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Analysis of Students' Action Decisions about SDGs Issues in Open Inquiry Activity with Real Open Data

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Abstract: The inquiry-based learning model is an instructional approach tailored to students' exploration of both the natural world and society. By integrating prominent Sustainable Development Goals (SDGs) and leveraging open data, this approach nurtures students' scientific literacy and data analysis proficiencies. In this context, the current study devised an online inquiry learning system named <City Auncel>, enabling students to engage with data and independently delve into socioscientific issues through an open inquiry learning model. The findings underscore that students exhibited a high level of immersion throughout the activity, along with adept data collection and summarization skills.
Keywords: Open-ended inquiry, Inquiry-based learning, Real open data, Action Decisions, Sustainable Development Goals (SDGs)

1. Introduction

<City Auncel> is a web system for inquiry-based learning embedded with real open data, which promotes inquiry learning in students' action decisions towards the Sustainable Development Goals (SDGs). Bangura and Ally (2020) highlighted that online learning has the potential to significantly broaden educational access, thereby contributing to the realization of the SDG's objective of achieving universal education. The main purpose of this study is to promote the inquiry-based learning to the interdisciplinary socioscientific issues. It aims to improve the problem of physical activities' inability to expand knowledge content and course resources in a timely manner. On the contrary, although the <City Auncel> system already has designated data from the real open data, the advantage of online learning allows students to freely explore related knowledge beyond the data offered in the system. Therefore, through promoting scientific literacy and active learning strategies, an inquirybased learning model was developed to encourage students for free exploration of problems, unimpeded collection, analysis and interpretation of exploratory content, and writing their ideas about social issues. In the end, students present their exploration results and content in the system.

This study utilizes the background of socioscientific issues to generate open-ended questions, serving as a guide for students to engage in initial open-ended inquiry activities. The system provides students with various forms of data, such as images, text, and data visualization, to facilitate an in-depth exploration of social science issues related to Taiwan. This allows students to actively explore and discover the complex relationships inherent in social science issues. The purpose of this study is to investigate how students can conduct open-ended inquiries in social science issues and what the content and outcomes of such inquiries are.

2. Related Work

2.1 Inquiry-Based Learning

Inquiry-based learning is a learning method based on problem-solving and exploration. This approach encourages active student engagement in the learning process through steps such as posing questions, gathering data, conducting experiments, analyzing, and evaluating to gain a deeper understanding of the subject matter. According to Prince (2004), inquiry-based learning enhances students' learning motivation and interest, encouraging them to explore the learned knowledge in depth. Banchi and Bell (2008) also suggest that inquiry-based learning is a teaching model designed around students' exploration of the natural world and society, aiming to help them construct their own knowledge by encouraging questioning, investigation, knowledge discovery, and application. Research by Kuhn (2007) indicates the benefits of inquiry-based learning for developing students' critical thinking and problemsolving abilities. It has also been shown to increase students' learning motivation and interest (Blumenfeld et al., 1991; Prince, 2004). However, implementing inquiry-based learning requires teachers to have sufficient time and resources for design and implementation, as well as continuous assessment and adjustment of instructional strategies to ensure that students achieve the learning goals (Banchi & Bell, 2008). While some scholars believe that inquiry-based learning is less effective than direct instruction, in practice, the effectiveness and applicability of inquiry-based learning largely depend on specific contexts and learning objectives, the extent of students' foundational learning skills and background knowledge, and the need for teachers to provide appropriate guidance and support. Therefore, further exploration and research are needed to fully understand the effectiveness and applicability of inquiry-based learning.

Based on the variations in the structure, guidance, and level of student and teacher involvement, inquiry-based learning can be categorized into structured, guided, and open inquiry learning models.

1. Structured Inquiry: Structured inquiry refers to the explicit definition and explanation of learning objectives by the teacher, who provides specific guidance and support to assist students in their inquiries. According to Hmelo-Silver et al. (2007), structured inquiry helps students grasp learning objectives and improves learning outcomes. Furthermore, structured inquiry can enhance students' learning outcomes and efficiency, enabling them to quickly master learning content and skills. However, structured inquiry may limit students' creativity and autonomy in learning (Kirschner et al., 2006).
2. Guided Inquiry: Guided inquiry involves the teacher providing a certain degree of guidance and support while allowing students some autonomy in their investigations. Research by Hung et al. (2005) indicates that guided inquiry helps students discover problems, enhance learning motivation and interest, and engage in interesting and challenging learning activities. Guided inquiry also promotes students' critical thinking and problem-solving abilities. However, guided inquiry may require teachers to invest more time and effort in designing and guiding learning activities.
3. Open inquiry: Open inquiry refers to the teacher not explicitly defining or explaining learning objectives, but instead allowing students to freely explore and discover knowledge. Studies by Hmelo-Silver et al. (2007) show that open inquiry enhances students' autonomy and creativity in learning. Students are free to explore and discover new knowledge, and it helps them develop critical thinking and problem-solving skills. However, open inquiry may require more time and resources to support students' learning.

