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Examining ChatGPT's validity as a source for scientific inquiry and its misconceptions regarding cell energy metabolism

Rıdvan Elmas[1] · **Merve Adiguzel-Ulutas**[2] · **Mehmet Yılmaz**[2]

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Abstract
Many people use technological tools that are widely accessible, respond quickly, and have extensive information networks today. Due to recent technological advances in education and the increasing acceptance of Artificial Intelligence (AI) technologies, the issues regarding their implementation in education require identification and analysis. ChatGPT (Chat Generative Pre-trained Transformer), an artificial intelligence program that emerged in 2022, contains notable characteristics. OpenAI created ChatGPT and released it to users in 2022. ChatGPT is a machine learning-powered chatbot that can deliver detailed responses to inquiries. This research aims to evaluate the validity of ChatGPT-generated responses when scientific questions related to the biochemistry discipline are posed. A document analysis was conducted to determine the scientific validity of responses produced by ChatGPT for five questions. Five questions originating from bio-chemistry content were asked to ChatGPT in a written format. The AI's generated answers were saved and analyzed depending on their scientific validity. As a result of the study, it was detected that ChatGPT responded with scientifically incorrect or incomplete answers to the five questions asked. Besides, when asked the reason for ChatGPT's response, it is seen that AI insisted on its invalid answers. Following prompts for certainty, the AI's performance was evaluated. It provided scientifically correct answers to the first two questions, partially correct answers to the third, and consistently offered invalid solutions for the remaining questions. Ultimately, ChatGPT's capabilities are limited in providing scientifically rigorous responses. To obtain accurate and appropriate answers, it is imperative to pose comprehensive and detailed inquiries that facilitate a more precise and informed response. Scholars and researchers must acknowledge that ChatGPT harbors certain misconceptions and consequently only constitutes a somewhat dependable and scientifically validated resource.

Keywords Artificial intelligence (AI) · Misconceptions · Biochemistry · ChatGPT

Extended author information available on the last page of the article

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1 Introduction

Artificial intelligence (AI) mimics human behaviors and processes with machine learning (Booth et al., 2021; Wartman & Combs, 2018). AI has come a long way since it was initially mentioned in 1955 (McCarthy et al., 2006). ELIZA, the earliest example of a natural language processing program, was created in the 1960s (Weizenbaum, 1966). Besides, the United States Department of Defense began training computers to mimic basic human skills during those very same years. Deep learning was introduced in the 1980s. Deep learning is the machine using previously stored information for new experiences. In this context, AI has acquired significant traction. In the 1990s, artificial neural networks were constructed. Deep Blue, an intelligent chess-playing algorithm, defeated the world chess champion in 1997. A humanoid robot was developed by MIT in 2001 (Breazeal, 2004). Furthermore, DeepMind's AlphaGo artificial intelligence system defeated Go Champion Lee Se-dol 4 − 1 in 2016 (Koch, 2016). The rise of smart assistants like Siri highlights the power of AI in defining, evaluating, and acting logically. These capabilities allow AI systems to interact with the natural world in increasingly sophisticated ways (Luckin et al., 2016). Therefore, many industries incorporate AI into their products, including electronics, mechanics, and informatics. Today, AI may be found in most industries, from smartphones to marketing to healthcare to finance (Mou, 2019). All these applications lead to AI moving systems to critical points in our lives. These applications are expected to advance soon (Shabbir & Anwer, 2015).

AI systems invade every industry and force us to make drastic adjustments. In this context, it is anticipated that it will take the lead in education. Education is set to undergo a profound transition due to the rise of AI, posing one of the most significant challenges and implications among the disciplines touched by this technology (Cooper, 2023; Forbes, 2020). Looking back over the last 50 years, we can observe that many technologies and tools like augmented reality (AR) and virtual reality (VR) still need to be fully integrated into educational settings (Lawrie, 2023). According to the Education Intelligence Unit (2019), AI will be fully embraced in education, and its applications will grow significantly over the next five years. Education has been considered among the most crucial factors, especially when nations are developing national AI strategies, as seen in Australia, China, Estonia, France, Singapore, South Korea, and the United States (UNESCO, 2019). Recognizing the considerable potential of AI, countries such as China and the United States are investing in educational AI applications (Chiu & Chai, 2020). Furthermore, a few private companies have created AI apps for teaching and learning. Carnegie Learning and Fuel Education are two companies that disseminate AI in K-12 education. ALEKS, another AI tool developed by McGraw Hill, is a learning and assessment system for grades K-12. Also, AI is commonly used to learn foreign languages. Many foreign language learning software programs include integrated AI. One is Duolingo, a language learning application; a whole university semester of language education is equivalent to 34 h on the Duolingo app (Vesselinov & Grego, 2012). Century is another software that helps teachers build tailored learning modules while reducing their workload. Priya Lakhani founded the Century AI tool in 2013 in London (Lakhani & Halfon, 2020).

ChatGPT, an AI program that emerged in 2022, contains notable characteristics. OpenAI created ChatGPT (Chat Generative Pre-trained Transformer) and released it to users in 2022. ChatGPT is a machine learning-powered chatbot that can deliver detailed responses to inquiries (Flanagin et al., 2023). ChatGPT could serve a purpose in real-world applications such as digital marketing, online content production, resolving customer service questions, or, as some users have discovered, even debugging code (Siddharth, 2022). Because of ChatGPT's potential, it rapidly piqued people's curiosity (Mollick, 2022). Along with the exhilaration, it brought the anxiety of providing inaccurate information (Davis, 2023). It is anticipated that it may raise some ethical concerns. It is unclear which strategy will be employed if it is used for homework or original article writing. Experts argue whether to include ChatGPT as a co-author (Stokel-Walker, 2023).

ChatGPT can also provide answers to scientific queries, which is an issue that must be investigated to determine whether it will be a reliable tool for learning new content. Teaching new knowledge and making it more persistent for memory is essential for learning. Students may develop misconceptions or need clarification if new knowledge is delivered incorrectly or incompletely. The misconceptions are accepted as individuals' unscientific information (Lamichhane et al., 2018). The misconceptions are mostly counted as barriers to meaningful learning. They persistently provide incomplete content knowledge (Nussbaum & Novick, 1982; Queloz et al., 2018). It is challenging to overcome misconceptions (Duit & Treagust, 2003). Besides, many students may already have misconceptions related to introductory chemistry and biology (Atchia et al., 2022; Brandriet & Bretz, 2014; Machová & Ehler, 2021; Naah & Sanger, 2012; Rosenthal & Sanger, 2012; Smith & Villarreal, 2015). Families, teachers, and technological experiences may form and spread misconceptions in various ways (Karpudewan et al., 2017).

Television, websites, and social media platforms are frequently utilized as reference sources for getting and sharing knowledge (Elmas et al., 2013). Students who come across incorrect or incomplete information may turn it into a misconception. For example, an individual's hair is usually called a feather in the media. Because of this, many students believe that there may be a characteristic of birds in humans who are mammals. (Adıgüzel & Yılmaz, 2020). Another study investigating the misconceptions about the Zika vaccine determined that the source of the misconceptions also came from social media. Specifically, there was misinformation suggesting that the Zika virus itself does not cause microcephaly in babies (Dredze et al., 2016).

Today, practically everyone uses technological tools that are widely accessible, respond quickly, and have extensive information networks (Elmas & Geban, 2012). Due to the latest technological breakthroughs in education and the increasing acceptance of AI technologies, the issues regarding their implementation in education require identification and analysis (Owoc et al., 2021; Jia et al., 2023). The objective is to assess the accuracy of ChatGPT's responses to scientific inquiries formulated explicitly within the context of biochemical processes.

2 Methodology

A document analysis has been conducted for five questions and the scientific validity of responses produced by ChatGPT. Document in the context of this study refers to the responses generated by ChatGPT to the questions researchers asked. Five questions were asked to ChatGPT in a written format, and the generated answers from the AI were saved and analyzed depending on their scientific validity. The unit of analysis is sentences. The steps of data generation are as follows (Merriam, 2009). Figure 1 shows the data generation steps of our study.

In this context, a three-tier misconception test was applied to the ChatGPT (Table 1). The three-tier misconception test is frequently used to identify misconceptions (Andariana et al., 2020; Elmas & Pamuk, 2021; Hasyim et al., 2018; Irwansyah et al., 2018; Suriani et al., 2022; Prodjosantoso & Hertina, 2019). In the three-tier misconception test with AI, the first stage involves asking open-ended questions to ChatGPT. The second stage involves AI writing down why it prefers to answer that way in the first stage. The difference between the three-tier misconception test and the two-tier misconception test is the inclusion of the options "I am sure" and "I am not sure" to determine whether students are confident in their answers. We directly asked AI whether the algorithm was sure about its answer. In this research, the version of ChatGPT 3.5 was used. The five questions are presented below. These questions are also common misconceptions about cell energy metabolism in students (Table 1).

