

Point-by-Point Response to Reviewer 1_Edward McGowan

General comments

I strongly believe this is a great manuscript that draws attention to popular types of media that non-geologists can easily encounter in the public domain. It is therefore important to understand how geology is represented in these media. Video games have been covered in several papers in the past few years, but this manuscript makes the reader consider other media forms, especially those other than film/TV.

The manuscript was well written, and the author, who is clearly a PTCG collector, considered many of the key aspects about the PTCG during their research, such as focusing only on English cards to avoid missing other language-exclusive artworks, and to make the dataset more manageable. They clearly put a lot of effort into analysing the data and presented it clearly.

I do, however, have some concerns about the content of the manuscript, such as whether it is plausible enough to consider that PTCG collectors would use AI to identify minerals in the artwork, especially when it is so rare for a card to include a mineral. Perhaps the AI aspect would be more appropriate as its own manuscript, investigating how accurately they perform against popular media forms (e.g. stills from movies, or in comic books as well). Furthermore, the final summary points and conclusion feel rushed and leave the reader lacking in their understanding of why this research is truly important.

Response

The author sincerely thanks the reviewer for the encouraging comments and thoughtful suggestions. The reviewer's familiarity with both geoscience and the PTCG has greatly improved the quality of this manuscript, particularly through comments regarding the practical use of the cards and their educational implications.

The author fully agrees that most collectors appreciate the artistic quality and fantasy setting rather than geological accuracy. This study explores the potential of PTCG as a science communication resource. In educational settings, learners without geological

training may naturally become curious about the illustrated minerals and use AI tools as an accessible starting point.

Therefore, the AI analysis serves as an educational case study. It acts as an objective proxy to reveal how stylization obscures diagnostic features, demonstrating that current AI should be used to encourage scientific reasoning rather than definitive identification. To address the reviewer's final concern, the **Discussion (Section 4.4)** and **Conclusion (Section 5)** have also been substantially expanded to better explain the broader significance of the study, including its implications for science communication and practical educational applications.

Specific comments

Does the author truly believe that there is a significant number of PTCG collectors who would use AI to identify minerals within the artwork? As a geologist and PTCG collector myself, I have never once considered the accuracy of the illustrations on the cards, nor thought to use AI to identify them. In my experience of over 20 years in the hobby, collectors are more likely to appreciate nice artwork and not question the realism of it. This can potentially even go as far as most collectors recognising it is depicting a fantasy world and therefore it is acceptable for the artwork to not be accurate.

Response

The author completely agrees that collectors appreciate the artwork's fantasy elements without questioning its geological realism. However, these unconstrained illustrations provide a unique opportunity to quantify the public's cultural image of a "crystal."

The AI analysis was introduced to test this stylization objectively. Because artists range from hyper-realistic to highly abstract, modern AI acts as a standardized machine-vision baseline to quantify exactly which diagnostic geological features are lost across different art styles. **Section 4.4 (paragraph 5, line 304)** has been revised to emphasize using these cards to stimulate critical thinking about media representations, confirming that scientific accuracy is unnecessary for the artwork's success.

If Pokémon cards that contain minerals only account for 1% of the entire English printed roster, how many ‘mineral cards’ would the average collector actually have/see? Taking a reasonable number of 2000 in a collection, that would equate to someone only having 20 ‘mineral cards’. This seems very low and might not have a significant impact on their understanding of true mineral structures. Furthermore, is it not possible collectors are able to understand that the artwork contains fantasy elements given they depict fantasy monsters.

Response

The author agrees that mineral-themed cards represent only a small fraction of the PTCG catalogue and are unlikely to substantially influence the average collector's understanding of mineralogy. Likewise, most collectors understandably recognize these illustrations as part of a fantasy world rather than realistic geological representations.

However, this study does not aim to evaluate their passive influence on collectors. Instead, it investigates the educational potential of this curated collection when intentionally used for science communication. Although mineral-themed cards account for only about one percent of all released cards, the dataset now contains 223 illustrations spanning nearly three decades, providing a diverse resource for classrooms, museums, and outreach activities.

Accordingly, **Section 4.4 (paragraph 1 and 2)** has been revised to clarify that the significance of this dataset lies in its educational application rather than its influence on the average collector.

