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From Inquiry to STEM Identity:
A Student-Led IB Mathematics Case Study Using Open Climate Data

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Abstract
This article presents a research-informed educational case study based on a student-led International Baccalaureate (IB) Mathematics Internal Assessment examining the relationship between sea surface temperature (SST) and hurricane frequency in the North Atlantic. The study uses open-access climate data from the National Oceanic and Atmospheric Administration (NOAA), including SST records from Providencia (Colombia), Puerto Rico (United States), and the Azores (Portugal) for the period 1995–1998, together with historical hurricane data from the HURDAT2 database. The analysis applies inferential statistical methods, specifically Pearson correlation and simple linear regression, to explore associations between ocean temperature and cyclonic activity. Although statistical significance is constrained by the short temporal range, the results indicate consistent positive relationships between SST and hurricane frequency, with stronger associations observed in tropical regions, in line with established climatological theory. Beyond the empirical analysis, the study conceptualizes the student-led inquiry as a situated instance of STEM identity development. By formulating a researchable question, engaging with scientific datasets used in professional research, and applying statistical reasoning under conditions of uncertainty, the inquiry positions the student as an active participant in STEM knowledge production. The findings support the integration of authentic data inquiry within secondary mathematics education as a means to promote data literacy, interdisciplinary reasoning, and the development of STEM identity at the secondary education level.

Keywords: *STEM identity; student-led inquiry; International Baccalaureate mathematics; authentic data analysis; climate data literacy.*

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INTRODUCTION

Climate-related extreme events constitute a central focus of contemporary climate science, with tropical cyclones representing one of the most significant sources of environmental risk for coastal and island regions worldwide. In the North Atlantic basin, hurricane formation and intensification are strongly mediated by ocean–atmosphere interactions, particularly sea surface temperature (SST), which regulates the availability of latent heat necessary for cyclogenesis. Extensive climatological research has identified SST thresholds near 26–27 °C as a necessary condition for tropical cyclone development, while positive SST anomalies are associated with increased storm frequency and intensity at interannual and decadal scales (Emanuel, 2005; Webster et al., 2005; Trenberth & Fasullo, 2007; Knutson et al., 2020).

Beyond their relevance for climate science, hurricanes and ocean temperature dynamics provide a robust interdisciplinary context for STEM education. Climate systems integrate mathematical modeling, statistical analysis, physics, oceanography, meteorology, and data science, offering an authentic setting in which quantitative reasoning functions as a tool for scientific inquiry rather than as an abstract academic exercise. Prior research indicates that engaging students with complex, real-world phenomena enhances conceptual

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understanding and supports the transfer of mathematical knowledge to applied scientific contexts (National Research Council, 2012; Boaler, 2016; Honey, Pearson, & Schweingruber, 2014).

The growing availability of open-access scientific datasets has expanded opportunities for authentic data inquiry in secondary and pre-university education. Repositories maintained by institutions such as the National Oceanic and Atmospheric Administration (NOAA) provide students with access to the same empirical data used in professional research, enabling engagement with uncertainty, variability, and methodological decision-making. Studies in STEM education consistently show that interaction with authentic datasets promotes data literacy, statistical reasoning, and critical interpretation skills, particularly when students are positioned as active investigators rather than consumers of predefined results (Wilkerson & Polman, 2016; Lehrer & Schauble, 2015; Konold & Higgins, 2003).

Within this landscape, increasing attention has been directed toward the role of learning experiences in the development of STEM identity. STEM identity is understood as the extent to which learners perceive themselves as legitimate participants in STEM-related practices, encompassing competence, recognition, and epistemic agency within disciplinary contexts (Carlone & Johnson, 2007; Gee, 2000; Hazari et al., 2010). Research suggests that identity formation is closely linked to opportunities for authentic participation in disciplinary practices, including the formulation of research questions, the use of professional tools, and engagement with uncertainty inherent in scientific inquiry (Barton & Tan, 2010; Nasir & Hand, 2008).

The International Baccalaureate (IB) Diploma Programme provides a curricular structure that explicitly supports inquiry-based learning through its Mathematics Internal Assessment (IA). The IA emphasizes independent exploration, real-world application of mathematical tools, and reflective evaluation of methodological limitations. When effectively implemented, this framework enables students to engage in investigations that resemble small-scale research processes, aligning with contemporary calls to position mathematics education within authentic scientific and societal contexts (International Baccalaureate Organization, 2021; Schoenfeld, 2014).