However, in inquiry-based learning, structured, guided, and open inquiry are commonly used approaches, each with its own advantages, disadvantages, and suitable contexts. According to Kirschner et al. (2006), structured inquiry emphasizes students learning in a structured environment, where teachers provide clear learning objectives, guidance, and detailed learning paths. This approach helps students acquire important knowledge and skills but may limit their creativity and independent thinking abilities.

On the other hand, guided inquiry offers more freedom and flexibility while providing students with appropriate guidance and support. Hung et al. (2005) found that guided inquiry emphasizes students discovering and solving problems during the inquiry process. Teachers provide relatively ambiguous learning objectives and guidance to stimulate students' learning motivation and creativity. This approach enhances students' autonomy and sense of responsibility in learning but may require them to face more challenges and difficulties. According to Lazonder & Harmsen (2016), guided inquiry often leads to higher learning effectiveness because it provides appropriate guidance, making it easier for students to understand the goals and process of inquiry. It is suitable for relatively simple and clear-cut problems.

Lastly, open inquiry is a completely independent learning approach suitable for complex problems that require students to engage in deeper exploration and analysis. Students have the freedom to choose problems and solutions and independently explore and learn during the process. Hmelo-Silver et al. (2007) found that open inquiry can stimulate students' learning interests and motivation, enhance their creativity and independent thinking abilities, as well as improve their autonomy and sense of responsibility in learning (Hung et al., 2005). However, open inquiry may also present challenges and difficulties. It requires students to have sufficient prior knowledge and skills; otherwise, it may lead to poor learning outcomes. Hmelo-Silver et al. (2007) noted that open inquiry can be challenging for students, particularly when they lack the necessary prior knowledge and skills. Therefore, teachers need to provide appropriate support and guidance in open inquiry to help students overcome difficulties and improve learning outcomes.

2.2 Real Open Data

Real open data can facilitate the effective utilization and management of resources. As highlighted by Davies et al. (2017), real open data can provide valuable information on energy, water resources, land use, waste management, and other aspects, thereby assisting governments and businesses in better managing these resources. Governments can gain a better understanding of energy consumption in each region through open data, enabling them to formulate more effective energy-saving policies. Real open data also promotes knowledge sharing and technological innovation. As articulated by Giest et al. (2017), real open data supports communication and collaboration among different knowledge domains, thereby fostering technological innovation and development. For example, open data allows scientists and researchers from various fields to share and utilize data, advancing scientific research. It can even drive sustainable investment and the development of a green economy. Pandey et al. (2017) underscore that real open data can provide information on environmental and social benefits, helping investors and businesses make more informed investment decisions. Additionally, it can promote green industries and innovation, thus propelling the growth of a green economy.

In addition to these issues, open data also has profound social and economic impacts. Firstly, open data can enhance transparency and trust in government and other institutions. Open data can increase public trust in the government, leading to increased public participation and support (Bertot et al., 2010). Secondly, open data can foster innovation and economic growth. Research by Kuk et al. (2016) suggests that open data can generate new business models and employment opportunities, thus promoting economic growth and innovation. Lastly, open data can also facilitate citizen science and social engagement. Wiggins and Crowston (2011) found that open data can enhance citizen science and social participation, increasing public understanding and involvement in scientific and social issues. It can even help governments and businesses better understand the problems they face and find more effective solutions (Janssen et al., 2012). In urban planning, real open data can provide valuable information on city traffic flow, pollution, water usage, and other aspects, helping urban planners gain a better understanding of the city's situation and make more informed decisions.

Furthermore, real open data can also promote public engagement and social innovation. Hui et al. (2014) stated that real open data enables the public to have a better

understanding of the operations of governments and businesses, thus facilitating public participation and oversight. Additionally, real open data can foster social innovation, such as through the innovative use of open data for new products and services.