Ice was identified by a human expert (the author) as the most common mineral (Figure 4). However, it is barely spoken about within the text. Instead, the text focuses mainly on the other five identifiable minerals (e.g. quartz, calcite, and zircon). What is ice's significance to the results in terms of accuracy of illustrations, reasonable environments etc? Either explain the results regarding ice or remove it from the criteria/data.

Response

The author agrees that the original manuscript did not adequately explain the significance of ice. Accordingly, **Section 4.2 (paragraph 1, line 227)** has been expanded to discuss this category in greater detail.

Ice represents the most confidently identified mineral because its interpretation is supported by both crystal morphology and contextual evidence. This makes it an ideal reference for evaluating whether the universal crystal template persists even when mineral identity is well constrained. Despite this high confidence, MCA shows that ice forms the most tightly clustered group, and more than half of the inferred ice crystals resemble tetragonal prisms, although terrestrial ice (ice Ih) crystallizes almost exclusively in the hexagonal system. These findings provide some of the strongest evidence for the proposed universal crystal template.

The implications of this research (Sections 4.3 and 5) feel very rushed. The results strongly support the author's conclusion that mineral depiction within PTCG is oversimplified. However, the reasoning provided for this is lacking, only stated as influenced by gemstone markets and museum displays. The author does not appear to consider the fact that many PTCG illustrators likely lack a geological background and that some art styles may purposely choose not to take inspiration from realism or detailed accuracy (e.g. Shinji Kanda or Hyogonosuke). The author does allude to the latter in Section 4.1 but not considered again. After 30 years of producing Pokémon cards, the hobby is arguably more popular than ever, and a lack of accurately illustrated minerals does not appear to dissuade collectors. Therefore, is the Pokémon Company not justified in its approach to continue to “reproduce this selective imagery”? It would be great to expand further on these considerations.

Response

Section 4.4 (paragraphs 3 and 5) has been substantially expanded to address these points. The revised discussion now recognizes that most Pokémon illustrators are professional artists rather than geologists and that highly stylized crystal imagery is an understandable artistic convention. The manuscript also explicitly acknowledges that the Pokémon Company is fully justified in prioritizing artistic appeal over scientific realism. Rather than criticizing this approach, the study examines how these shared

artistic conventions shape public perceptions of minerals and how they can be used for geoscience communication.

Continuing the last point, the author simply says “geoscience educators might consider addressing these media representations”, which I agree with. However, it would be great to also expand on this further and provide examples. This would improve the significance of the manuscript by providing educators with potential starting points that they could adapt into their lessons.

Response

Section 4.4 (paragraph 2, line 289) has also been expanded to provide practical examples for geoscience education. The revised discussion suggests using Pokémon cards as visual "hooks" in classrooms, museums, and outreach activities by comparing stylized illustrations with real mineral specimens to discuss mineral identification, geological environments, and artistic conventions. The manuscript also notes that these illustrations are freely available through public online card databases, making them readily accessible for educational use.

Technical comments

- Section 2.1, Line 39: How did you reach a total of 19,875 cards? I cannot find an online reference to this total anywhere, even on Pikawiz. Also, it is worth noting that some artworks are reprinted, not just for mini-sets but in full sets (e.g. “Professor Elm’s Training Method” has the same artwork used in E-series base, Unseen Forces, and Dragon Frontier). Therefore, this total would not represent unique artworks.

Response

The original number (19,875) referred to the total number of card entries listed in the *Pikawiz* database. Because many cards, particularly Promo and mini-set releases, reuse existing artwork, reporting an exact total is potentially misleading. Accordingly, the manuscript (**Section 2.1, paragraph 1, line 50**) has been revised to state that approximately 20,000 card entries were manually screened.

- Section 2.1, Line 40: Did you include Promo cards or other mini-sets such as the McDonalds or Trick & Trade sets as well? Most of the latter reprint existing artwork and count it as a new card by including a new holo pattern or stamp.

Response

Yes, Promo cards and mini-sets, including the McDonald's and Trick & Trade series, were included in the initial screening. However, most are reprints of existing artwork with different holo patterns or stamps. Only cards containing new artwork were retained as unique entries. **Section 2.1 (paragraph 1, line 54)** has been revised to explicitly state this exclusion criterion.

- Section 2.1, Line 40: Was the Pikawiz database cross-referenced with any other database to confirm all cards were accounted for?