Across educational systems, a continuing challenge in STEM education is how to move beyond procedural mathematics instruction toward meaningful student participation in authentic scientific inquiry. Although inquiry-based learning and STEM identity have been widely discussed, their intersection through student-led mathematical investigations using open scientific data remains an important area for pedagogical examination. The international relevance of this study lies in examining how accessible scientific datasets, student ownership of inquiry, and mentored statistical reasoning can be brought together within a school-based learning experience. While situated in an International Baccalaureate context in Colombia, the case offers an analytical perspective on instructional principles that may be adapted to different curricula, institutional resources, and educational settings. Its contribution is therefore not to establish a universally effective model, but to inform broader international discussions on authentic STEM participation and the educational conditions that may support students' developing disciplinary agency.

This article presents a research-informed educational case study based on a student-led IB Mathematics Internal Assessment conducted at Gimnasio Campestre Los Cerezos (Colombia). The study examines the relationship between sea surface temperature and hurricane frequency in the North Atlantic using open-access climate data. SST records from three strategically selected locations—Providencia (Colombia), Puerto Rico (United States), and the Azores (Portugal)—are analyzed alongside historical hurricane data from NOAA's HURDAT2 database for the period 1995–1998. Inferential statistical methods, including Pearson correlation and simple linear regression, are applied to explore potential associations between ocean temperature and cyclonic activity.

The selection of these locations reflects their position along the Gulf Stream system, enabling a longitudinal perspective from tropical to mid-latitude regions. While the limited temporal scope constrains

statistical inference, the study is intentionally exploratory, prioritizing methodological transparency, interpretative rigor, and educational relevance over definitive climatological claims.

The purpose of this article is twofold. First, it reports the empirical findings of a student-led statistical exploration of SST and hurricane frequency using authentic climate data. Second, it conceptualizes the inquiry as a situated instance of STEM identity development, illustrating how engagement with real scientific datasets and inferential reasoning can position secondary school students as active participants in STEM knowledge production. By documenting the inquiry process in full, the study contributes to research on inquiry-based STEM education and the role of authentic data practices in supporting data literacy, interdisciplinary reasoning, and STEM identity formation at the pre-university level.

The distinctive contribution of this case lies in connecting three dimensions of secondary STEM education: student ownership of scientific inquiry, the use of authentic environmental datasets for mathematical reasoning, and opportunities for epistemic participation associated with STEM identity. Rather than presenting these dimensions as separate educational benefits, the study examines their intersection within a mentored inquiry experience. This perspective offers a context-sensitive analytical basis for discussing how authentic mathematical investigations may support students' participation in STEM practices across different educational settings.

RESEARCH OBJECTIVES

This study is grounded in the analysis of a student-led inquiry conducted within the International Baccalaureate (IB) Mathematics framework, using authentic open-access climate data to explore a real-world scientific phenomenon. Beyond examining an environmental relationship, the research seeks to understand how engagement with professional scientific datasets and inferential statistical methods can support meaningful STEM learning and identity development at the secondary level. Specifically, the study pursues the following objectives:

1. To examine the relationship between sea surface temperature (SST) and hurricane frequency in the North Atlantic using open-access climate data from NOAA and applying inferential statistical methods appropriate for secondary-level mathematics.
2. To examine how a student-led investigation using authentic scientific data illustrates opportunities for data literacy and interdisciplinary reasoning within an IB Mathematics Internal Assessment/.
3. To interpret the documented inquiry process through a STEM identity perspective, with particular attention to student agency, authentic participation, and opportunities for engagement in disciplinary knowledge practices.
4. To identify pedagogical implications for integrating authentic data inquiry into K–12 STEM education, with particular attention to mentored inquiry models and identity-oriented learning outcomes.

LITERATURE REVIEW

This study is based exclusively on secondary open-access climate data, ensuring transparency, replicability, and ethical compliance. The use of publicly available scientific datasets aligns with established standards in climate research and supports reproducibility in educational inquiry (Wilkinson et al., 2016). Two primary data sources provided by the National Oceanic and Atmospheric Administration (NOAA) were employed.

Sea surface temperature (SST) data were obtained from the Optimum Interpolation Sea Surface Temperature (OISST), Version 2 dataset, developed and maintained by the NOAA National Centers for Environmental Information. OISST integrates observations from satellite sensors (including AVHRR and GOES), in situ measurements from ships and moored and drifting buoys, and Argo floats, using a bias-corrected

interpolation scheme to generate spatially complete and temporally consistent SST fields (Reynolds et al., 2007; Huang et al., 2021). This dataset is widely used in climatological and oceanographic research and has been validated for the analysis of interannual variability and climate-related phenomena, making it suitable for both scientific and educational applications.

