Situating Scientific Literacy within the Context of a Pandemic

Genejane M. Adarlo
Ateneo de Manila University, Philippines, https://orcid.org/ 0000-0002-9047-9195

Marlene M. De Leon
Ateneo de Manila University, Philippines, https://orcid.org/ 0000-0003-3270-593X

Abigail Marie T. Favis
Ateneo de Manila University, Philippines, https://orcid.org/ 0000-0001-9807-104X

Abstract: Society has increasingly looked upon science education to prepare the public for Industrial Revolution 4.0, as scientific reasoning and practices can hone 21st century skills, including scientific literacy. However, the COVID-19 pandemic has changed how science is taught and learned. Hence, this mixed methods study seeks to determine if there would be a significant increase in scientific literacy among undergraduate students after taking a six-week online course offered during the first year of the pandemic as part of their science education. It also aims to examine which aspects of the course offering students attributed, if any, their scientific literacy. Using a one-tailed paired sample t-test ($\alpha = 0.05$) to compare the Global Scientific Literacy Questionnaire scores of 67 undergraduate students surveyed at the start and end of the online course, this study demonstrated a significant increase in their scientific literacy despite the constraints brought by the pandemic ($p = 0.03$). Specifically, these students became better at systematic thinking and information management ($p = 0.01$) as well as self-directed planning and monitoring ($p = 0.02$). A focus group discussion with five students revealed that course design and the nature of remote learning could explain the gain in their scientific literacy.

Keywords: Scientific literacy, Science education, Industrial revolution 4.0, COVID-19 pandemic

Citation: Adarlo, G., M., De Leon, M.M., & Favis, A.M.T. (2023). Situating Scientific Literacy within the Context of a Pandemic. In M. Koc, O. T. Ozturk & M. L. Ciddi (Eds.), *Proceedings of ICRES 2023-- International Conference on Research in Education and Science* (pp. 601-613), Cappadocia, Turkiye. ISTES Organization.

Introduction

The digital revolution that characterizes the 21st century has ushered our society into Industrial Revolution (IR) 4.0 (Reddy, 2021). It has accelerated scientific progress more than ever by making most of the technological advancements of previous industrial revolutions: the use of steam power in the mechanization of manufacturing during the first industrial revolution, electrical energy for large-scale production during the second industrial revolution, and computerized information technology for automated production during the third industrial revolution (Melinda & Sa'ud, 2022). Although science and technology have become accessible to many because of this digital revolution, pseudoscientific views and misinformation have also abounded (Reddy, 2021). These attempts to discredit science can be countered though by nurturing scientific literacy among the public wherein they, according to the Organisation for Economic Co-operation and Development (2019) in their Programme for International Student Assessment, demonstrate the "ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (p. 16).

Science education has therefore become more salient in fostering scientific literacy in this age of IR 4.0. It has been increasingly viewed in society as a strategic approach to equip students with 21st century skills that will allow them to navigate through the socio-economic and socio-cultural transformation involved in IR 4.0 (Dovgyi et al., 2020). Expectedly, institutions responsible for science education must respond to the demands and challenges brought by the technological breakthroughs of IR 4.0 to our society (Moraes et al., 2022). They need to address four essential elements comprising Education 4.0 as a counterpart of IR 4.0: development of critical competencies in today's students, application of new learning methods, incorporation of current and emerging technologies in the teaching-learning process, and use of innovative infrastructure to enhance the educative experience (Miranda et al., 2021).

However, the COVID-19 pandemic has disrupted our daily lives, including how science is taught. Teaching in many parts of the world suddenly shifted to remote learning as campuses abruptly closed to mitigate the spread of COVID-19. This unprecedented shift has exacerbated the digital divide between developed and less developed countries, adversely affecting the attainment of educational outcomes, such as scientific literacy, due to disparate access among and within countries to inclusive, equitable, and quality education (United Nations, 2020).

Nonetheless, "the COVID-19 pandemic," as Shi (2022) argues, "offers vivid examples of teachable aspects of the nature of science" (p. 311). For example, the public has witnessed the role of scientific progress and technological innovation in overcoming the pandemic as well as the importance of scientific culture and scientific spirit in making informed decisions and policies during such a global crisis (Han, 2020). These teachable aspects for scientific literacy take place despite the "infodemic of misleading information about the pandemic" (Schneegans & Nair-Bedouelle, 2021, p. 17) as the scientific community and the education sector, among others, have growingly recognized "the critical need for prompt, universal access to science" in a time of a public health crisis (Persic et al., 2021, p. 14).