Response

The original submission relied solely on the *Pikawiz* database. To address this point, a second manual screening was conducted in July 2026 by cross-referencing *Pikawiz* with the *Pokellektor* database (<https://www.pokellektor.com/sets>), which also included the recent Chaos Rising set. The two databases showed a high degree of consistency, with only minor discrepancies among promotional cards. The methodology (**Section 2.1, paragraph 1, line 53**) has been updated accordingly.

- Section 2.1, Line 43: How confident are you that the coverage and list you came up with was “exhaustive”? Did you manually screen the cards once or more times? A quick search on Google and Bulbapedia shows there are several cards from the HGSS series that include evolution stones (e.g. HGSS base Arcanine #1), and there are at least three different artworks for “Old Amber”. From my interpretation of your methodology, these cards agree with your criteria.

Response

The reviewer is correct that the original claim of an "exhaustive" dataset based on a single screening was overstated. A second manual screening using both databases identified 21 additional mineral-themed artworks, including four previously overlooked "Old Amber" illustrations.

Regarding the Evolution Stones (e.g., Arcanine HGSS), these objects were intentionally excluded because this study focuses on environmental geological backgrounds created by illustrators, rather than pre-defined, franchise-specific items or gameplay mechanics (e.g., Evolution Stones and Terastal phenomena). **Section 2.1 (paragraph 2, line 61)** has been revised to clarify these inclusion and exclusion criteria to ensure a strict focus on natural environmental depictions.

- Section 2.1, Line 45: “distinct geological formations” is a very broad term that could capture many different elements that do not appear to be included, such as volcanoes. Also, how can you accurately identify a “limestone cave”? You later state on Line 98 that it is not possible to identify the lithology of host rocks. The definitions you describe in the Appendix (Line 285: Major rock types) are much better. I would recommend using them in the main text body as well as the Appendix.

Response

The term "distinct geological formations" has been replaced with broader environmental categories, and the unsupported reference to a "limestone cave" has been removed from the main text (**Section 2.1, paragraph 2, line 60**). To improve readability, the detailed visual diagnostic criteria have been relocated to Appendix B, while Section 2.1 now contains only the essential methodological description.

- Section 2.1, Line 48: “202 cards”, again I believe there are more.

Response

Following a second manual screening using two independent databases, the final dataset has been expanded from 202 to 223 unique artworks (**Section 2.1, paragraph 3, line 64**).

- Section 2.1, Line 48: “84 different artists”. I would be interested to know later in the manuscript if there are particular artists who like to include minerals in their artwork, or if there is a general average of 2-3 cards per artist.

Response

Thank you for this valuable suggestion. **Appendix A3** now includes a new analysis of illustrator distributions. The updated dataset contains 223 mineral-themed cards created by 85 illustrators, with an average of 2.6 cards per illustrator. However, approximately 70% of illustrators contributed only one or two cards, whereas six illustrators account for 29% of the dataset. Comparison with each illustrator's total published Pokémon cards further suggests that, with the exception of 5ban Graphics, several illustrators contributed mineral-themed artwork more frequently than expected. These results have been added to **Appendix A3** and briefly summarized in **Section 3.1 (paragraph 2, line 121)**. (Table and Figure preserved in response).

Table. Top six illustrators contributing mineral-themed PTCG artwork.

Artist	Mineral-themed cards	Total Pokémon cards	Percentage (%)
5ban Graphics	12	1777	0.68
Kouki Saitou	11	669	1.64
Kagemaru Himeno	11	669	1.64
Midori Harada	10	360	2.78

Artist	Mineral-themed cards	Total Pokémon cards	Percentage (%)
Masakazu Fukuda	10	487	2.05
Ryo Ueda	10	472	2.12