Historical records of tropical cyclones were retrieved from the HURDAT2 database and complementary Tropical Cyclone Reports (TCRs) published by the NOAA National Hurricane Center. HURDAT2 provides authoritative, best-track information on the number, intensity, and temporal evolution of tropical cyclones in the North Atlantic basin and is commonly used in peer-reviewed studies examining hurricane frequency and variability (Landsea & Franklin, 2013). These records enable a consistent measure of annual hurricane counts for the period analyzed.

The analysis focuses on the North Atlantic basin, one of the most active regions for tropical cyclone formation globally. To capture spatial variability in sea surface temperature along a major oceanic circulation pathway, three geographically distinct locations were selected: Providencia (Colombia), Puerto Rico (United States), and the Azores (Portugal). These sites were chosen based on their position along the trajectory of the Gulf Stream system, allowing for a longitudinal perspective spanning tropical to mid-latitude regions (Talley et al., 2011).

The temporal scope of the study covers the period 1995–1998, selected to illustrate interannual variability in both SST and hurricane activity within a dataset of manageable size for secondary-level inquiry. Although this time frame does not permit long-term trend analysis, it includes years characterized by contrasting levels of cyclonic activity, supporting an exploratory examination of SST–hurricane relationships. Such bounded temporal designs are consistent with exploratory studies intended to demonstrate methodological application rather than to establish climatological causality (Emanuel, 2005; Knutson et al., 2020).

Monthly SST values were extracted for each of the three selected locations and aggregated to compute annual mean SST values for each year of the study period. This aggregation facilitated direct comparison with annual hurricane frequency, which is conventionally reported at a yearly temporal resolution in climatological literature (Webster et al., 2005).

The resulting dataset consisted of paired annual observations linking SST values and hurricane counts. Data organization and preliminary calculations were conducted using spreadsheet software, ensuring transparency in data handling and enabling reproducibility by other students or educators. This approach reflects common practices in introductory data-driven climate analysis and supports the pedagogical goal of making analytical procedures explicit and accessible (Konold & Higgins, 2003).

To explore the relationship between sea surface temperature and hurricane frequency, the study employed inferential statistical methods commonly introduced at the upper-secondary level, specifically Pearson's correlation coefficient and simple linear regression. Pearson's correlation was used to assess the strength and direction of linear associations between SST and annual hurricane counts for each location, as well as for the mean SST across the three sites.

Simple linear regression was subsequently applied to model the association between mean SST and hurricane frequency, providing an estimate of the expected change in hurricane count associated with a one-degree Celsius increase in SST. These methods are widely used in exploratory climatological studies and are appropriate for examining linear relationships in small datasets when interpreted with caution (Wilks, 2019).

A significance level of $\alpha = 0.05$ was adopted for statistical testing. Given the limited sample size ($n = 4$ years), the analysis emphasized careful interpretation of p-values, effect sizes, and explained variance. Rather than supporting causal inference, the statistical analysis was used as an exploratory tool to identify patterns consistent with established theoretical expectations regarding SST and tropical cyclone activity.

Several methodological limitations must be acknowledged. The short temporal range restricts statistical power and precludes robust significance testing or generalization beyond the study period. Additionally, hurricane frequency is influenced by multiple climatic factors beyond SST, including vertical wind shear, atmospheric circulation patterns, and large-scale climate oscillations such as ENSO and the Atlantic Multidecadal Oscillation (Kossin et al., 2017; Knutson et al., 2020). These variables were not included in the present analysis due to the exploratory and educational scope of the study.

Despite these limitations, the methodology is appropriate for the study's dual purpose. From a scientific perspective, it enables a preliminary examination of SST–hurricane relationships using validated climate datasets. From an educational perspective, it demonstrates how secondary school students can apply inferential statistics to authentic scientific data, engage in critical interpretation, and recognize the epistemic limits of quantitative analysis. Such methodological awareness is a central component of both scientific literacy and emerging STEM identity development.

RESEARCH METHOD

This study is situated within the context of the International Baccalaureate (IB) Diploma Programme, specifically the Mathematics Internal Assessment (IA), which constitutes a core component of the curriculum and represents a substantial proportion of the final subject grade. The IA is designed to assess students' capacity to independently explore a mathematically grounded problem of personal interest, apply appropriate analytical tools, and critically evaluate the validity and limitations of their findings. In contrast to standardized examinations, the IA emphasizes inquiry, originality, and the application of mathematical reasoning to real-world contexts, aligning with contemporary perspectives on mathematics as a practice-oriented discipline (International Baccalaureate Organization, 2021; Schoenfeld, 2014).