Further research is warranted though to support views that science education within the context of a pandemic can bring about scientific literacy. Hence, this study aims to determine if there would be a significant increase in scientific literacy among undergraduate students after taking the mandated *Science, Technology, and Society* as a six-week online course offered during the first year of the COVID-19 pandemic. It also seeks to examine which aspects of their science education in a time of a pandemic would these students find helpful in making them scientifically literate. Findings from this study can contribute to efforts geared toward achieving

Sustainable Development Goals on quality education by providing valuable insights on how science education can best promote scientific literacy despite the challenges and constraints brought by adverse situations, including the recent pandemic.

Theoretical Framework

Scientific literacy, as a social construct, has differed through the years to suit the ever-changing circumstances and needs of society (Choi et al., 2011). Its meaning has evolved from a public understanding of science to critical engagement with the social practices of science (Braund, 2021). However, the notion of scientific literacy as an individual characteristic to possess still prevails against radical views of it as a collective human praxis (Choi et al., 2011; Roth, 2003). This predominant concept though is deemed as no longer responsive to meet the demands and challenges of the 21st century (Mun et al., 2015). Hence, there are resounding calls to rethink current stances of scientific literacy to account for perspectives, competencies, and values orientation that are necessary to live in a global society (Choi et al., 2011; Mun et al., 2015).

In response to these calls, Choi et al. (2011) propose Global Scientific Literacy as a framework that can be more fitting in the 21st century wherein local issues have become worldwide concerns. This Global Scientific Literacy Framework consists of five dimensions that work together: scientific content knowledge, habits of mind, character and values, science as a human endeavor, and metacognition and self-direction. Scientific content knowledge refers to an integrated understanding of core ideas of science, which are foundational to applying scientific concepts to solve real-world problems (Mun et al., 2015). Habits of mind are characterized by the use of scientific reasoning and practices to explore natural phenomena and address science-related social, ethical, and moral issues (Choi et al., 2011; Mun et al., 2015). These scientific reasoning and practices include skills in critical thinking, problem solving, decision-making, information management, communication, and collaboration (Choi et al., 2011).

Character and values, on the other hand, pertain to a display of ecological worldview, moral and ethical sensitivity, appreciation of cultural diversity, socio-scientific accountability, an ethic of care, and compassion for others (Mun et al., 2015). They stand for belief systems and preferences that have become utmost necessary in the 21st century society (Choi et al., 2015). Science as a human endeavor involves having an awareness of science as tentative, subjective, and value-laden, an understanding of how science, technology, and society are interrelated, and adherence to the spirit of science, such as curiosity, intellectual honesty, creativity, skepticism, tolerance of ambiguity, and openness to new ideas (Mun et al., 2015). Lastly, metacognition and self-direction are key processes that bind these four dimensions together (Choi et al., 2011). These cognitive processes include self-directed planning to determine which strategies and resources are needed to complete a task, self-directed monitoring to track one's progress in view of identified strengths and limitations, and self-directed evaluating to reflect on one's past experiences and use these insights in tackling similar situations in the future (Choi et al., 2011; Mun et al., 2015).

Method

A mixed methods research design was carried out in this study to make the most of the quantitative and qualitative approaches in understanding the development of scientific literacy among undergraduate students during a pandemic. Specifically, an explanatory sequential research design was used as findings from the focus group discussion (qualitative data) were tapped to make sense of the results from the survey (quantitative data). Qualitative data gathering and analysis in this instance followed quantitative data gathering and analysis to arrive at an explanation of the phenomenon under study (Edmonds & Kennedy, 2017).

Setting and Participants

This mixed methods study was set at Ateneo de Manila University, an institution of Jesuit higher education in the capital of the Philippines. Its undergraduate curriculum includes *Science, Technology, and Society* as part of the students' science education and in fulfillment of the general education curriculum mandated by the country's Commission of Higher Education (CHED). To foster scientific literacy, the following are the learning outcomes of *Science, Technology, and Society* as stated in the syllabus:

1) Students should be able to evaluate the capabilities as well as limitations of Science and Technology through distinguishing what questions and methods are valid in the realm of science based on its nature and practice.
2) Students should be able to contextualize issues using perspectives from and beyond Science and Technology to dissect the interplay of various factors in analyzing the complexity of the human experience.
3) Students should be able to synthesize insights from various disciplines to propose solutions to contemporary issues with a view toward sustainable development and improving quality of life.
4) Students should demonstrate how individuals and an entire generation - guided by Ignatian Values - can participate in and contribute to the practice of Science and Technology, driving the transformation of society through their various professions and leadership.