In today's society, sustainable development has become a global issue due to the significant impact of human lifestyles and economic activities on the Earth's environment. To achieve sustainable development, innovation and improvement are required in various fields. In this regard, real open data has been proven to be a highly valuable tool with significant application value and advantages in the context of sustainable development.

However, there are also challenges that need to be addressed, such as privacy and security concerns, as well as potential shortcomings in data quality and reliability. The research of Halevy et al. (2009) found that many open datasets suffer from missing values, errors, and inconsistencies with reality, which can negatively impact data analysis and applications, affecting data effectiveness. Additionally, issues related to privacy and security may lead to the exposure of personal identities and sensitive information, as well as potential misuse. Moreover, open data can potentially have negative social impacts, such as perpetuating racial discrimination and implicit biases. Therefore, effective measures need to be implemented in the application and promotion of real open data to address these issues and achieve more effective and sustainable development.

Although open data is a powerful tool that can play a crucial role in various domains, but there are also challenges and issues that need to be addressed. To maximize the value of open data, efforts should be focused on resolving privacy and security concerns, improving data quality and reliability. Additionally, further exploration is needed to understand the social and economic impacts of open data better, in order to grasp its value and potential more effectively.

2.3 Action Decision

Action decision is a situation that humans often face in daily life, and many scholars have conducted in-depth research on this type of decision-making. For example, Dawes and Corrigan (1974) pointed out that "in action decision-making, individuals typically refer to their experience and knowledge, but at the same time are also influenced by non-rational factors such as emotions, motives, and situations." In other words, when individuals make decisions, they not only consider their own knowledge and experience but also are influenced by non-rational factors such as emotions and motives. In the actual decisionmaking process, people can use various methods. For example, Simon (1956) proposed the concept of "bounded rationality," stating that people only consider local factors when making decisions and cannot consider all possible choices. In addition, people can also use heuristics and rules to simplify the decision-making process (Tversky & Kahneman, 1974).

In the field of education, action decision refers to the action choices made by learners when facing various situations, which is an important process of self-adjustment and reflection for learners. Action decision refers to the action choices made by learners in a specific context and is made after considering multiple factors (Muis et al., 2015). These factors can be the learner's learning goals, understanding of the task, time constraints, learning experience, and so on. Zimmerman and Risemberg (1997) pointed out in their research that learners' action decisions can reflect their learning motivation and learning strategies. At the same time, action decisions can also affect learners' learning outcomes. If learners can choose the most suitable action plan, their learning effect may be better. Helping learners improve their ability to make action decisions is an important teaching goal.

3. Online System Design and Activity Process for Socioscientific Issues

This study focuses on the socioscientific issue of the "Endangered Status of The Leopard Cat," encompassing SDGs 11 (Sustainable Cities and Communities), 13 (Climate Action), and 15 (Life on Land). The study's exploration data primarily originates from the Miaoli area of Taiwan, where the leopard cat's survival and activity rates are relatively high. Students

utilize the <City Auncel> system to access data pertaining to designated land based on information about the leopard cat's endangered status. They gather information from diverse sources to address this socioscientific issue.

The system categorizes the data into five sections (*Figure 1*): (1) Water resources (latest & historical river water quality monitoring data, river distribution, etc.). (2) Land information (1984-2015 land use change, contour lines, terrain distribution, slope, etc.). (3) Introduction to the leopard cat (characteristics, habits, habitat, observed locations, road kill records, etc.). (4) Forestland (forest type and distribution), and (5) Demographics (population distribution, age distribution, etc.).

The online system offers a diverse array of data and records the outcomes of students' explorations, facilitating the review of each student's findings post-exploration. Through the online system, various forms of data presentation are available, including interactive images, text, and statistical data tables. These aids help learners quickly comprehend the activity content and engage in a comprehensive inquiry-based learning process. The insights gained from the inquiry can also be incorporated back into the learning materials.