The research was conducted at Gimnasio Campestre Los Cerezos, a private secondary school in Colombia offering the IB Diploma Programme. Within this educational setting, the school has implemented a Science Lab model aimed at fostering interdisciplinary integration of knowledge across mathematics, natural sciences, and data-informed inquiry. The Science Lab functions as a pedagogical framework rather than a single instructional space, promoting problem-centered learning, experimental reasoning, and the use of scientific tools to address complex phenomena. This model complements the IB curriculum by providing structured opportunities for students to engage with authentic scientific practices beyond disciplinary boundaries, in line with research highlighting the educational value of integrated STEM learning environments (Honey, Pearson, & Schweingruber, 2014; National Academies of Sciences, Engineering, and Medicine, 2018).

The Science Lab is further aligned with the STEP methodology, which emphasizes inquiry cycles involving problem formulation, exploration, evidence-based reasoning, and reflective synthesis. Through this approach, students are encouraged to mobilize concepts and methods from multiple disciplines while maintaining epistemic rigor and methodological transparency. Prior studies indicate that such inquiry-oriented and interdisciplinary learning designs support deeper conceptual understanding and enhance students' capacity to transfer knowledge across contexts (Lehrer & Schauble, 2015; Fortus et al., 2016). Within the present study, the Science Lab provided a conducive environment for situating the IB Mathematics IA within a broader STEM inquiry ecosystem, reinforcing the relevance of mathematics as a mediating tool for scientific analysis.

From a research design perspective, the study adopts a student-led inquiry model under academic supervision. The student author was responsible for defining the research focus, selecting data sources, conducting the statistical analysis, and interpreting the results. Academic supervision was provided by the corresponding author, affiliated with the Research Group *Educación y Educadores* at Universidad de La Sabana, whose role was limited to methodological guidance, ethical oversight, and support in aligning the inquiry with established standards of scientific reasoning and academic writing. This supervisory arrangement reflects a

mentorship-based model rather than a co-construction of results, preserving the integrity and authorship of the student-led research process (Brew, 2013).

The inquiry was framed as an exploratory, non-experimental case study based exclusively on secondary data obtained from open-access scientific repositories. No human participants were involved, and no primary data were collected. This design aligns with ethical standards for educational research involving minors while enabling engagement with authentic datasets commonly used in professional scientific research. The educational interpretation is based on the documented characteristics of the inquiry rather than on independent measurements of student learning or STEM identity. Accordingly, the case is treated as an illustrative example of authentic STEM participation, not as an empirical evaluation of changes in students' identity, competence, or learning outcomes. This distinction defines the evidentiary boundaries of the educational claims developed in the discussion. Working with real climate data, rather than simulated or textbook examples, allowed the student to approximate key epistemic practices of scientific inquiry, including data validation, uncertainty management, and interpretative caution (Wilkerson & Polman, 2016).

Pedagogically, the research design is grounded in principles of inquiry-based STEM education and authentic data use, which prioritize learning through investigation, interpretation, and reflection rather than procedural repetition. A substantial body of research has demonstrated that such approaches contribute to the development of data literacy, statistical reasoning, and sustained engagement with STEM disciplines (Konold & Higgins, 2003; Ben-Zvi & Garfield, 2004; Lehrer & Schauble, 2015). Within the IB framework, the Mathematics IA provides a formal structure for operationalizing these principles, while the Science Lab and STEP methodology extend them through interdisciplinary integration and iterative inquiry cycles.

In this context, the present study serves a dual function. At the empirical level, it explores a potential relationship between sea surface temperature and hurricane frequency in the North Atlantic. At the educational level, it documents how a secondary school student can engage meaningfully with complex scientific questions through inferential statistics and open climate data within an interdisciplinary learning environment. By situating the inquiry at the intersection of the IB Mathematics IA, the Science Lab model, and STEP methodology, the study illustrates a scalable approach for bridging secondary education and research-informed STEM practices, while supporting the development of STEM identity through authentic participation in scientific inquiry.

FINDINGS

Sea Surface Temperature Patterns

Annual mean sea surface temperature (SST) values for the three selected locations—Providencia, Puerto Rico, and the Azores—exhibited clear spatial and interannual variability over the period 1995–1998. Providencia consistently recorded the highest SST values, with annual means ranging between 27.8 °C and 28.7 °C. Puerto Rico showed similarly elevated temperatures, though slightly lower than those observed in Providencia, with annual means ranging from 27.3 °C to 28.3 °C. In contrast, the Azores presented substantially lower SST values, characteristic of mid-latitude conditions, with annual means ranging from 18.9 °C to 20.9 °C.