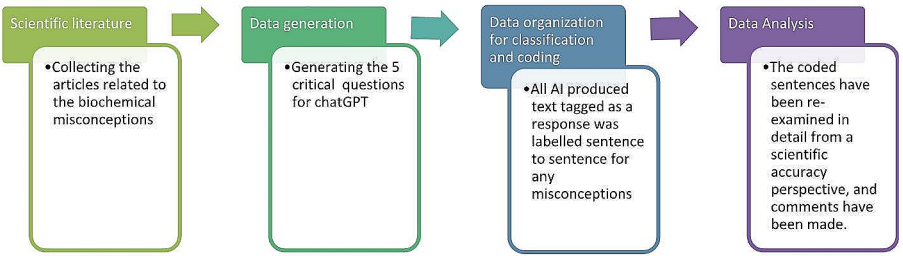


Fig. 1 The steps of data generation

Table 1 Questions in the form of a three-tier test

Questions (Tier 1)	Reasons (Tier 2)	Confidence (Tier 3)
1a. Is fermentation an anaerobic respiration?	1b. Why is fermentation anaerobic respiration?	1c. Are you sure of your answer?
2a. What are the final electron acceptor molecules in fermentation?	2b. Why these molecules are the final electron acceptor molecules in fermentation?	2c. Are you sure of your answer?
3a. Does oxidative phosphorylation occur in anaerobic respiration?	3b. Why does not oxidative phosphorylation occur in anaerobic respiration?	3c. Are you sure of your answer?
4a. Does oxidative phosphorylation occur in chemosynthesis?	4b. Why does not oxidative phosphorylation occur in chemosynthesis?	4c. Are you sure of your answer?
5a. In which metabolic processes does chemophosphorylation occur?	5b.Why does chemophosphorylation occur in these metabolic processes?	5c. Are you sure of your answer?

2.1 Data Collection process

Firstly, the question, 'Is fermentation an anaerobic respiration?' was asked. Figure 2 depicts ChatGPT's response. https://chat.openai.com/share/f974e796-9d0c-4578-9a4c-10ba0d913f95.

When Fig. 2 is examined, fermentation is precisely expressed as anaerobic respiration. Besides, the question 'Why is fermentation anaerobic respiration?' was asked. Figure 3 depicts ChatGPT's response.

When Fig. 3 is examined, fermentation is referred to as anaerobic respiration because it occurs in an oxygen-depleted environment. Also, the question 'Are you sure of your answer?' was asked. Figure 4 depicts ChatGPT's response.

When Fig. 4 is examined, it was observed that ChatGPT seemed unsure of its response and desired to alter it. Secondly, the question 'What are the final electron acceptor molecules in fermentation?' was asked. Figure 5 depicts ChatGPT's response. https://chat.openai.com/share/507f4ff2-d3fd-4841-944c-bd97946e0c09.

When Fig. 5 is examined, it seems that ethanol and lactic acid are considered the final electron acceptors in the fermentation pathway. Besides, the question 'Why are these molecules the final electron acceptor molecules in fermentation?' was asked. Figure 6 depicts ChatGPT's response.

When Fig. 6 is examined, it is observed that ChatGPT's response is insisted upon. Also, the question 'Are you sure of your answer?' was asked. Figure 7 depicts ChatGPT's response.

When Fig. 7 is examined, it is observed that ChatGPT seemed unsure of its response and desired to alter it. Thirdly, the question 'Does oxidative phosphorylation occur in anaerobic respiration?' was asked. Figure 8 depicts ChatGPT's response. https://chat.openai.com/share/2ec056e6-fefa-4eb8-bb70-7509116f23e5.

When Fig. 8 is examined, it is noted that oxidative phosphorylation does not occur in anaerobic respiration. The question 'Why does not oxidative phosphorylation occur in anaerobic respiration?' was asked. Figure 9 depicts ChatGPT's response.

When Fig. 9 is examined, it is observed that ChatGPT's response is insisted upon. In addition, according to its response, oxygen is required for oxidative phosphoryla-

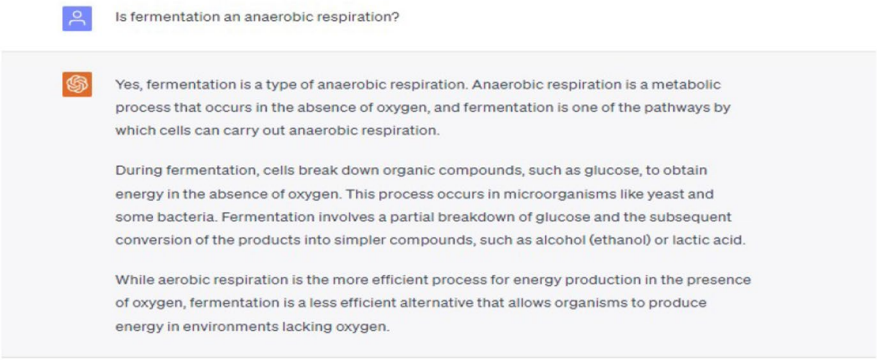


Fig. 2 Is fermentation an anaerobic respiration?

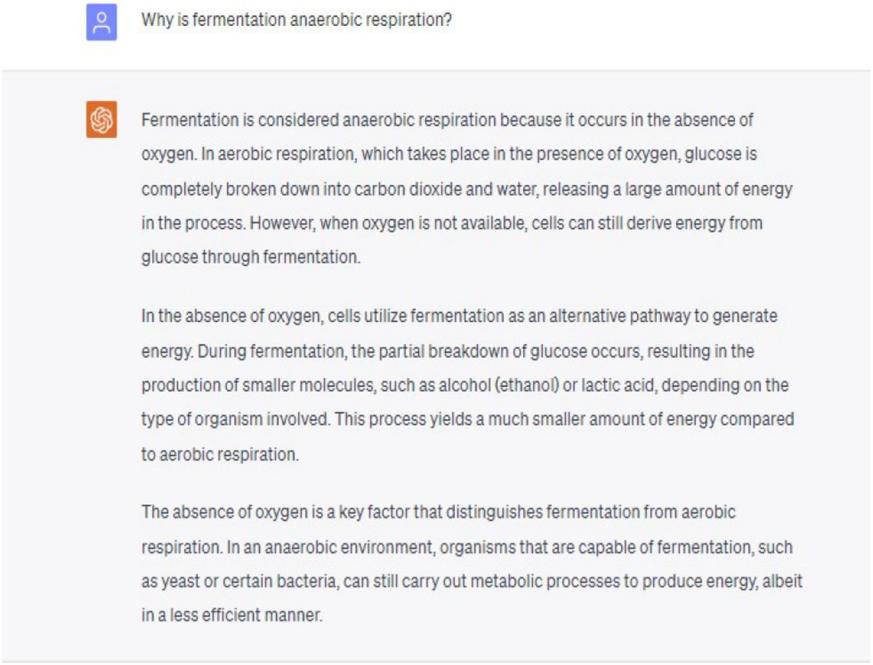


Fig. 3 Why is fermentation anaerobic respiration?

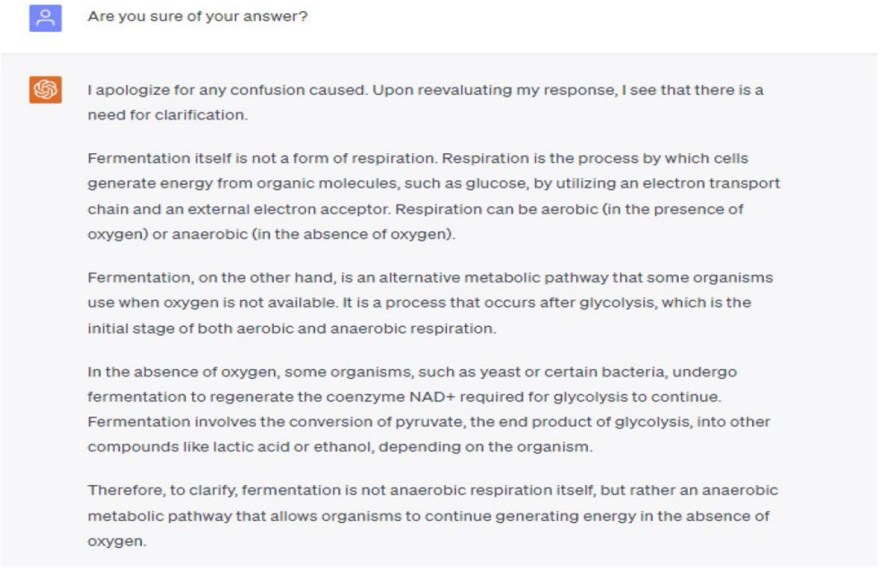


Fig. 4 Are you sure of your answer?

