominal values: bulb A - 100W/120V; bulb B - 60W/120V; bulb C - 40W/120V. These bulbs are connected in series and the set is connected to a constant voltage source of 120V. In this situation, which bulb will have the highest electrical power?

Gemini: All three bulbs will have the same electrical power because they are connected in series. In a series circuit, the current is the same throughout the circuit, so each bulb will have the same current flowing through it. The electrical resistance of the three bulbs is also the same because they are all the same brand and model. Therefore, the three bulbs will have the same electrical power.

ChatGPT: When light bulbs are connected in series, the current flowing through them is the same because they are in the same circuit. The total voltage of the circuit is divided among the bulbs. In this case, since the bulbs are all connected in series, the current is the same in all of them, as is the voltage of 120V. Electrical power is calculated using the formula $P = V \times I$, where P is power, V is voltage, and I is current. Therefore, in the case of the bulbs being connected in series, they will all have the same electrical power.

4. DATA DISCUSSION

In an initial analysis, the obtained answers show minimal variations compared to those obtained in clinical interviews with students or even large-scale examinations. This observation aligns with our initial hypothesis that chatbots rely on general information embedded in their programming, including common sense, which consequently influences their responses.

This observation becomes evident in specific instances. For instance, when asked question 6, Gemini accurately responds that the battery consistently supplies the same current to all circuits due to its provision of a constant voltage. Similarly, ChatGPT states in question 7 that a battery supplies the same current whether connected to one or two resistances.

However, it is important to note that the answers lack logical coherence, even within the same chatbot. This inconsistency is a common finding in research conducted in the field of Physics education. A notable example is the discrepancy between the responses provided by both chatbots to questions 1 and 2. Question 1 asserts that the intensity of electric current remains constant throughout a circuit, whereas question 2 claims that the intensity decreases when passing through an electric motor.

To further explore the two alternative conceptions examined in this study, a comprehensive analysis of all responses provided by the two chatbots will be conducted.

4.1. Weakening of the Current

Despite initially affirming that the electric current has the same intensity throughout the circuit, Gemini's subsequent four answers reveal a different understanding. Gemini's responses suggest that elements in an electric circuit can hinder the motion of electrons, causing them to accumulate and cease movement. This perspective aligns with a localized analysis of electrical circuits and can be represented by a theorem-in-action, such as the notion that "electrical resistance reduces the movement of charges, resulting in a decrease in current intensity as they pass through an electrical apparatus." This can be analogized to a mechanical barrier that applies force to charge-bearing particles, causing them to halt.

Similarly, ChatGPT demonstrates inconsistency between the first question and the following four, while presenting a similar theorem-in-action. However, the justification provided is somewhat fragmented and incoherent, occasionally referring to Ohm's Law and at other times to the Joule effect.

The reference to Ohm's Law is inaccurately made, as there appears to be confusion between the concepts of electric potential and voltage. Although it is true that electric potential varies when an electric current passes through a resistor, the chatbot incorrectly states that electrical voltage decreases, leading to a decrease in current intensity. By equating the concept-in-action of electric voltage with the same epistemological status as electric potential, the chatbot presents an incorrect explanation, despite employing a true theorem-in-action. Consequently, the flawed analysis of current based on electric potential, as if it were the potential difference, results in an erroneous conclusion derived from a valid proposition, namely Ohm's Law.

At this point, both chatbots can, in their interaction with learners, reinforce the alternative conception associated with the attenuation of current along a circuit, even though their explanations for this phenomenon may differ.

4.2. Battery as a Constant Source of Current

The responses provided by both Gemini and ChatGPT in questions 6 and 7 are incorrect, but interestingly, they are incorrect for different reasons. In question 6, Gemini claims that a battery always supplies the same current, while ChatGPT states that a battery provides a constant voltage, but the current depends on the circuit's characteristics. However, in question 7, Gemini states that the current intensity differs when one or two resistances are connected to the same battery, whereas ChatGPT claims that the current generated by a battery is the same regardless of the number of resistors connected. The explanation provided by ChatGPT uses linear logic, extending the statement that "in a series circuit, the current is the same at all points" to conclude that "in all circuits, the current intensity must be the same."

We can compare the answers given to the last three questions in order to identify traces of the misconception that batteries act as sources of constant electric currents. In question 8, Gemini asserts that the power is the same in all three situations because all batteries are identical, implying that all currents are equal. In question 9, Gemini states that the power of circuit 2 is greater because its equivalent resistance is higher, assuming implicitly that the current intensity is equal in the first two circuits. This same line of reasoning is present in question 10, where Gemini claims that all lamps have the same power since the current intensity is the same in all of them. Although not explicitly stated in these three answers, they seem to rely on the incorrect assumption that "each type of voltage source produces a definite and constant electric current." Since this statement is scientifically false, the provided answers are incorrect.

On the other hand, ChatGPT's response further reinforces the notion of a constant current for each battery. By explaining that the greatest power is obtained when two batteries are connected in parallel, followed by batteries in series and a single battery, it becomes evident that the corresponding assumption is that "each battery generates an electric current characteristic to itself." The explanation goes as follows: when two batteries are in parallel, each generates a current of intensity i , resulting in a total current of $2i$, which produces greater power. When two batteries are in series, the current generated is i , but the total electrical voltage is doubled. According to ChatGPT, this results in less dissipated power compared to the first case, suggesting that the current is the main source of electrical energy rather than the voltage, even though this is not explicitly stated. Finally, in the third case, there is a current of intensity i and the voltage of a single battery, leading to the lowest power of all.

The same explanation suggests that the first two setups in question 9 have the same power. According to ChatGPT, if a battery is the source of a constant current, whether there is a single lamp or two connected in series, the electrical power (the product of battery voltage and current) should remain constant. However, in explaining the third scenario where two lamps are connected in parallel, there is a deviation from the concept of electric current to that of electric voltage. ChatGPT correctly states that each lamp in parallel is connected to the same voltage, resulting in a total power higher than the previous cases. This shift in focus from electric current to electric voltage allows for a correct proposition regarding the determination of the circuit's total power.

In question 10, the concept of current takes precedence again, and the assumption that the current is the same in a series connection leads ChatGPT to conclude that all three lamps have the same brightness.

5. CONCLUSION

This exploratory research aims to initiate discussions on the utilization of artificial intelligence tools in learning practices related to electrical circuits. It represents the initial phase of a large-scale research project that will model these learning practices.

Our hypothesis proposes that chatbots, in their generated answers to physics problems, may exhibit elements resembling the alternative conceptions previously observed in human beings. Furthermore, we intend to analyze these conceptions through the lens of the Theory of Conceptual Fields, as the epistemic content of the answers can be broken down into instances of relevance and accuracy.

After subjecting the two GAI tools to 10 questions, we were able to preliminarily identify significant correlations between the alternative conceptions discussed in the field of science education and the obtained answers. Additionally, exploring the possibility of identifying concepts-in-action and theorems-in-action in chatbot responses provided valuable insights into the similarities between human and GAI responses.

Based on these results, we can further develop research methodologies to investigate the interaction patterns between learners and chatbots. The aim is to categorize different modes of learning and examine the modifications in learners' cognitive structures that occur during discussion sessions with GAI tools.

This research project is long-term in nature, both due to the depth required to address the topic and the limited existing research on chatbots. Nevertheless, it has the potential to illuminate best practices for learning with GAI assistance and how schools can leverage them to overcome historical challenges in understanding physics.

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