Across the four-year period, 1998 was identified as the warmest year at all three locations, while 1996 and 1997 showed comparatively lower SST values. These patterns provided a descriptive basis for examining potential associations between ocean temperature and hurricane activity during the same period.

Hurricane Frequency in the North Atlantic

Historical records from the HURDAT2 database indicate marked interannual variability in hurricane frequency during the study period. In 1995, a total of 11 hurricanes were recorded in the North Atlantic basin,

followed by 9 hurricanes in 1996. In contrast, 1997 registered substantially reduced activity, with only 3 hurricanes, whereas 1998 recorded the highest activity level of the period, with 14 hurricanes.

The contrast between the low-activity year (1997) and the high-activity year (1998) provided a clear comparative reference for the exploratory analysis, as these years also corresponded to lower and higher SST values, respectively.

Correlation Analysis

Pearson correlation analysis indicated positive relationships between SST and hurricane frequency across all three locations, with varying magnitudes. The strongest correlations were observed in the tropical locations. Providencia exhibited a high positive correlation ($r \approx 0.87$), while Puerto Rico showed a similarly strong positive association ($r \approx 0.82$). In the Azores, the correlation was positive but more moderate ($r \approx 0.46$).

None of the correlations reached statistical significance at the $\alpha = 0.05$ level, reflecting the limited sample size. Nevertheless, the consistent direction of the relationships across locations suggests a coherent pattern in the association between SST and hurricane frequency within the study period.

Regression Analysis

Simple linear regression applied to the average SST across the three locations indicated a positive association between SST and annual hurricane frequency. Within this four-year dataset, the estimated regression slope was approximately 5.5 additional hurricanes per 1 °C difference in mean SST, with $R^2 \approx 0.47$. These values describe the fitted relationship within the selected observations and should not be interpreted as reliable estimates of hurricane responses to temperature changes. Given the very small sample and the nonsignificant regression result, the analysis serves primarily as an educational illustration of statistical modelling and its inferential limitations.

Despite this proportion of explained variance, the regression model did not achieve statistical significance ($p > 0.05$), consistent with the constraints imposed by the short temporal range. These results confirm the exploratory character of the analysis.

Summary of Key Findings

Overall, the results indicate a consistent positive association between sea surface temperature and hurricane frequency during the period examined, with stronger relationships observed in tropical locations. Years characterized by higher SST values, particularly 1998, coincided with increased hurricane activity, whereas cooler years, such as 1997, were associated with reduced activity. Although statistical significance could not be established, the observed patterns provide a coherent empirical basis for subsequent discussion.

DISCUSSION

The findings of this study indicate a consistent positive association between sea surface temperature (SST) and hurricane frequency in the North Atlantic during the period 1995–1998. Although statistical significance was not achieved due to the limited temporal scope of the dataset, the direction and relative magnitude of the observed relationships are consistent with established climatological theory linking warm ocean conditions to tropical cyclone development and intensification (Emanuel, 2005; Webster et al., 2005; Knutson et al., 2020). In particular, the stronger associations identified in tropical locations such as Providencia and Puerto Rico align with previous research highlighting the role of SST as a necessary, though not sufficient, condition for cyclogenesis.

The comparatively weaker association observed in the Azores can be interpreted in relation to its mid-latitude position, where tropical cyclone activity is less directly dependent on SST and more strongly influenced

by atmospheric circulation patterns and extratropical dynamics. This spatial differentiation underscores the importance of geographic context when interpreting SST–hurricane relationships and is consistent with prior studies emphasizing regional variability in the drivers of cyclonic activity across the North Atlantic basin (Trenberth & Fasullo, 2007; Kossin et al., 2017).

From a scientific standpoint, the regression analysis provides an illustrative example of how interannual SST variability may be associated with changes in hurricane frequency. The estimated increase in hurricane counts associated with a 1 °C rise in mean SST, while not statistically conclusive, is directionally consistent with broader empirical findings reported in climatological literature. The proportion of variance explained by SST in this exploratory model further highlights the relevance of ocean temperature as a key variable, even when other influential factors—such as vertical wind shear or large-scale climate oscillations—are not explicitly included (Knutson et al., 2020).