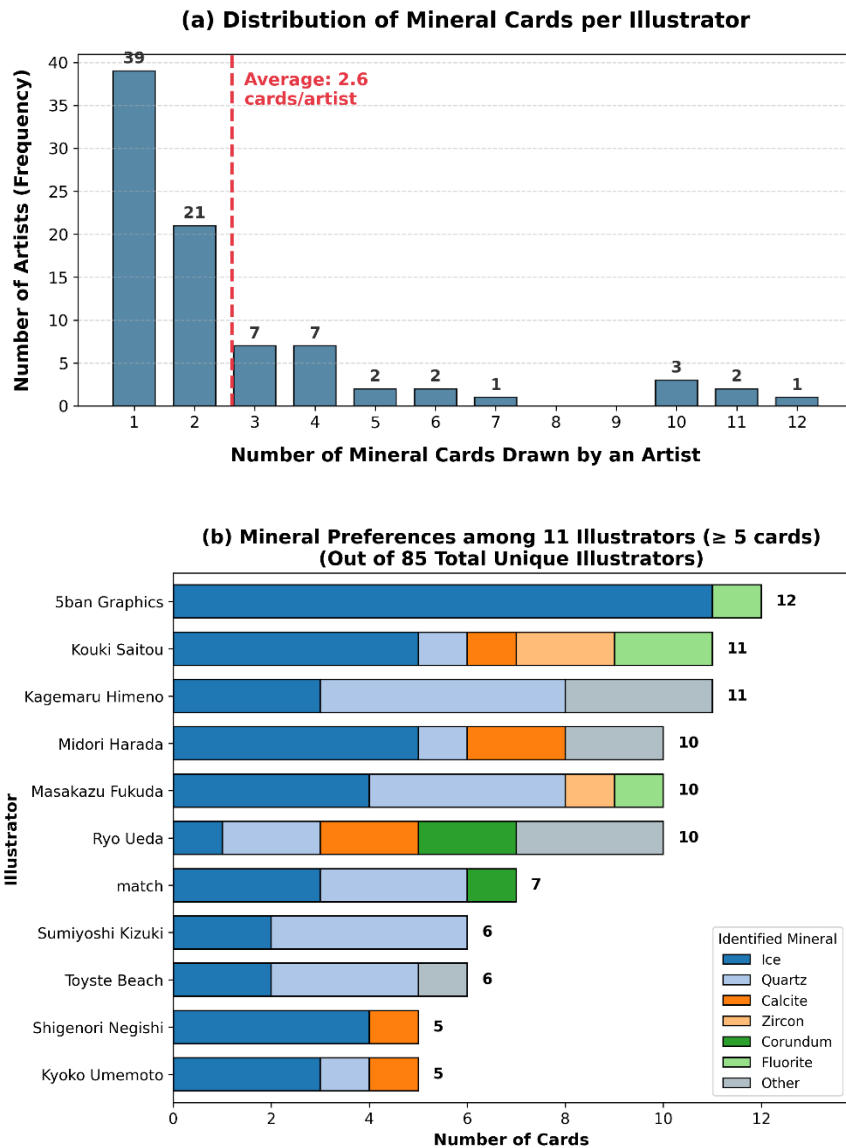


Figure. Illustrator distributions and mineral preferences. (a) Distribution of the number of mineral-themed cards designed per artist across all 85 identified illustrators. (b) Mineral type preferences among the top 11 illustrators who have each designed five or more mineral-themed cards.

- Section 2.3, Line 85: How does ChatGPT and Gemini fair against identifying real minerals?

Response

The author thanks the reviewer for this important suggestion. To determine whether AI misidentifications resulted from artistic stylization rather than limited mineral recognition, a new baseline experiment using 43 photographs of real mineral specimens was conducted.

The results showed high identification accuracy, with Gemini achieving 95%, ChatGPT 86%, and the specialized application 74%. A summary has been added to **Section 3.2 (paragraph 2, line 64)**, and the full methodology and results are provided in the new **Appendix C** and **Supplementary Excel dataset**.

- Section 2.3, Line 86: Why was Rock Identifier used as the specialised app? Did it have the most positive reviews?

Response

Rock Identifier was selected because of its wide public accessibility and market dominance. At the time of this study, it was the highest-ranked geoscience application on both the Google Play Store and Apple App Store, with more than 10 million downloads and average ratings above 4.6 stars. As this study evaluates AI tools likely to be used by the general public, **Section 2.3 (paragraph 2, line 107)** now explicitly explains this selection rationale.

- Section 3.1, Line 96: Provide an exact number/ percentage of how many minerals occurred in caves and that were fully exposed.

Response

The requested values have been added to **Section 3.1 (paragraph 3, line 127)**.

- Section 3.1, Line 101: It is not explained or alluded to until the Appendix how the length of minerals are calculated. I would recommend including a short explanation earlier in the text, such as in Section 2.1, so that readers are aware.

Response

A brief explanation has therefore been added to **Section 3.1 (paragraph 4, line 130)**, stating that the official Pokémon heights were used as standard scale bars.