During the first year of the COVID-19 pandemic, *Science, Technology, and Society* was delivered online for six weeks using Zoom for synchronous learning and Canvas Learning Management System for asynchronous learning. In general, this course consisted of four modules, namely 1) the Nature and Practice of Science and Technology; 2) Science, Technology, and Lifestyle; 3) Environment and Sustainable Development; 4) the Origin of Life and Universe.

After this study obtained ethics approval from an accredited institutional review board, undergraduate students enrolled in *Science, Technology, and Society* during the second semester of the academic year 2020 to 2021 in

Ateneo de Manila University were recruited by volunteer sampling to take part in this study. The second semester of academic year 2020 to 2021 was chosen as the period for data gathering instead of the first semester so that both teachers and students were accustomed to online learning by then. Students eligible as participants for this study completed the four modules either from 10 February 2021 to 7 April 2021 or from 12 April 2021 to 5 June 2021.

Data Gathering

A pre-test survey was sent through the institutional emails of eligible study participants at the start of the course. An online survey was deployed in this study as it was the most appropriate mode of administration given the lockdown and restrictions imposed by the Philippine government as a response to the pandemic. This survey included demographic questions and 48 items from the Global Scientific Literacy Questionnaire (GSLQ) by Mun et al. (2015). The 5-point Likert scale items from the GSLQ were developed to measure four dimensions of the Global Scientific Literacy Framework: habits of mind (i.e., 5 items for communication and collaboration, while 8 items for systematic thinking and information management), character and values (i.e., 7 items for ecological worldview and compassion, while 2 items for socio-scientific accountability), science as a human endeavor (i.e., 3 items for characteristics of scientific knowledge, whereas 10 items for science and society as well as the spirit of science), and metacognition and self-direction (i.e., 10 items for planning and monitoring, whereas 3 items for evaluating). Scientific content knowledge was not included in the development of GLSQ by Mun et al. (2015) as they believed this dimension may require other measures. These scale items were tested validly based on exploratory and confirmatory factor analysis. The items in each dimension also showed good internal consistency as they displayed a Cronbach's alpha of 0.80 and above.

A post-test survey was then emailed at the end of the course to the study participants, who completed the pre-test questionnaire. This survey included the same questions and items from the pre-test questionnaire to facilitate comparison. Specifically, giving the same questions and items for the pre-test and post-test to the students allowed the researchers to determine if *Science, Technology, and Society* as a six-week online course offered within the context of a pandemic can bring about an increase in scientific literacy.

To make sense of the results gathered from the surveys, a focus group discussion was carried out after the grades were released for the second semester. A focus group discussion, as Stewart and Shamdasani (2015) point out, can add depth to the survey responses by making most of the group interaction to yield "a very rich body of data expressed in the respondents' own words and context" (p. 42). Around four to six students, as suggested by Krueger (2015), were needed as participants in the focus group discussion. Aside from offering a comfortable environment, this small focus group size is conducive for participants to detail insights and observations about their experience. In this study, participants in the focus group discussion were randomly sampled from the list of undergraduate students enrolled in *Science, Technology, and Society* during the second semester of the academic year 2020 to 2021. Those who consented were asked to take part in the focus group discussion via Zoom as the videoconferencing platform.

Data Analysis

Mean and standard deviation were employed to describe the central tendency of the GSLQ scores on pre-test and post-test. To determine if there is a significant increase in scientific literacy among undergraduate students after taking *Science, Technology, and Society* as a six-week online course offered during the COVID-19 pandemic, a one-tailed paired sample t test of the GSLQ scores was performed at a 95% confidence interval and 0.05 level of significance using Microsoft Excel. To examine which aspects of the course these students find helpful in making them more scientifically literate at a time of a pandemic, a thematic analysis of the verbatim transcript of the focus group discussion was carried out to find out recurring meanings. Thematic analysis in this study involved 1) familiarizing with the data through reading and re-reading the transcript; 2) generating initial codes through in vivo coding; 3) coming up with candidate themes by searching for meaningful patterns among the codes; 4) reviewing and re-classifying the themes by checking them against the transcript; 5) reporting the findings based on the emerging themes that were drawn from the gathered data (Braun et al., 2018).