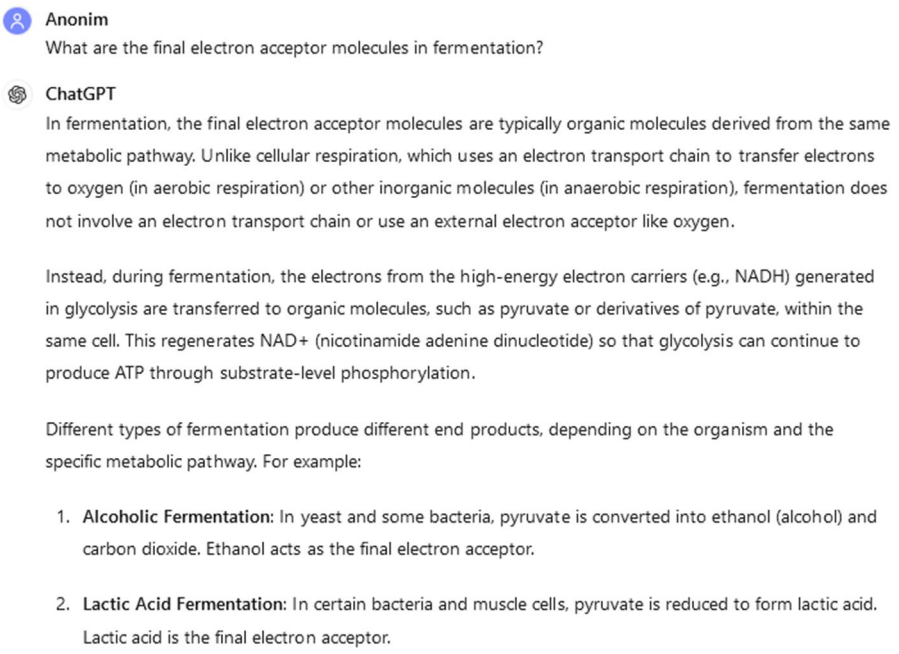


Fig. 5 What are the final electron acceptor molecules in fermentation?

tion. Also, the question 'Are you sure of your answer?' was asked. Figure 10 depicts ChatGPT's response.

When Fig. 10 is examined, it is observed that ChatGPT's response was unsure and desired to be altered. Although limited, it noted that oxidative phosphorylation can occur during anaerobic respiration. Fourth, the question 'Does oxidative phosphorylation occur in chemosynthesis?' was asked. Figure 11 depicts ChatGPT's response. https://chat.openai.com/share/7db89d8c-87e0-4f4a-83c1-94feba1de477.

When Fig. 11 is examined, it is noted that oxidative phosphorylation does not occur in chemosynthesis. Besides, 'Why does oxidative phosphorylation not occur in anaerobic respiration?' was asked. Figure 12 depicts ChatGPT's response.

When Image 12 is examined, it is observed that ChatGPT's response is insisted upon. Also, the question 'Are you sure of your answer?' was asked. Figure 13 depicts ChatGPT's response.

When Fig. 13 is examined, it is observed that ChatGPT's response is still insisted upon. Fifth, the question 'In which metabolic processes do chemophosphorylation occur?' was asked. Figure 14 depicts ChatGPT's response. https://chat.openai.com/share/579df106-e2b6-47a2-a0e6-5f54fdf004ce.

When Fig. 14 is examined, ChatGPT noted that chemophosphorylation occurs in two main metabolic processes: cellular respiration and photosynthesis. Besides, 'Why does chemophosphorylation occur in these metabolic processes?' was asked. Figure 15 depicts ChatGPT's response.

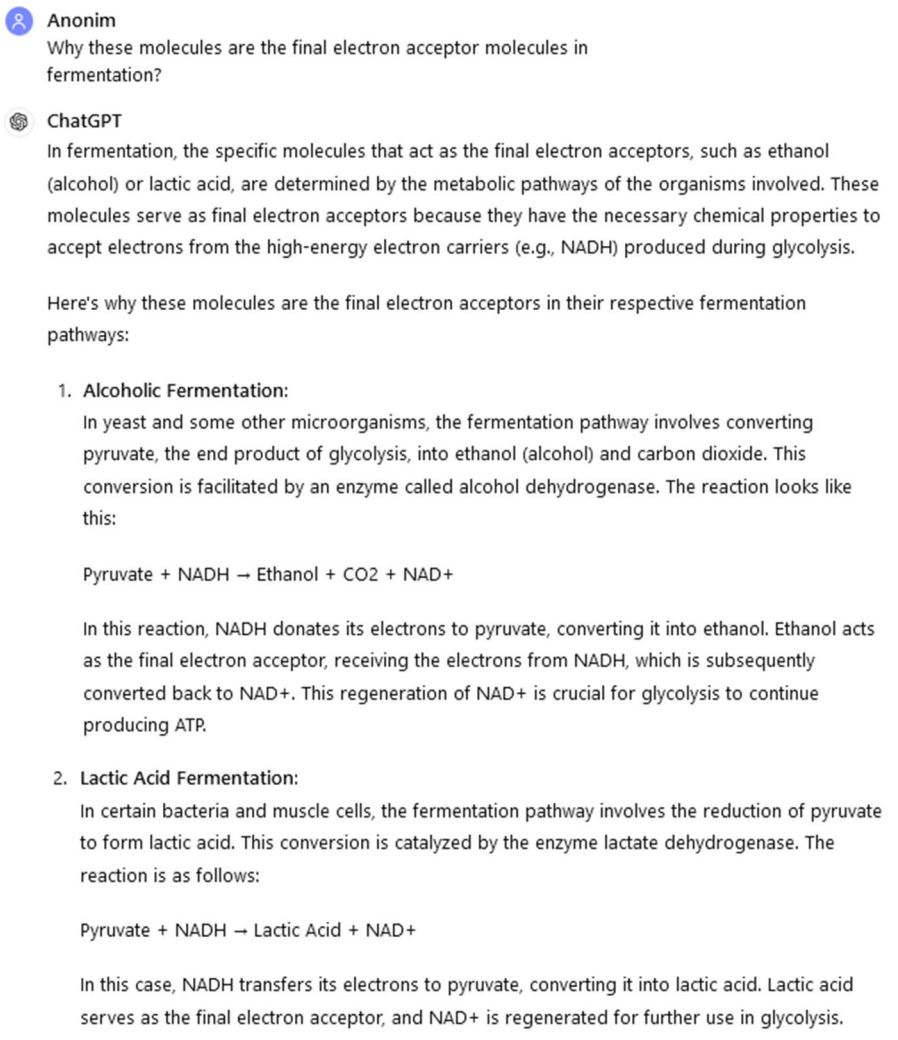


Fig. 6 Why these molecules are the final electron acceptor molecules in fermentation

When Fig. 15 is examined, it is observed that ChatGPT's response is insisted upon. Also, the question 'Are you sure of your answer?' was asked. Figure 16 depicts ChatGPT's response.

When Fig. 16 is examined, it is observed that ChatGPT's response is still insisted upon.

2.2 Data Analysis

Analyzed data were scrutinized by a team comprising three faculty members, one chemistry and two biology. Additionally, two other faculty members, one from chemistry and the other from biology were assigned to oversee and verify the findings'

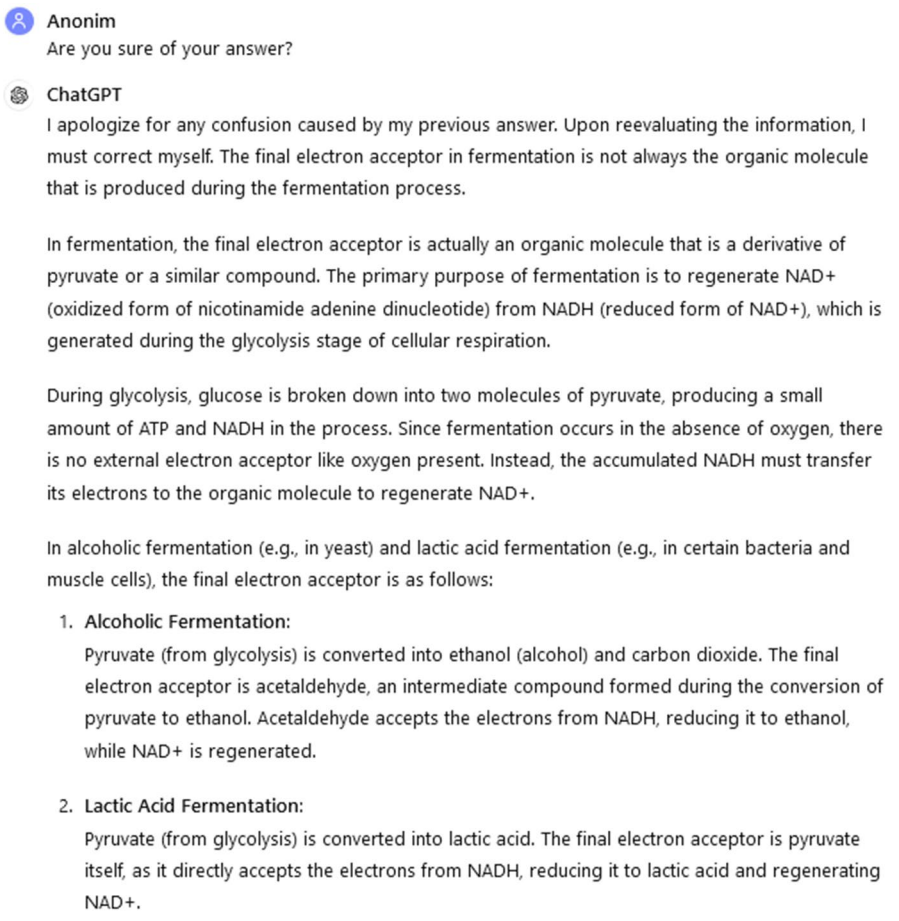


Fig. 7 Are you sure of your answer?