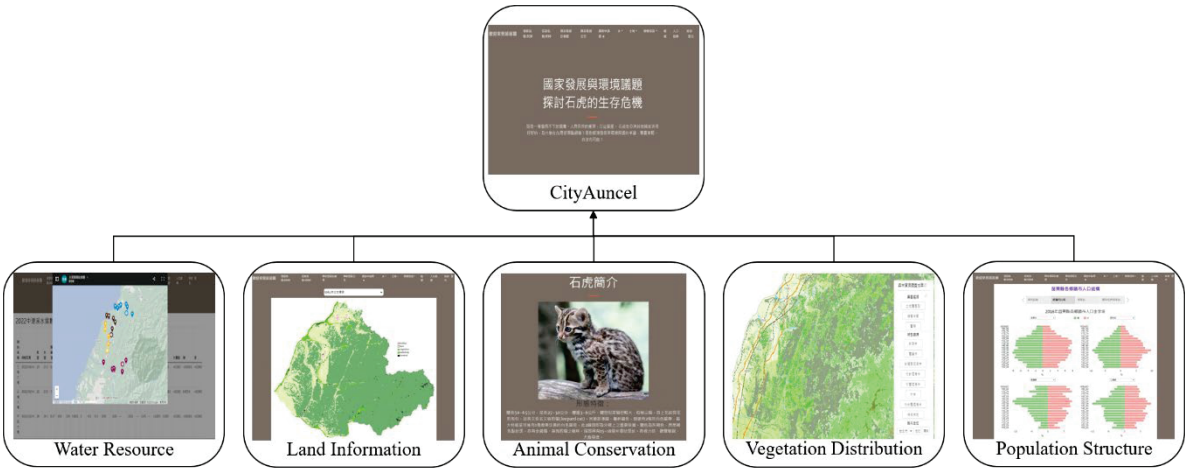

Figure 1. Real Open Data Domains <City Auncel>

This activity is structured around three roles, each representing a country's government, conservation groups, and corporations. Through role-playing, students initially delve into the endangered status of leopard cats and subsequently analyze appropriate regions for development or conservation efforts. They then engage in discussions and coordination to determine potential overlaps between areas earmarked for development and those requiring conservation, ultimately crafting a cohesive national plan. In this activity, students encounter three open-ended questions presented from distinct role perspectives (*Figure 2*). This approach empowers them to engage in open-ended inquiry, fostering the generation of distinct insights into socioscientific matters. Through meaningful discussions and thoughtful reflections, they gain exposure to their peers' research findings and outcomes, thereby enhancing their comprehension of the significance and intricacy inherent in socioscientific issues.

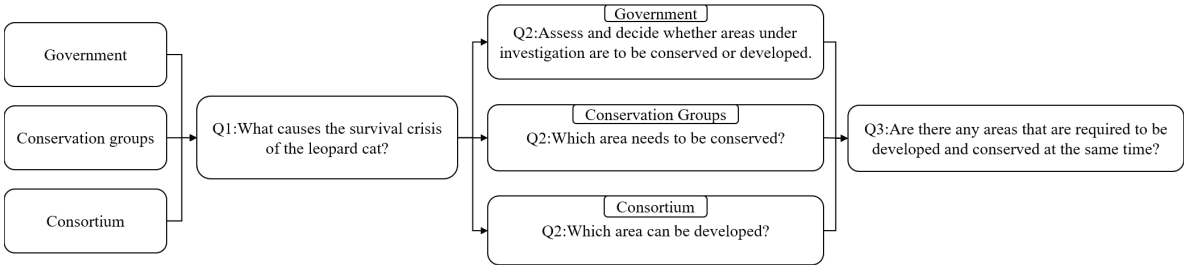

Figure 2. Inquiry of respective role

The activity comprises four stages (*Figure 3*) During Step 1, students receive a 15minute introduction to the activity's theme and system operation. In Step 2, students delve

into answering three open-ended questions: (1) the survival crisis of the leopard cats, (2) identifying suitable areas for development or conservation, and (3) examining whether areas chosen for development and conservation align across different roles. This stage takes approximately 90 minutes. Moving to Step 3, students explore the reasons behind overlapping areas for development and conservation and propose potential solutions. Lastly, Step 4 involves voluntary sharing of exploration content, reflections on the topic, and overall sentiments about the activity.

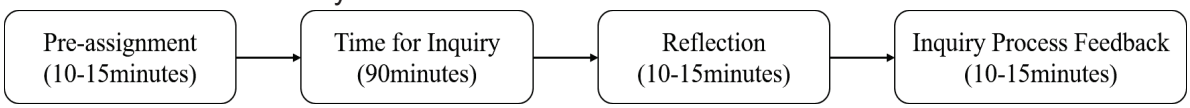

Figure 3. Activity Process

4. Research Design

The study's experimental subjects consisted of students from a university's in-service graduate program in Taiwan. The participants were grouped randomly, with each group comprising 3 students, resulting in a total of 18 students divided among 6 groups. The majority of these students possessed educational and information backgrounds. Their ages ranged from 24 to 50 years on average.