Results

A total of 67 students coming from different sections completed both the pre-test and post-test surveys sent to them via email. These surveys yielded an approximately 10% response rate. The survey respondents were 19.54 $\pm$ 0.93 years old. 62.69% (42 of them) were females, while 37.31% (25 of them) were males. Almost all were in their second year of undergraduate studies.

Table 1 shows the GSLQ scores of the survey respondents on pre-test and post-test. Out of the highest possible sum of 240, their total GSLQ scores on pre-test and post-test were 205.33 $\pm$ 17.15 and 208.54 $\pm$ 20.76, respectively. One-tailed paired sample t test revealed there was a statistically significant increase in the total GSLQ scores of the survey respondents after taking *Science, Technology, and Society* over for six weeks during the first year of the COVID-19 pandemic (p = 0.03). Among the constructs of the Global Scientific Literacy Framework, statistically significant higher scores were observed at the end vis-à-vis at the start of the course for systematic thinking and information management (p = 0.01) as well as self-directed planning and monitoring (p = 0.02). The rest of the constructs, however, posted no significant difference in scores before and after the six-week online classes in *Science, Technology, and Society*.

Table 1. Pre-Test and Post-Test GSLQ Scores (n = 67)

Dimensions of Global Scientific Literacy Framework	*Pre-Test Score*	*Post-Test Score*	*p value*
Habits of Mind			
Communication/Collaboration	20.87 $\pm$ 2.75	21.10 $\pm$ 2.43	0.21
Systematic Thinking/Information Management	33.12 $\pm$ 4.46	38.28 $\pm$ 4.13	0.01
Character and Values			
Ecological Worldview/Compassion	29.30 $\pm$ 4.26	29.75 $\pm$ 4.98	0.14

Socio-Scientific Accountability	08.13 ± 1.95	08.34 ± 1.97	0.15
Science as a Human Endeavor			
Characteristics of Scientific Knowledge	13.51 ± 1.39	13.28 ± 1.45	0.13
Science and Society/Spirit of Science	46.54 ± 3.17	46.59 ± 4.26	0.47
Metacognition and Self-Direction			
Planning and Monitoring	41.70 ± 4.87	42.85 ± 5.23	0.02
Evaluating	12.16 ± 2.09	12.45 ± 2.21	0.15
Total	205.33 ± 17.15	208.54 ± 20.76	0.03

A total of five students took part in the focus group discussion. They were 19.40 ± 0.55 years of age. 20% (1 student) described themselves as female, whereas 80% (4 students) identified themselves as male. 60% (3 students) and 40% (2 students) were in their second year and third year of undergraduate studies, respectively. 60% (3 students) were from the field of science and engineering, 20% (1 student) belonged to the field of humanities, and another 20% (1 student) came from the field of management.

When asked during the focus group discussion what are their understanding of scientific literacy, student A considered it as "beyond being knowledgeable about scientific facts." For student B, scientific literacy is "not just about formulas." He defined it as the "use of science in real, urgent issues." Scientific literacy, as student C pointed out, also involves the application of scientific reasoning and practices to "connect the dots" to arrive at "a better grasp of real-world phenomena." It entails, according to students B, D, and E, "triangulating credible sources" to distinguish the scientific truth from erroneous claims.

Whether they regard themselves as scientific literate based on their understanding of it, all of them believed so and they partly attributed their increase in scientific literacy to *Science, Technology, and Society*. Student A felt this course reinforced and built on the competencies they learned from previous science classes. Student B even brought up how "thankful" he is that his classes in *Science, Technology, and Society* "reminded [him] of what matters the most about science," while student C found the course offering itself as "very insightful and interesting."

This positive feedback about their experiences in *Science, Technology, and Society* can be due to the topics covered in class as they piqued the interest of the focus group discussion participants. Although students A and C found topics, such as the scientific method and the environmental impact of climate change, were already tackled in their previous subjects, the discussion of the module contents offered them "new perspectives." Specifically, the application of "social frameworks" in understanding how science and technology are intertwined with society, as student C explained, gave them an "interdisciplinary view." For student B, the approach to *Science, Technology, and Society* was "very different from how [he] learned in elementary." It was not "bookish." Furthermore, the assigned readings and complementary resources like the curated YouTube videos, according to students C, D, and E, were quite engaging. The learning materials made available to them also impressed students B and E as several of these resources are "contextualized to Philippine realities."