scientific accuracy and explanatory aspects. Current university-level chemistry and biology textbooks widely used internationally are utilized as references to assess the answers provided by ChatGPT. Scientific sources used are:

- Biochemistry (Berg et al., 2002),
- (Denniston et al., 2004).
- Lehninger Principles of Biochemistry (Nelson & Cox, 2008).
- Biological Science (Freeman et al., 2014).
- Life: The Science of Biology (Sadava et al., 2014).
- Campbell Essential Biology (Simon et al., 2017).
- Biology of Microorganisms (Madigan et al., 2019).
- Life: The Science of Biology (Hillis et al., 2020).
- Campbell Biology (Urry et al., 2021).

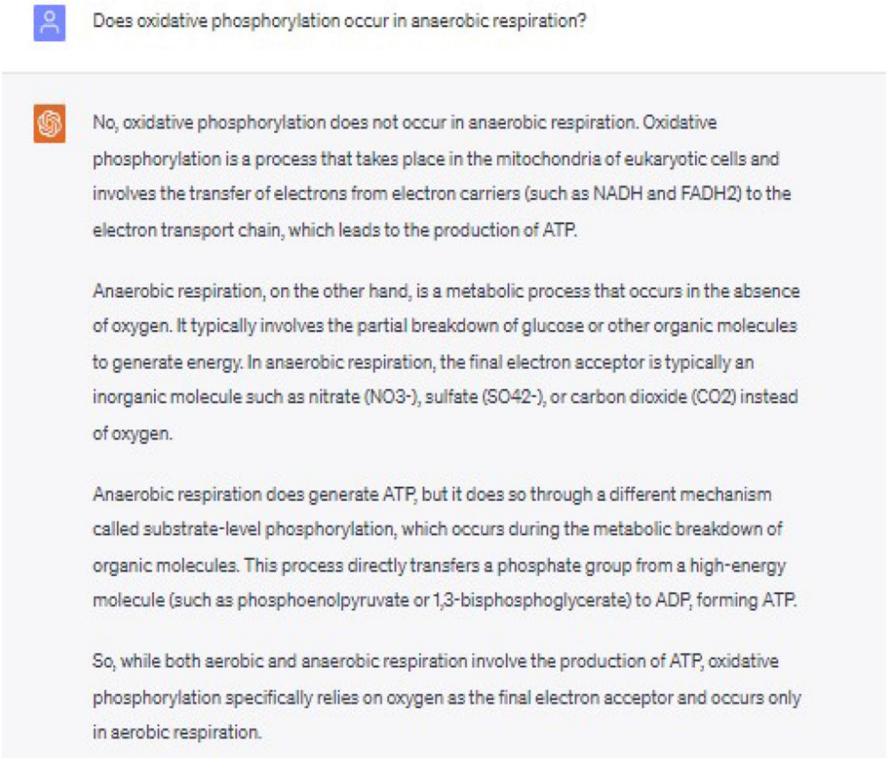


Fig. 8 Does oxidative phosphorylation occur in anaerobic respiration?

3 Findings

The responses of ChatGPT to common misconceptions about energy metabolism in the cell were examined, and the findings are given in Table 2.

When Table 2 is examined, it is seen that ChatGPT provided scientifically incorrect answers to the five questions asked. Besides, when asked the reason for ChatGPT's answer, it is seen that ChatGPT insisted on giving the wrong answers. Following prompts for certainty, the AI's performance was evaluated. It provided scientifically correct answers to the first two questions, partially correct answers to the third, and consistently offered invalid solutions for the remaining questions.

4 Discussion and conclusions

It has become apparent that the responses generated by ChatGPT contain inaccuracies and omissions, underscoring the importance of scrutinizing such AI-generated content, especially within a specific discipline (Dahlkemper et al., 2023; Fergus et al., 2023). This study sets the stage for a broader discussion on the reliability of AI in producing correct, factual, and comprehensive information (Bitzenbauer, 2023). Duda et

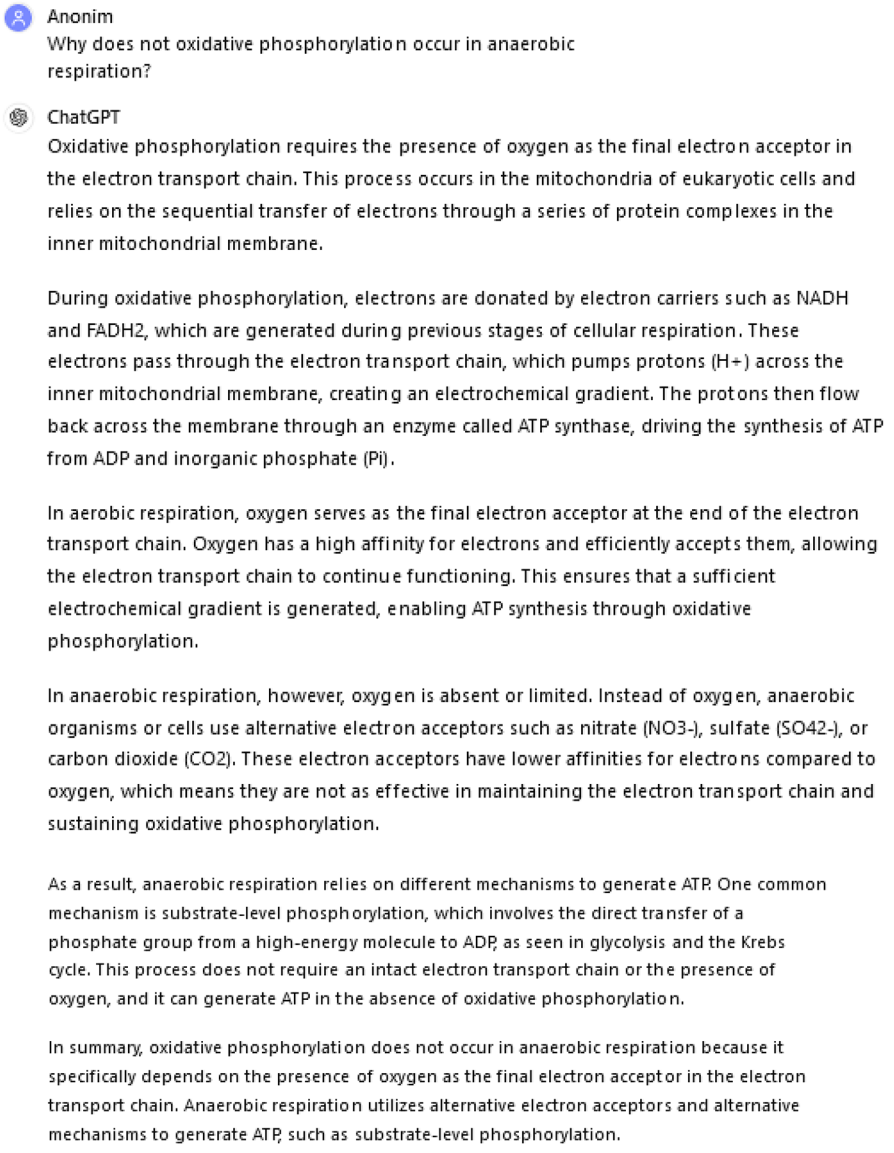


Fig. 9 Why does not oxidative phosphorylation occur in anaerobic respiration?

al. (2020) discovered that students who took the biotechnology course might generate misconceptions about fermentation. Adıgüzel & Yılmaz (2020) determined that undergraduate students have misconceptions about fermentation, anaerobic respiration, and oxidative phosphorylation. Cakır et al. (2002) emphasized that students have misconceptions about cellular respiration concepts. Scott (2005) mentioned common misconceptions regarding aerobic and anaerobic energy expenditure. Jena (2015) has detected that misconception concerning mitochondrial oxidative phosphorylation.