- Section 3.2, Line 135: Provide an exact percentage for the rock-scanning app to highlight how much less this agreed compared to the other AI apps.

Response

Section 3.2 (paragraph 3, line 169) has been revised to include the exact agreement rate (12%) for the specialized rock-scanning application.

- Section 3.2, Line 139: Provide one or two examples of “fantasy elements” identified in the cards.

Response

Section 3.2 (paragraph 4, line 172) now includes representative examples of fantasy elements to clarify this description.

- Figure 3 caption: Reference back to Section or Appendix as to what the “13 categorical features” are so that readers can quickly look at the figures and know where to go to in the text.

Response

The **Figure 3** caption has been revised to direct readers to **Appendix B**, where the 13 categorical features are described in detail.

- Figure 3 caption: Include a mention about the Benzécri correction in the main body of the text.

Response

A brief explanation of the Benzécri correction and its purpose has been added to **Section 3.2 (paragraph 1, line 160)** before referring readers to the Appendix.

- Section 4.1, Line 167: Has the lack of paragenesis and focus on rare crystals been reported in other forms of media? If so, it would be good to cite that here.

Response

The author searched the available literature but found no previous quantitative study specifically examining the scarcity of paragenetic mineral assemblages or the dominance of rare crystal morphologies in popular media.

- Section 4.1, Line 179: Artists may also be more familiar with particular mineral types or lack true awareness of other forms. I highly suspect many illustrators only have a limited background in geology, if any background at all.
- Section 4.1, Line 182: Again, it may not be an “artistic shortcut” if the illustrators are not fully aware of other crystal types. If their knowledge of minerals comes from limited geological media such as museums (as mentioned in the text), then they are only replicating what they have seen themselves.

- Section 4.1, Line 192: Again, perhaps the illustrators are unaware of other minerals such as amphibole or mica.

Response

The author agrees with the reviewer's interpretation. **Section 4.1 (paragraph 3)** has been revised to avoid implying that illustrators intentionally simplified mineral forms. Instead, the discussion now emphasizes that most Pokémon illustrators likely have limited geological training and are reproducing mineral imagery commonly encountered through museums, commercial mineral markets, books, and other popular media. Accordingly, the scarcity of amphibole, mica, and other common rock-forming minerals is interpreted as reflecting limited public familiarity rather than deliberate artistic choice. The Discussion also acknowledges that scientific realism is not required for the success of the PTCG, while noting that greater mineralogical diversity could further enhance its value for science communication without compromising artistic creativity.

- Section 4.1, Line 190: What do the statistics show when considering ice only?

Response

Section 4.2 (paragraph 1, line 227) now includes a dedicated discussion of ice. Although terrestrial ice crystallizes in the hexagonal system, more than half of the inferred ice illustrations depict tetragonal prisms. This provides strong evidence that even the most confidently identified mineral conforms to the same generalized crystal template.

- Section 4.2, Line 213: “Failure” is a strong word for saying this manuscript is investigating the minerals of a ‘fantasy world’. Numerous aspects of the Pokémon world are impossible in the real world. Why can minerals not be included in this?

Response

The author agrees that "failure" was unnecessarily strong for a fantasy setting. The manuscript (**Abstract and Section 4.3, paragraph 1, line 263**) has been revised to replace this wording with the more neutral terms "analytical limitation" and "discrepancy," clarifying that the discussion concerns the limitations of current AI rather than the artwork itself.

- Section 4.2, Line 216: "A human *could* recognize". A trained geologist such as the author is capable of easily doing this, but could a non-geologist?

Response

The author agrees that this interpretation requires geological training rather than representing the perspective of a typical player. The manuscript (**Section 4.3, paragraph 2, line 267**) now specifies that this observation refers to a geologically trained observer. **Section 4.4 (paragraph 2, line 289)** further explains how such knowledge gaps create opportunities for science communication by encouraging comparisons between stylized illustrations and real geological environments.

- Section 4.3, Line 235: Hyper-realistic digital illustrators such as 5ban Graphics and REND are relatively new to illustrating cards. Although their work is hyper-realistic, they have yet to illustrate cards with minerals. Perhaps with time, new cards will appear.

Response

Section 4.4 (paragraph 4, line 297) has been revised to acknowledge that the visual template identified in this study reflects patterns observed over nearly three decades of PTCG illustrations. The discussion also recognizes that future artists and evolving illustration styles may naturally introduce greater mineralogical diversity.