The open-ended inquiry process and the content of <City Auncel> are presented in Table 1. The initial step aims to help students comprehend the issue's significance and the contributing factors to the survival crisis. For this purpose, the question "What causes the survival crisis of the leopard cat?" is posed. In <City Auncel>, students have the opportunity to explore the central topic and pinpoint the factors that have led to the crisis.

The second question caters to the unique inquiries from different roles, specifically addressing the need for conservation or development in certain areas. This question encourages students to generate their own crisis factors, requiring them to focus on their designated roles and explore outcomes that align with their interests as corporations, government representatives, or conservation groups.

The third question is strategically designed to stimulate collaboration and discussions among students. It centers on determining whether any overlap exists between the areas targeted for conservation by conservation groups and those earmarked for development by corporations. To accomplish this, the query "Is there an overlap between areas that can be developed and areas that need to be conserved?" is presented.

Through the formulation of these three open-ended questions, students are prompted to delve deeper into investigating and addressing the issues at hand.

Table 1. *Open Inquiry Model*

Step	Purpose	Question Type	<City Auncel> example
Step 1	Discover Problems	open-ended	What causes the survival crisis of the leopard cat?
Step 2	Solve / Generate Crisis		Which area need to be conserved/developed? Why does it need?
Step 3	Consultations		Is there an overlap between areas that can be developed and areas that need to be conserved? How to solve it?

Considering the previously outlined design of open-ended questions, this study examines students' textual responses to these three inquiries. The hypothesis posits that students derive their answers from the data made available through the system. Table 2 presents analyzed sample sentences extracted from student responses. The categorization of students' answers is structured around five dimensions: (1) Water Resources, (2) Land Information, (3) Animal Conservation, (4) Vegetation Distribution, (5) Population, and (6)

Other Aspects. In cases where a student's writing addresses multiple dimensions, their text is subjected to a multidimensional textual analysis approach.

Table 2 Text Analysis Example

Role	Example Sentences	Data Domain	Multiple or Single
Consortium	Water quality: RPI=7.25, severe pollution (6+10+3+10). Land use map: Mostly developed area. The region is an important habitat for leopard cats.	Water Resources Land Information Animal Conservation	multiple
Consortium	According to water quality detection, the data indicates that the pollution index of the “Nangang Creek Bridge River” reaches a high level of 7.25, classified as severe pollution.	Water Resources	single
Conservation Groups	From the roadkill statistics of leopard cats in various sections of Miaoli County, it can be observed that Section 128 of the county is a high-risk roadkill zone for the leopard cats. Furthermore, based on the highway network map of the Miaoli region, it is evident that this section constitutes an expressway. Consequently, the construction of this expressway would place the leopard cats at a heightened risk.	Land Information Animal Conservation	multiple

5. Results

While exploring the question "What causes the survival crisis of the leopard cat?", 18 students divided into six groups undertook diverse perspectives, yielding 56 distinct inquiry outcomes (Table 3). Upon analyzing and categorizing phrases and statements featured in students' reports, it becomes evident that a significant portion of the students centered their inquiries around water resources, land resources, and animal data.

Upon analyzing the textual results of students' inquiries, it was evident that nearly all students recognized the significant issue of roadkill as a primary contributor to the leopard cats' survival crisis. Moreover, students identified areas affected by water pollution and acknowledged the consequences of historical land development changes on the survival of leopard cats. These factors collectively led to extensive habitat destruction for the leopard cats, resulting in a continual decline in population and worsening living conditions.

However, aspects such as vegetation distribution and population structure were less frequently acknowledged in the students' inquiry outcomes. The researcher of this study suggests that students might have encountered challenges in linking data related to vegetation and population structure with the leopard cats' survival crisis. This discrepancy could arise from the fact that, within the system, issues concerning water resources, land information, and animal data were more immediate and easily discernible matters that could be addressed using accessible data. On the other hand, comprehending the correlation between vegetation and population structure required more intricate connections with other data points. Put simply, students may have identified issues stemming from land development but perhaps did not extend their thoughts to encompass the relationship between these issues and population structure. The same logic applies to vegetation data, where although vegetation holds relevance for the leopard cats' habitat, its connection to the specific question might not have been as apparent.