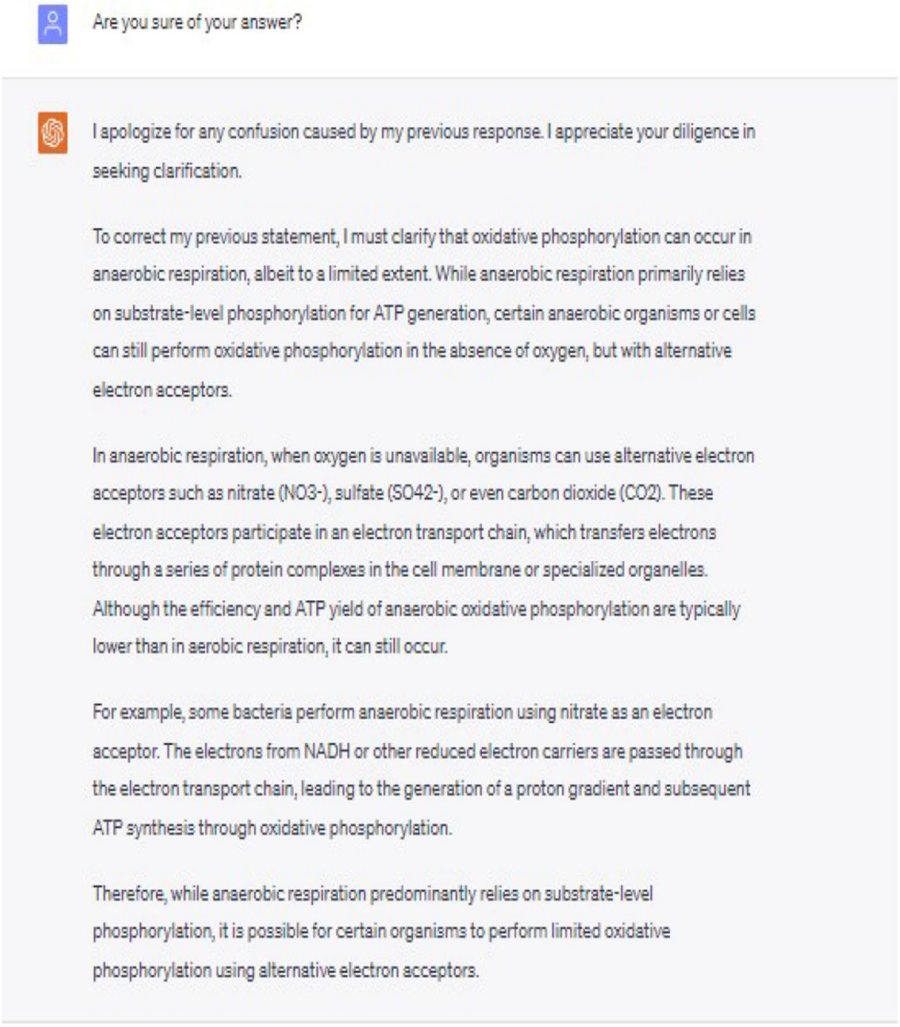


Fig. 10 Are you sure of your answer?

These misconceptions can stem from a variety of sources, such as teachers (Moodley & Gaigher, 2019), textbooks (Novitasari et al., 2019; Gündüz et al., 2019), and technological tools (Acar-Sesen & Ince, 2010). Yılmaz et al., (2019) found that social media led to misconceptions in science teachers. Meel and Vishwakarma (2020) raised concerns about information inflation in social media and the internet, including invalid scientific knowledge (Dev & Bhatnagar, 2020). Considering that people spend a considerable amount of time in their daily lives on the Internet and that the use of the Internet has increased after the pandemic (Lin, 2020), misinformation is likely to disseminate and might become a misconception.

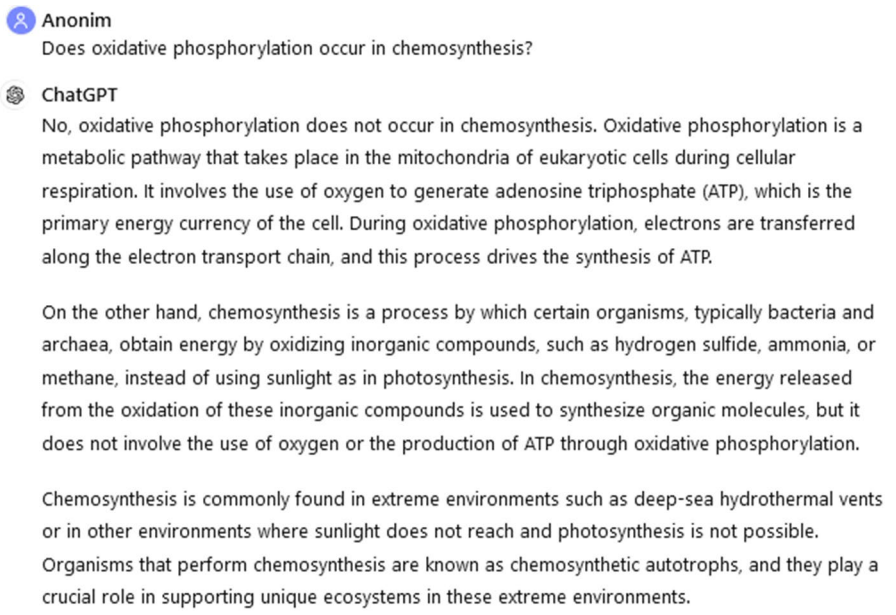


Fig. 11 Does oxidative phosphorylation occur in chemosynthesis?

There are studies on the potential and positive aspects of ChatGPT in the literature (Biswas, 2023; Baidoo-Anu & Owusu Ansah, 2023; Frieder et al., 2023; Surameery & Shakor, 2023; Zhu et al., 2023). Education can benefit from the responsible and ethical application of artificial intelligence technologies such as ChatGPT (Kasneci et al., 2023). Typically, ChatGPT produces responses that are both clear and prompt. Particularly noteworthy is the format of its answers to binary questions, starting with 'Do/Does' or 'Is/Are'; ChatGPT consistently initiates its responses with either 'Yes' or 'No.' So, we can say that ChatGPT's answer is definitive. Hill-Yardin et al. (2023) mentioned that the ChatGPT is fast and straightforward, generating 500 words in less than two minutes. Manohar and Prasad (2023) used ChatGPT to write the academic article in their study. As a result of the research, they concluded that ChatGPT can produce clear and understandable text in some form.

Aside from this potential, it may also present us with invalid information from the database. The problem is caused by information inflation in the database used, not directly by the ChatGPT software. ChatGPT is trained on an unlabeled text dataset, like that used by Wikipedia and many other websites (Floridi & Chiriatti, 2020). The limitation of ChatGPT is that it can only generate text based on the input it gets and has no access to additional data or the ability to browse the Internet (Deng &Lin, 2022). So, we can find scientific incorrect and missing statements in ChatGPT's responses. Mogali (2023) found that ChatGPT gave inconsistent and invalid information to some questions about anatomy. Some research has determined that ChatGPT generated fake citations for bibliographies (Baidoo-Anu & Owusu Ansah, 2023;

Anonim

Why does not oxidative phosphorylation occur in chemosynthesis?

ChatGPT

Oxidative phosphorylation does not occur in chemosynthesis because they are two different metabolic processes that involve different mechanisms and utilize different sources of energy.

1. Source of Energy:

- Oxidative phosphorylation occurs during cellular respiration in eukaryotic cells and relies on the oxidation of organic molecules, like glucose, that come from the breakdown of carbohydrates, fats, and proteins. The energy released during the breakdown of these organic molecules is used to transport electrons through the electron transport chain and generate a proton gradient, which ultimately drives ATP synthesis.
- Chemosynthesis, on the other hand, involves the oxidation of inorganic compounds like hydrogen sulfide, ammonia, or methane. These inorganic compounds serve as the energy source for the synthesis of organic molecules by certain bacteria and archaea. In this process, energy is released through chemical reactions involving the oxidation of these inorganic compounds, but it is not used to generate a proton gradient for ATP synthesis.

2. Location:

- Oxidative phosphorylation takes place in the mitochondria of eukaryotic cells, which are membrane-bound organelles responsible for energy production in the cell.
- Chemosynthesis occurs in specific bacteria and archaea that have specialized biochemical pathways to convert inorganic compounds into organic molecules. It does not involve mitochondria or the same cellular machinery as oxidative phosphorylation.

3. Electron Donors and Acceptors:

- In oxidative phosphorylation, the electron transport chain utilizes oxygen as the final electron acceptor, leading to the production of water as a byproduct.
- In chemosynthesis, different electron donors and acceptors are used, depending on the specific inorganic compounds involved. For example, hydrogen sulfide can serve as an electron donor and be oxidized to sulfur, while other inorganic compounds may have different electron acceptors.