Equally important is the explicit acknowledgment of the study's methodological limitations. The small sample size constrains statistical power and precludes causal inference, while the exclusion of additional climatic variables limits explanatory scope. However, these constraints should not be interpreted as shortcomings of the inquiry itself. Rather, they reflect the intentionally bounded design of the study and align with contemporary views of scientific reasoning that emphasize transparency, uncertainty recognition, and epistemic humility as integral components of quantitative analysis (Wilks, 2019).

Beyond its empirical contributions, the study offers insights of particular relevance for STEM education. Engagement with authentic climate datasets required the student to navigate key features of real-world scientific data, including variability, uncertainty, and methodological trade-offs. The application of inferential statistical methods in this context extended beyond procedural computation, fostering interpretative reasoning and alignment with theoretical expectations. Prior research has consistently shown that such experiences support the development of data literacy and scientific thinking by positioning learners as active agents in knowledge construction rather than passive recipients of established results (Lehrer & Schauble, 2015; Wilkerson & Polman, 2016).

The inquiry further illustrates how secondary-level mathematics can function as an entry point to interdisciplinary STEM learning. By integrating statistical analysis with concepts from oceanography and meteorology, mathematics operated as a mediating discipline connecting abstract quantitative tools to applied scientific questions. This interdisciplinary engagement is widely recognized as a key factor in promoting conceptual coherence and sustained interest in STEM fields, particularly when learning activities are grounded in socially and scientifically relevant phenomena (Honey et al., 2014; National Academies of Sciences, Engineering, and Medicine, 2018).

From a STEM identity perspective, this case illustrates conditions under which student-led inquiry may create opportunities for identification with STEM practices. The student's engagement in research question formulation, authentic data analysis, and methodological reflection can be interpreted through the concepts of epistemic agency and disciplinary participation. However, whether these experiences produce measurable changes in STEM identity remains an empirical question requiring additional evidence. By formulating a researchable question, engaging with professional-grade datasets, and critically reflecting on methodological limitations, the student was positioned as a legitimate participant in STEM-related knowledge production. Research on STEM identity emphasizes that such opportunities for epistemic agency and authentic participation are central to fostering a sense of belonging and competence within STEM disciplines, particularly at the pre-university level (Carlone & Johnson, 2007; Hazari et al., 2010; Barton & Tan, 2010).

In this sense, the value of the present study lies not in definitive climatological conclusions, but in its demonstration of a research-informed learning process grounded in authentic scientific practice. The findings invite future investigations employing extended temporal ranges, additional climatic variables, and more advanced analytical techniques, while also underscoring the pedagogical potential of authentic data inquiry

within interdisciplinary learning environments. By situating student-led analysis within a rigorous yet supportive framework, the study contributes to ongoing discussions on how secondary education can prepare learners for meaningful participation in STEM fields through both cognitive and identity-related development. Conceptually, the case suggests that authentic data inquiry can be examined through three interconnected dimensions: epistemic agency, expressed through students' responsibility for research decisions; interdisciplinary reasoning, expressed through the application of mathematics to scientific phenomena; and disciplinary participation, expressed through engagement with practices associated with scientific knowledge production. These dimensions provide a provisional analytical perspective for future research investigating the relationship between inquiry experiences and STEM identity. Their proposed connection requires further empirical examination rather than being regarded as a validated developmental model.

CONCLUSION

The findings of this study have several implications for STEM education, particularly with respect to the use of authentic scientific data, inquiry-based learning, and the promotion of STEM identity across K–12 educational contexts. Although the empirical analysis presented here is exploratory and context-specific, the pedagogical processes underlying the inquiry offer insights that are transferable beyond the International Baccalaureate (IB) Mathematics Internal Assessment and applicable to a broader range of school-based STEM initiatives.

First, the study highlights the pedagogical value of authentic data inquiry as a core strategy for STEM education. Engagement with open-access scientific datasets from institutions such as the National Oceanic and Atmospheric Administration (NOAA) exposed students to the complexity, uncertainty, and decision-making processes inherent in real scientific work. In contrast to simplified textbook exercises, authentic datasets require learners to confront variability, incomplete information, and methodological trade-offs, thereby supporting a more realistic understanding of how scientific knowledge is generated and validated. Prior research suggests that such experiences are critical for fostering scientific literacy and sustained engagement with STEM disciplines from early educational stages onward (National Academies of Sciences, Engineering, and Medicine, 2018; Wilkerson & Polman, 2016).