Consequently, the students' inquiry results indicate that during the discussion phase of the inquiry process, students predominantly emphasized interpreting data tied to pivotal factors. Essentially, within the context of the inquiry question, students gravitated towards interpreting and investigating data directly pertinent to water, land, and animal information. This encompassed addressing concerns such as roadkill, water quality pollution, and modifications in land development. These factors stood out as the most directly influential elements affecting the survival environment of the leopard cats.

Table 3. *Total Frequencies of Inquiry Items in Data Categories*

Data Domain	Total Frequencies of Inquiry Content Items
Water Resources	**13**
Land Information	**17**
Animal Conservation	**21**
Vegetation Distribution	2
Population	3
Total Items	**56**

Regarding the second question, "Which area needs to be conserved/developed?" The outcomes derived from students' inquiries reveal that, upon analyzing content items mentioned in their reports and categorizing them by different roles, the Conservation group generated 23 inquiry results, while the Consortium produced 27, resulting in a total of 50 (refer to Table 4). In comparison to the first question, students' responses to this question exhibit greater depth and diversity. However, the overall focus of inquiry remains aligned with that of the first question, with a higher emphasis on land data and animal information in contrast to other data aspects.

Additionally, when inspecting the outcomes through the lens of role differentiation, students assuming the role of Conservation groups predominantly concentrated on animal data for this question. Most Conservation groups cited areas marked by pronounced leopard cat roadkill and habitat concerns as key areas for conservation.

Conversely, drawing from the outcomes of students in the Consortium role, it becomes apparent that their exploration and explanation of answers to this question unfolded in a more multifaceted manner. Their primary inquiries revolved around geographical location and population distribution driving the tourism sector, among other factors. This diverges from the content of the first question, thereby displaying a lower degree of similarity. Textual analysis outcomes demonstrate that the primary basis for development centered on the convenience of transportation due to geographical location or population distribution. These research results underscore a high level of engagement among students and reveal distinctly varied inquiry focuses based on the roles they undertook.

Table 1. *Differences in Content of the Inquiry*

Data Domain	Conservation Groups	Consortium	Total
Water Resources	4	3	7
Land Information	5	9	**14**
Animal Conservation	10	5	**15**
Vegetation Distribution	4	0	4
Population	0	7	7
Others	0	3	3
Total Items	23	27	50

6. Conclusion

This study developed an online platform <City Auncel> for exploring social issues utilizing real data. Through an inquiry-based learning approach, it aims to foster students' scientific literacy and underscore sustainability concerns tied to the Sustainable Development Goals (SDGs). The platform offers a variety of interactive visualized data. Educators can craft learning materials or activities to facilitate three modes of inquiry-based learning: structured, guided, and open-ended.

Within this study, an open-ended inquiry-based learning model was introduced, affording students the autonomy to explore a range of authentic and open data. Throughout the inquiry-based learning process, spanning from content investigation and data collection to final deduction and interpretation, students construct their own knowledge to address socioscientific issues.

The study's outcomes demonstrate that on the whole, students adeptly executed inquiries using the system. They identified multiple factors contributing to the survival crisis of the leopard cats. Textual analysis unveiled that students' inquiry directions tended to concentrate on key data closely linked to the issue. However, data with weaker associations were less likely to emerge in students' inquiries. This matter warrants further investigation and analysis. Researchers could classify the multidimensional data provided into levels of simplicity, moderate complexity, and challenge, thus better gauging students' inquiry capabilities.

Moreover, whether evaluating the overall inquiry outcomes or individual student inquiries, uneven distributions in data exploration were observed. This suggests that while the data and inquiry questions formulated in this study were open-ended, students' roleplaying potentially constrained their comprehensive data exploration and interpretation. This bias might result from incomplete data exploration dimensions. Despite presenting diverse data for student exploration, the study uncovered skewed outcomes in the broader inquiry process. To broaden students' access to data and information, the relevance of role-playing needs consideration. Alternatively, enhancing interactions and debates among roles could help counteract bias in data exploration.

Nonetheless, the study highlights a high level of engagement among students. Each role exhibited distinct inquiry foci, and students made logical action decisions based on their inquiry findings. However, situations requiring physical coordination and interaction were influenced by real interpersonal relationships, impacting assessment outcomes. From these findings, it's evident that online open-ended inquiry, shaped by role-playing, can guide students' attention toward specific key data while providing them with an immersive learning experience.

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