Overall, oxidative phosphorylation and chemosynthesis are distinct processes that have evolved to utilize different energy sources and perform different functions in different types of organisms. While oxidative phosphorylation is a vital process for energy production in eukaryotic cells, chemosynthesis plays a critical role in supporting life in unique ecosystems where sunlight is not available.

Fig. 12 Why does not oxidative phosphorylation occur in chemosynthesis?

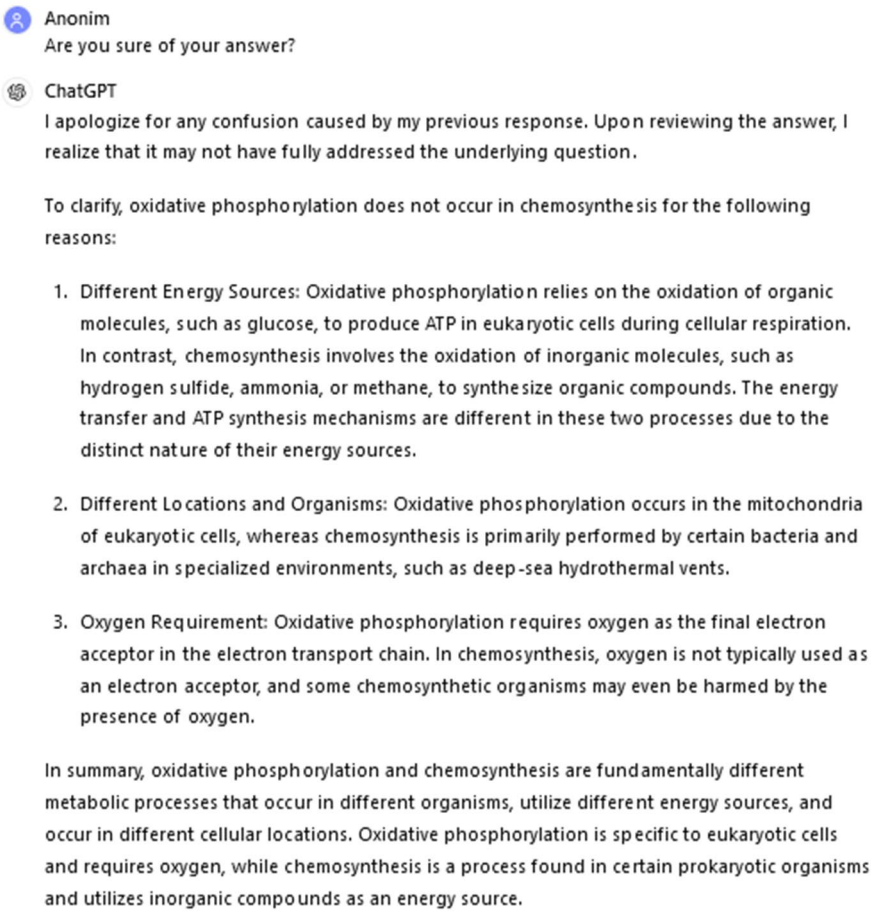


Fig. 13 Are you sure of your answer?

King, 2023; Szabo, 2023). Wittmann (2023) emphasized that when questioned for details and references, ChatGPT struggled and made various inconsistent statements.

Improving ChatGPT's accuracy in answering scientific questions, especially domain-specific ones often met with conceptual misunderstandings, involves several strategies. Some suggestions for developing ChatGPT might be domain-specific fine-tuning, enhanced data training, expert feedback incorporation, enriched contextual database, and collaboration with the scientific community (Rice et al., 2024). By implementing these strategies, AI developers can enhance ChatGPT's capability to handle domain-specific scientific questions more accurately, making it a more reliable tool for educational and research purposes. Improving the correctness of answers from AI in response to scientific questions significantly hinges on the art of prompt engineering—meticulously crafting questions to guide the AI's domain-specific response (Korzynski et al., 2023). A question's clarity, specificity, and rel-

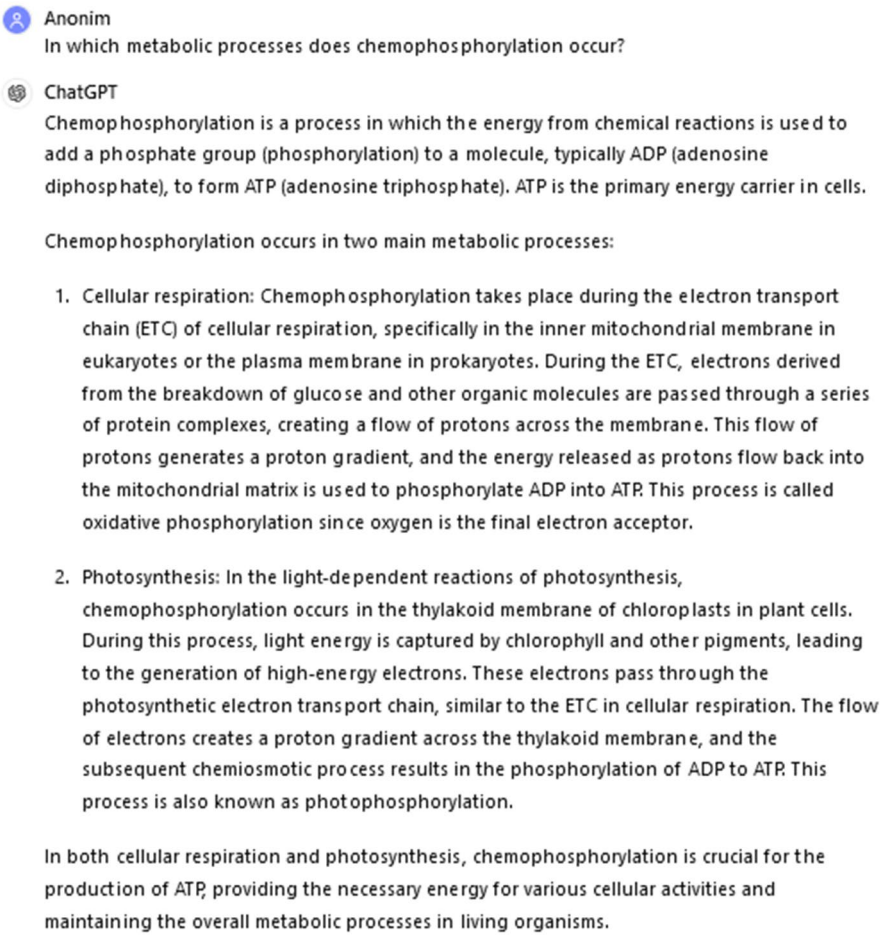


Fig. 14 In which metabolic processes do chemophosphorylation occur?

evance directly influence the AI's ability to process it, making it essential to articulate inquiries with care (Okonkwo & Ade-Ibijola, 2021). By being domain-specific and using relevant scientific concepts, questioners can sharply define the scope and context of their question, enabling the AI to fetch and generate ideas and concepts that closely align with the intended search. Incorporating precise scientific and domain-specific terminology and providing context help mitigate misconceptions and incorrect answers (Bozkurt & Sharma, 2023). It's also important to ask one question at a time and clarify the desired depth of explanation, whether seeking a brief overview or a detailed analysis of the related scientific problem. This level of specificity in questioning improves the correctness and relevance of responses. Besides, follow-up questions can refine and clarify initial answers. The continuous development of scientific knowledge and, in many cases, the possibility of multiple valid perspectives

Anonim
Why does chemophosphorylation occur in these metabolic processes?

ChatGPT
Chemophosphorylation occurs in cellular respiration and photosynthesis because it serves as a critical mechanism for capturing and storing energy in the form of ATP. Both cellular respiration and photosynthesis are energy-requiring processes, and ATP acts as the primary energy currency in cells. Here's why chemophosphorylation is essential in these metabolic processes:

1. Cellular respiration:
   Cellular respiration is a series of metabolic reactions that break down glucose and other organic molecules to produce ATP. The overall process can be summarized in three main stages: glycolysis, the citric acid cycle (Krebs cycle), and the electron transport chain (ETC).

During glycolysis and the citric acid cycle, some ATP is directly generated through substrate-level phosphorylation, where a phosphate group is transferred directly to ADP from a phosphorylated intermediate. However, these initial ATP production steps are relatively limited in terms of the overall ATP yield.

The most substantial production of ATP occurs during the electron transport chain, which is the final step of cellular respiration. As electrons derived from glucose and other organic molecules pass through the protein complexes of the ETC, a proton gradient is generated across the inner mitochondrial membrane. This proton gradient creates a form of potential energy.

Chemophosphorylation occurs in the ETC when the protons flow back into the mitochondrial matrix through the enzyme ATP synthase. ATP synthase harnesses the energy from this proton flow to phosphorylate ADP, creating ATP. This process is known as oxidative phosphorylation because it occurs in the presence of oxygen, which serves as the final electron acceptor in the ETC.