Second, the integration of inferential statistical methods within a real-world climate context supports the development of advanced data literacy across K–12 levels. Rather than treating correlation and regression as isolated computational techniques, the inquiry positioned these methods as analytical tools for exploring socially and scientifically relevant questions. Interpreting effect sizes, uncertainty, and model limitations in relation to theoretical expectations encouraged critical reasoning and epistemic humility—competencies increasingly recognized as essential for learners operating in data-rich and algorithmically mediated environments (Ben-Zvi & Garfield, 2004; Lehrer & Schauble, 2015).

Third, the interdisciplinary structure of the inquiry underscores the role of mathematics as a connective discipline within STEM education. By linking statistical analysis with concepts from oceanography and meteorology, the study demonstrates how mathematical reasoning can mediate understanding across disciplinary boundaries. Such integrative approaches are particularly valuable in K–12 contexts, where complex phenomena such as climate change demand systems-oriented thinking and coordinated use of multiple forms of knowledge. Research on integrated STEM learning indicates that interdisciplinary problem-solving supports conceptual coherence and enhances learners' capacity to transfer knowledge across contexts (Honey, Pearson, & Schweingruber, 2014).

A further implication concerns the promotion of STEM identity among K–12 learners. Participation in student-led inquiry that mirrors authentic scientific practice can support students in perceiving themselves as legitimate participants in STEM-related activities. The processes of formulating research questions, engaging

with professional-grade data, and critically reflecting on methodological limitations contribute to the development of competence, recognition, and epistemic agency—dimensions consistently identified as central to STEM identity formation (Carlone & Johnson, 2007; Hazari et al., 2010; Collazos Guzmán, 2025). Importantly, identity-oriented outcomes are not limited to advanced or specialized students but can be cultivated progressively across educational stages when inquiry experiences are appropriately scaffolded.

From an instructional design perspective, the study also emphasizes the value of mentored inquiry models that connect school-based learning with research-informed academic practices. The supervisory framework employed in this case—linking secondary-level inquiry to a university research environment—illustrates a scalable approach for enhancing rigor while preserving student ownership. Similar mentorship-based models have been shown to support both cognitive development and identity-related outcomes by providing learners with access to disciplinary norms, feedback, and recognition (Brew, 2013; Barton & Tan, 2010). Such models are particularly relevant for K–12 systems seeking to bridge the gap between school-level STEM learning and post-secondary expectations. Beyond the International Baccalaureate context, the case offers a potentially adaptable approach to authentic STEM inquiry through the use of publicly accessible scientific data, structured mathematical investigation, and teacher-supported reflection. Its implementation in other educational systems would depend on curriculum requirements, students' statistical preparation, technological access, and available mentoring capacity. Consequently, its international relevance lies in identifying adaptable instructional principles rather than demonstrating effectiveness across different countries or school systems.

LIMITATION AND FUTURE RESEARCH

Looking forward, future research could extend this methodological approach by employing longer temporal datasets, incorporating additional climatic variables, and applying more advanced analytical techniques. From an educational perspective, longitudinal studies examining how repeated exposure to authentic data inquiry influences STEM identity development across K–12 trajectories would be particularly valuable. Comparative studies across diverse school contexts could further clarify the conditions under which authentic inquiry most effectively supports inclusion, engagement, and persistence in STEM pathways.

These findings are particularly relevant for curriculum designers and school leaders seeking to embed data-driven inquiry and identity-oriented STEM practices within existing mathematics and science curricula.

Taken together, these implications suggest that integrating authentic data inquiry into K–12 STEM curricula can enhance both cognitive and identity-related learning outcomes. While the specific empirical findings of the present study are context-dependent, the underlying educational principles—authenticity, inquiry, interdisciplinarity, and mentored supervision—offer a transferable framework for promoting STEM identity and preparing students for meaningful participation in STEM fields in an increasingly complex and data-driven world.

REFERENCES

Barton, A. C., & Tan, E. (2010). We be burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences, 19*(2), 187–229. https://doi.org/10.1080/10508400903530044

Ben-Zvi, D., & Garfield, J. (2004). *The challenge of developing statistical literacy, reasoning, and thinking*. Kluwer Academic Publishers.

Boaler, J. (2016). *Mathematical mindsets: Unleashing students' potential through creative math, inspiring messages and innovative teaching*. Jossey-Bass.