- Section 4.3, Line 240: Explain further why this is beneficial and how educators could use the PTCG as effective communication tools.

Response

Section 4.4 (paragraph 2, line 288) has been expanded to provide practical examples for educators. The revised discussion suggests using Pokémon cards as visual "hooks" in classrooms, museums, and outreach activities, where comparisons with real mineral specimens can encourage observation, geological reasoning, and critical evaluation of media representations.

- Section 5, Line 245: What about ice? This was the most common mineral identified.

Response

The **Conclusion (Section 5, paragraph 1, line 316)** now explicitly discusses ice as the most frequently identified material, emphasizing that even this well-constrained category conforms to the same generalized crystal template.

- Section 5, Line 247: It has been previously mentioned AI also fall short in their ability to correctly identify minerals correctly for several other reasons such as not being able to consider surrounding environmental aspects or struggling with 2D image identification.

Response

The concluding paragraph (**Section 5, paragraph 1, line 318**) has been revised to summarize the multiple factors contributing to AI misclassification, including limited contextual reasoning, difficulty interpreting crystal symmetry, and reliance on simplified visual features.

- Figure A1, Graph: The Scarlet & Violet series ended in September 2025 and was succeeded by Mega Evolutions, which is likely to continue well into 2027.

Response

The figure (**Fig. A1**) has been updated accordingly.

- Appendix B1, Line 293: “Official *average* heights” were used. Individual Pokémon, even from the same species, can drastically range in size. Also, where were the measurements acquired? Were they written on the cards or from Bulbapedia, for example?

Response

The measurements were obtained from the Bulbapedia database (https://bulbapedia.bulbagarden.net/wiki/Main_Page), which compiles official Pokédex data. Although individual Pokémon may vary in size, the official species height provides the most objective and standardized reference available. Appendix B1 has been revised to clarify the data source and scaling protocol (**Appendix B1, line 393**).

Point-by-Point Response to Reviewer 2

general comments

The manuscript analyzed 202 mineral illustrations from the Pokémon Trading Card Game between 1999 and 2026. Multiple Correspondence Analysis was applied to identify the visual characteristics and found the contrasts with natural systems. Comparisons between human interpretation and AI-based identification further showed that these stylized images lack sufficient diagnostic information for consistent classification.

Response

The author sincerely thanks the reviewer for the positive evaluation of this study. The encouraging comments regarding its quantitative approach and contribution to mineral science communication are greatly appreciated.

specific comments

This article calls for the importance of popular science education on minerals and conducted in-depth quantitative analysis of the minerals in Pokémon Trading Card Game, which are good. It would be even better if further suggestions could be given on how to enhance professionalism.

Response

The author thanks the reviewer for this valuable suggestion. To address this point, **Section 4.4 (paragraph 4, line 297)** has been substantially expanded to provide more concrete recommendations for enhancing the scientific value of future PTCG illustrations while preserving artistic freedom. The revised discussion suggests that illustrators could draw inspiration from museum collections, mineral markets, and geological references, while collaboration with mineralogists and economic geologists could introduce scientifically recognizable mineral properties, crystal habits, and geological settings. It also provides practical examples of how these illustrations can be incorporated into classrooms, museum exhibitions, and science outreach activities.

technical corrections

Because the mineral images in the Pokémon Trading Card Game are more artistic than practical, is it fair to use them test AI tools?

Response

The author thanks the reviewer for this important comment and agrees that Pokémon card illustrations are artistic creations rather than scientifically realistic depictions. Accordingly, the purpose of introducing AI was not to evaluate the artistic quality of the illustrations, but to investigate how current AI systems interpret the same stylized images that educators or learners may use in future science communication activities.

To clarify this rationale, a baseline experiment using photographs of real mineral specimens has been added (**Appendix C**). The results show that current AI systems identify real minerals accurately but perform much less consistently on stylized illustrations, indicating that the observed discrepancies primarily reflect the limited diagnostic geological information in the artwork rather than a general inability of AI to recognize minerals.

The Discussion (**Section 4.3, paragraph 1, line 257**) has also been revised to emphasize that AI serves as a comparative analytical tool for understanding how media-driven visual simplification influences both human and machine interpretation, while providing guidance for future educational applications.