2. Photosynthesis:
   Photosynthesis is the process by which plants, algae, and some bacteria convert light energy into chemical energy, specifically glucose, and other organic molecules. It occurs in two main stages: the light-dependent reactions and the light-independent reactions (Calvin cycle).

During the light-dependent reactions, light energy is absorbed by chlorophyll and other pigments in the thylakoid membranes of chloroplasts. This energy excites electrons, which are then passed through the photosynthetic electron transport chain. As in cellular respiration, this electron transport generates a proton gradient across the thylakoid membrane.

Chemophosphorylation occurs during the light-dependent reactions when the proton gradient drives ATP synthase to phosphorylate ADP into ATP. This process is known as photophosphorylation.

In summary, chemophosphorylation occurs in cellular respiration and photosynthesis because it enables the efficient production and storage of ATP, which is essential for powering cellular activities and maintaining the energy balance in living organisms. ATP provides the necessary energy for various cellular processes, including biosynthesis, active transport, muscle contraction, and nerve impulse transmission, among many others.

Fig. 15 Why does chemophosphorylation occur in these metabolic processes?

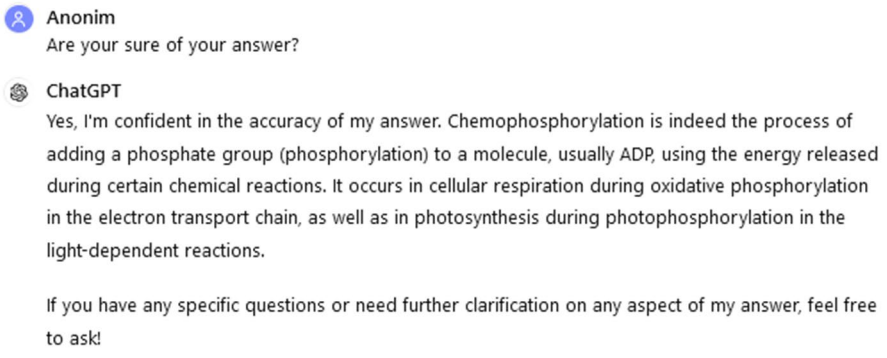


Fig. 16 Are you sure of your answer?

on an answer further enriches the engagement with AI. Prompt engineering emerges as a critical skill in the effective use of AI for scientific questioning, emphasizing the need for clear, contextually rich, and well-structured questions to extract the most accurate and insightful answers.

Ultimately, ChatGPT's capabilities are limited in providing scientifically rigorous responses. To obtain accurate and appropriate answers, it is imperative to pose comprehensive and detailed inquiries that facilitate a more precise and informed response. Scholars and researchers must acknowledge that ChatGPT harbors certain misconceptions and consequently only constitutes a somewhat dependable and scientifically validated resource.

Table 2 Statements in ChatGPT's responses and scientific explanations

Number of questions	Statements from ChatGPT's responses	Accuracy of the response	Scientific explanations
1a.	'*Fermentation is a type of anaerobic respiration*'	Incorrect	Fermentation is when some cells produce ATP by oxidizing organic fuel without using oxygen. However fermentation is not a type of anaerobic respiration (Nelson & Cox, 2008; Urry et al., 2021; Sadava et al., 2014).
1a. 1b.	'*Anaerobic respiration is a metabolic process that occurs in the absence of oxygen, and fermentation is one of the pathways by which cells can carry out anaerobic respiration*' '*Fermentation is considered anaerobic respiration because it occurs in the absence of oxygen*'	Incorrect	Two general mechanisms enable some cells to produce ATP by oxidizing organic fuel without using oxygen: anaerobic respiration and fermentation. The electron transport chain operates in anaerobic respiration, which occurs in some prokaryotic organisms living in anaerobic environments. However, oxygen is not used as an electron acceptor at the end of the chain. In fermentation, there is no electron chain and an organic molecule such as pyruvate or acetaldehyde serves as the final electron acceptor. Although fermentation occurs under anaerobic conditions, it is not called anaerobic respiration because it does not have an electron transport system and uses organic substances as the final electron acceptor (Urry et al., 2021; Sadava et al., 2014).
1c.	'*I apologize for any confusion caused. Upon reevaluating my response, I see that there is a need for clarification*' '*Fermentation itself is not a form of respiration. Respiration is the process by which cells generate energy from organic molecules, such as glucose, by utilizing an electron transport chain and an external electron acceptor. Respiration can be aerobic (in the presence of oxygen) or anaerobic (in the absence of oxygen)*'	Correct	These statements are scientifically correct (Urry et al., 2021; Sadava et al., 2014).
2a-2b	'*Ethanol acts as the final electron acceptor*' '*Lactic acid is the final electron acceptor*'	Incorrect	In ethanol fermentation, the final electron acceptor is acetaldehyde, not ethanol (Urry et al., 2021: p.180). In lactic acid fermentation, the final electron acceptor is pyruvate, not lactic acid (Urry et al., 2021: p.180; Freeman et al., 2014: p.173; Simon et al., 2020: p.136–137; Hillis et al., 2020: p.187–188).

Table 2 (continued)

Number of questions	Statements from ChatGPT's responses	Accuracy of the response	Scientific explanations
2c	*'In fermentation, the final electron acceptor is actually an organic molecule that is a derivative of pyruvate or a similar compound'* *'Alcoholic Fermentation*: *Pyruvate (from glycolysis) is converted into ethanol (alcohol) and carbon dioxide. The final electron acceptor is acetaldehyde'* *'Lactic Acid Fermentation*: *Pyruvate (from glycolysis) is converted into lactic acid. The final electron acceptor is pyruvate'*	Correct	These statements are scientifically correct (Urry et al., 2021: p.180; Freeman et al., 2014: p.173; Simon et al., 2020: p.136–137; Hillis et al., 2020: p.187–188).
3a.	*'Oxidative phosphorylation does not occur in anaerobic respiration'*	Incorrect	Oxidative phosphorylation does occur in anaerobic respiration (Urry et al., 2021; Sadava et al., 2014). Oxidative phosphorylation is the end result of a sequence of energy transformations known as cellular respiration or just respiration in general (Berg et al., 2002).
3a.	*'Oxidative phosphorylation is a process that takes place in the mitochondria of eukaryotic cells and involves the transfer of electrons from electron carriers (such as NADH and FADH2) to the electron transport chain, which leads to the production of ATP'*	Incomplete	Oxidative phosphorylation is a process that takes places in the mitochondria and chloroplast of eukaryotic cells. In addition, it occurs in the membranes of prokaryotic cells (Madigan et al., 2019; Nelson & Cox, 2008; Sadava et al., 2014).
3b.	*'Oxidative phosphorylation requires the presence of oxygen as the final electron acceptor in the electron transport chain'* *'Anaerobic respiration relies on different mechanisms to generate ATP. One common mechanism is substrate-level phosphorylation, which involves the direct transfer of a phosphate group from a high-energy molecule to ADP, as seen in glycolysis and the Krebs cycle. This process does not require an intact electron transport chain or the presence of oxygen, and it can generate ATP in the absence of oxidative phosphorylation'*	Incorrect	Oxidative phosphorylation is the process of producing ATP using energy from the redox reactions of the electron transport chain (Berg et al., 2002; Denniston et al., 2004). Cellular respiration technically refers to both aerobic and anaerobic activities. In aerobic respiration, oxygen is at the conclusion of the electron transport chain, but in anaerobic respiration, other inorganic or organic molecules might be employed as the ultimate electron acceptor (Urry et al., 2021; Sadava et al., 2014; Madigan et al., 2019).

Table 2 (continued)

Number of questions	Statements from ChatGPT's responses	Accuracy of the response	Scientific explanations
3c.	*'Oxidative phosphorylation can occur in anaerobic respiration, albeit to a limited extent' and 'although the efficiency and ATP yield of anaerobic oxidative phosphorylation is typically lower than in aerobic respiration, it can still occur.'*	Incomplete	This response was deemed to be partially adequate. Anaerobic respiration occurs in many bacterial and archaeal species. Inorganic materials such as sulfur (S^0), nitrate (NO_3^-), sulfate (SO_4^{2-}) and organic materials such as fumarate can be used as the final electron acceptor. In aerobic respiration, where 1 mol of glucose is used as a substrate, 30 or 32 ATP is generated depending on the cell type, whereas in anaerobic respiration, a very similar quantity of ATP is obtained, but not as much, depending on the organism type (Urry et al., 2021; Sadava et al., 2014; Madigan et al., 2019; Simon et al., 2020; Mader & Windelspecht, 2018). Aerobic metabolism is significantly more productive than anaerobic metabolism (Denniston et al., 2004).
4a.	*'No, oxidative phosphorylation does not occur in chemosynthesis. Oxidative phosphorylation is a metabolic pathway that takes place in the mitochondria of eukaryotic cells during cellular respiration. It involves the use of oxygen to generate adenosine triphosphate (ATP), which is the primary energy currency of the cell. During oxidative phosphorylation, electrons are transferred along the electron transport chain, and this process drives the synthesis of ATP'* *'In chemosynthesis, the energy released from the oxidation of these inorganic compounds is used to synthesize organic molecules, but it does not involve the use of oxygen or the production of ATP through oxidative phosphorylation'*	Incorrect	ChatGPT made two separate scientific mistakes in this statement. The first is that oxygen will not be used in chemosynthesis, and the other is that oxidative phosphorylation does not occur. The electron transport chain functions during chemosynthesis in various prokaryotic organisms. In these chains, SO, SO^{4-}, NO^{3-}, O_2 can be used as the final electron acceptor. ATP is synthesized by oxidative phosphorylation, thanks to the proton motive force produced during electron transport (Madigan et al., 2019: p.131).