Brew, A. (2013). Understanding the scope of undergraduate research: A framework for curricular and pedagogical decision-making. *Higher Education, 66*(5), 603–618. https://doi.org/10.1007/s10734-013-9624-x

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching, 44*(8), 1187–1218. https://doi.org/10.1002/tea.20237

Collazos Guzmán, G. (2025). *Marco teórico-relacional para el análisis de identidad digital STEM*. Revista Científica y Académica, 5(2), 2285–2303. https://doi.org/10.61384/r.c.a..v5i2.1276

Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature, 436*(7051), 686–688. https://doi.org/10.1038/nature03906

Fortus, D., Krajcik, J., Dershimer, R. C., Marx, R. W., & Mamlok-Naaman, R. (2016). Design-based science and real-world problem-solving. *International Journal of Science Education, 27*(7), 855–879. https://doi.org/10.1080/09500690500038165

Gee, J. P. (2000). Identity as an analytic lens for research in education. *Review of Research in Education, 25*, 99–125. https://doi.org/10.2307/1167322

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice. *Journal of Research in Science Teaching, 47*(8), 978–1003. https://doi.org/10.1002/tea.20363

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research*. National Academies Press. https://doi.org/10.17226/18612

Huang, B., Liu, C., Banzon, V. F., Freeman, E., Graham, G., Hankins, W., … Smith, T. M. (2021). Improvements of the daily optimum interpolation sea surface temperature (OISST) version 2.1. *Journal of Climate, 34*(8), 2923–2939. https://doi.org/10.1175/JCLI-D-20-0166.1

International Baccalaureate Organization. (2021). *Mathematics: Analysis and approaches guide*. International Baccalaureate.

Knutson, T. R., Camargo, S. J., Chan, J. C. L., Emanuel, K., Ho, C.-H., Kossin, J., … Walsh, K. (2020). Tropical cyclones and climate change assessment: Part II. *Bulletin of the American Meteorological Society, 101*(3), E303–E322. https://doi.org/10.1175/BAMS-D-18-0194.1

Konold, C., & Higgins, T. (2003). Reasoning about data. *Educational Studies in Mathematics, 45*(1–3), 5–32. https://doi.org/10.1023/A:1013838715874

Kossin, J. P., Emanuel, K. A., & Vecchi, G. A. (2017). The poleward migration of the location of tropical cyclone maximum intensity. *Nature, 509*(7500), 349–352. https://doi.org/10.1038/nature13278

Landsea, C. W., & Franklin, J. L. (2013). Atlantic hurricane database uncertainty and presentation of a new database format. *Monthly Weather Review, 141*(10), 3576–3592. https://doi.org/10.1175/MWR-D-12-00254.1

Lehrer, R., & Schauble, L. (2015). Learning progressions: The whole world and the classroom. *Science, 347*(6218), 1269–1271. https://doi.org/10.1126/science.aaa5601

Nasir, N. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *Journal of the Learning Sciences, 17*(2), 143–179. https://doi.org/10.1080/10508400801986108

National Academies of Sciences, Engineering, and Medicine. (2018). *How people learn II: Learners, contexts, and cultures*. National Academies Press. https://doi.org/10.17226/24783

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

Reynolds, R. W., Smith, T. M., Liu, C., Chelton, D. B., Casey, K. S., & Schlax, M. G. (2007). Daily high-resolution blended analyses for sea surface temperature. *Journal of Climate, 20*(22), 5473–5496. https://doi.org/10.1175/2007JCLI1824.1

Schoenfeld, A. H. (2014). What makes for powerful classrooms, and how can we support teachers in creating them? *Educational Researcher, 43*(8), 404–412. https://doi.org/10.3102/0013189X14554450

Talley, L. D., Pickard, G. L., Emery, W. J., & Swift, J. H. (2011). *Descriptive physical oceanography: An introduction* (6th ed.). Academic Press.

Trenberth, K. E., & Fasullo, J. T. (2007). Water and energy budgets of hurricanes and implications for climate change. *Journal of Geophysical Research: Atmospheres, 112*(D23). https://doi.org/10.1029/2006JD008303

Webster, P. J., Holland, G. J., Curry, J. A., & Chang, H.-R. (2005). Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science, 309*(5742), 1844–1846. https://doi.org/10.1126/science.1116448

Wilkerson, M. H., & Polman, J. L. (2016). Situating data science: Exploring how relationships between data and phenomena are recontextualized during data analysis activities. *Journal of Research in Science Teaching, 53*(3), 317–347. https://doi.org/10.1002/tea.21301

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., … Mons, B. (2016). The FAIR guiding principles for scientific data management and stewardship. *Scientific Data, 3*, Article 160018. https://doi.org/10.1038/sdata.2016.18

Wilks, D. S. (2019). *Statistical methods in the atmospheric sciences* (4th ed.). Academic Press.