Table 2 (continued)

Number of questions	Statements from ChatGPT's responses	Accuracy of the response	Scientific explanations
4a.	*Chemosynthesis is commonly found in extreme environments such as deep-sea hydrothermal vents or in other environments where sunlight does not reach and photosynthesis is not possible. Organisms that perform chemosynthesis are known as chemosynthetic autotrophs, and they play a crucial role in supporting unique ecosystems in these extreme environments.*	Incomplete	Chemosynthesis is specific only to some prokaryotic organisms. In this process, energy obtained from the oxidation of inorganic chemicals such as H_2S, NH_3, or Fe^{2+} is used as an energy source, and compounds such as CO_2, HCO^{3-} are used as a carbon source (Urry et al., 2021). Organisms that perform chemolithotrophic reactions are called chemolithotrophs. Various inorganic compounds can be oxidized, for example gaseous hydrogen (H_2), hydrogen sulfide (H_2S), ammonia (NH_4^+) and ferrous iron (Fe^{2+}). Related groups of chemolithotrophs typically specialize in the oxidation of a group of related inorganic compounds, and so are "sulfur" bacteria, "iron" bacteria, "nitrifying" bacteria, so on (Madigan et al., 2019: p.114). Organisms that can use inorganic chemicals as electron donors are called chemolithotrophs. Examples of common inorganic electron donors include H_2S, H_2, Fe^{2+} and NH_4^+ (Madigan et al., 2019: p.131). The electron transport chain is involved in the process of chemosynthesis. A proton gradient is formed during the transfer of electrons from electron donor inorganic compounds from the electron transport chain to the final electron acceptor molecules. ATP is synthesized in accordance with the chemiosmotic mechanism (oxidative phosphorylation). Oxidative phosphorylation is the process of producing ATP from a proton-motive force formed by electron transport of electrons from organic or inorganic electron donors (Madigan et al., 2019: p.137).
4b.	*Oxidative phosphorylation does not occur in chemosynthesis because they are two different metabolic processes that involve different mechanisms and utilize different sources of energy.* *Source of Energy*: *Oxidative phosphorylation occurs during cellular respiration in eukaryotic cells and relies on the oxidation of organic molecules, like glucose, that come from the breakdown of carbohydrates, fats, and proteins.*	Incorrect	ChatGPT still insists that its answer is correct at this stage. Another misconception that arises here is that it assumes that oxidative phosphorylation only occurs in eukaryotic cells. However, oxidative phosphorylation can occur in eukaryotes as well as in some bacteria and archaea.

Table 2 (continued)

Number of questions	Statements from ChatGPT's responses	Accuracy of the response	Scientific explanations
4b.	*Chemosynthesis, on the other hand, involves the oxidation of inorganic compounds like hydrogen sulfide, ammonia, or methane. These inorganic compounds serve as the energy source for the synthesis of organic molecules by certain bacteria and archaea. In this process, energy is released through chemical reactions involving the oxidation of these inorganic compounds, but it is not used to generate a proton gradient for ATP synthesis.*	Incorrect	There are very important scientific mistakes in this statement. In this process, inorganic compounds act as electron donors. As these electrons are transferred in the electron transport chain, a proton gradient is created on both sides of the membrane's plasma membrane. ATP is synthesized during the influx (diffusion) of protons through ATP synthase. This ATP is used during the synthesis of organic matter from inorganic carbon compounds (such as CO_2, CO^{3-}) in the other part of chemosynthesis (Madigan et al., 2019; Urry et al., 2021).
4c.	*'To clarify, oxidative phosphorylation does not occur in chemosynthesis for the following reasons:'* *'The energy transfer and ATP synthesis mechanisms are different in these two processes due to the distinct nature of their energy sources'* *'Oxidative phosphorylation occurs in the mitochondria of eukaryotic cells'* *'Oxygen Requirement: Oxidative phosphorylation requires oxygen as the final electron acceptor in "the electron transport chain'* *'In summary, oxidative phosphorylation and chemosynthesis are fundamentally different metabolic processes that occur in different organisms, utilize different energy sources, and occur in different cellular locations. Oxidative phosphorylation is specific to eukaryotic cells and requires oxygen, while chemosynthesis is a process found in certain prokaryotic organisms and utilizes inorganic compounds as an energy source'*	Incorrect	ChatGPT suggests that oxidative phosphorylation and chemosynthesis occur in different organisms. This statement is scientifically incorrect. Because ATP produced by oxidative phosphorylation is used during chemosynthesis. Again, ChatGPT reports that oxidative phosphorylation is specific to eukaryotic cells and requires oxygen. This statement is also scientifically incorrect. Because oxidative phosphorylation also occurs in aerobic processes where oxygen is used as the final electron acceptor and in anaerobic processes where other final electron acceptors are used instead of oxygen (Madigan et al., 2019; Nelson & Cox, 2008; Sadava et al., 2014; Urry et al., 2021).

Table 2 (continued)

Number of questions	Statements from ChatGPT's responses	Accuracy of the response	Scientific explanations
5a.–5b.	*'Chemophosphorylation is a process in which the energy from chemical reactions is used to add a phosphate group (phosphorylation) to a molecule, typically ADP (adenosine diphosphate), to form ATP (adenosine triphosphate). ATP is the primary energy carrier in cells'* *'Chemophosphorylation occurs in two main metabolic processes*: *Cellular respiration, Photosynthesis'* *'Chemophosphorylation occurs in cellular respiration and photosynthesis because it serves as a critical mechanism for capturing and storing energy in the form of ATP. Both cellular respiration and photosynthesis are energy-requiring processes, and ATP acts as the primary energy currency in cells. Here's why chemophosphorylation is essential in these metabolic processes'*	Incorrect	There is no such thing as chemophosphorylation in scientific works. The literature includes the concepts of phosphorylation, substrate-level phosphorylation, oxidative phosphorylation, photophosphorylation, and dephosphorylation. Photophosphorylation: The process of producing ADP from inorganic phosphate and ADP by means of chemiosmosis using the proton-driven force created by the thylakoid membrane of the chloroplast or the cell membrane of some prokaryotes during the light reactions of photosynthesis. Oxidative phosphorylation: The production of ATP using energy from the redox reactions of the electron transport chain. Substrate-level phosphorylation: It is the event of creating ATP by directly transferring the phosphate group from an intermediate to ADP in the catabolism event. Phosphorylation and dephosphorylation: Adding a phosphate group to a molecule is called phosphorylation, and removing phosphate groups from a molecule is called dephosphorylation (Hillis et al., 2020: p.223–224; Madigan, 2019: p.129–131; Nelson & Cox, 2008: p.567; Raven & Johnson, 2002: p.162; Urry et al., 2021: p.151–152; Urry et al., 2021: p.169). Although the term chemophosphorylation is not included in scientific sources, it is a conceptual misconception that refers to ATP produced by oxidative phosphorylation during chemosynthesis and used in high school textbooks and supplementary textbooks used by teachers and students preparing for exams.

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Data availability All data obtained were analyzed using a free AI platform available on the internet. Different researchers can obtain similar answers by asking the same questions. All the questions used in this study have been provided, and screenshots of all the answers received are available to researchers.

Declarations

Ethical approval In this study, human interaction has not been foreseen. The manuscript has not been submitted to more than one journal for simultaneous consideration. The submitted work is original and has not been published elsewhere.

Informed consent In this study, human interaction has not been foreseen.

Statement regarding research involving human participants and/or Animals.
Human interaction has not been foreseen in this study.

Consent to participate Human interaction has not been foreseen in this study.

Consent to Publish All authors have provided full consent for the article's publication.

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Authors and Affiliations

Rıdvan Elmas[1] · Merve Adiguzel-Ulutas[2] · Mehmet Yılmaz[2]

✉ Merve Adiguzel-Ulutas
merveadiguzel@gazi.edu.tr

[1] Department of Mathematics and Science Education, Afyon Kocatepe University, Afyon, Türkiye

[2] Department of Mathematics and Science Education, Gazi University, Ankara, Türkiye