Student B appreciated the compulsory use of the discussion board in their Canvas Learning Management System in fostering his scientific literacy as there were opportunities to exchange views with his classmates about science-related issues. Additionally, most of the focus group discussion participants, such as student A, identified the classes held online through Zoom as helpful in making them learn and become more scientifically literate since their teachers can explain further the concepts and synthesize the main points of the module. The way they were assessed for the course learning outcomes could have contributed as well to facilitating their scientific literacy. Instead of being given objective test items, which for students B, C, and D can be easily passed through rote memorization, they were "challenged to understand the lessons well," "research on the topic," and "organize their thoughts" so that they could better compose essays synthesizing their learning and insights about the module. There were also occasions to learn from their classmates and gather different perspectives as they must collaborate for their group requirements.

The focus group participants, however, felt that the six-week duration to go through the four modules in *Science, Technology, and Society* was rather short. For instance, the assigned readings, as student D pointed out, "was too much" given the limited time to complete the course. Students B and E deemed they could have learned further if there was a presentation of their module synthesis in which they could share with others their insights and engage the class in a meaningful discussion. Such activities were not taken up in their classes due to time constraints, among others.

Discussion

The COVID-19 pandemic has upended the way we carry out our daily lives. How science is taught and learned is no exception as educational institutions across the world have resorted to online delivery of classes to minimize the disruption to learning in spite of the public health crisis. On one hand, this abrupt shift from in-person classes to remote learning has posed challenges to teachers and students alike as both have been caught off guard by the pandemic: teachers must swiftly translate their lessons to make them suitable for remote learning, while students must quickly adapt to the unfamiliar terrains of learning in an online environment. On the other hand, the pandemic has accelerated the adoption of online platforms for teaching as educational institutions harness the positive aspects of information technology in promoting scientific literacy, among others, despite the global crisis. There are, however, few studies that look at students' acquisition of scientific literacy within the context of adverse situations, such as a pandemic. Hence, this study seeks to find out if there would be a significant increase in scientific literacy among undergraduate students after taking the government-mandated science education as a six-week online course offered during the first year of the COVID-19 pandemic. It also intends to understand which aspects of their science education during a time of pandemic would these students find helpful in facilitating their scientific literacy.

Comparing the total GSLQ scores on pre-test and post-test, this study showed there was a significant increase in scientific literacy among undergraduate students after going through a six-week online course offered during the first year of the pandemic as part of their science education. Qualitative data from the focus group discussion supported these results as student participants felt they became more scientifically literate by the end of the course offering based on their understanding of scientific literacy as the use of scientific reasoning and practices not only to comprehend the world but to also solve urgent issues in society. This gain in scientific literacy could be particularly attributed to improvement in their systematic thinking and information management as well as in self-directed planning and monitoring.

Systematic thinking and information management are foundational to scientific inquiry (Krajcik & Sutherland, 2010). They represent higher levels of thinking, which allow individuals to see the whole without losing sight of its parts (Almamuri & Shaalan, 2021). They entail logically organizing gathered data and critically evaluating various resources to find relevant information, methodically analyzing data for patterns to explain observations and arrive at valid conclusions, and innovatively applying new or prior understanding to draw the best solutions to real-world problems (Mun et al., 2015).

In this study, students probably became better at systematic thinking and information management due to the course design. First, the topics covered in class were engaging for the students, affording them to see multiple perspectives with the use of social frameworks to examine science-related issues. Ensuring that the course content in an online setting would be engaging to students, as Tsang et al. (2021) point out, is crucial in motivating them to learn in adverse situations. Doing so can foster higher levels of thinking despite the constraints brought by the pandemic as students are given meaningful opportunities to break down, integrate, and synthesize concepts, discover nuances, and apply the knowledge they acquired in challenging ways (Schaber & Shanedling, 2012). Second, the incorporation of online discussion boards as part of the students' asynchronous learning helped them to externalize their thinking and exchange views with other students about science-related issues. Embedding student-student interaction using online discussion boards can facilitate student-content interaction as students, according to Ertmer et al. (2011), are offered meaningful opportunities to "interact with each other over course-related topics" through the "processes of articulating, reflecting on, and negotiating their understandings of course content" without the pressure of responding to the posts instantaneously (p. 158). Third, employing videoconferencing for synchronous learning provided the students with real-time support from their teachers as concepts in class can be clarified and main points from the module can be run through. This student-teacher interaction, which among others involves students asking questions and their teachers providing timely feedback, is vital in promoting higher levels of thinking and mediating learning outcomes as there are meaningful opportunities to connect new concepts with prior knowledge (Tsang et al., 2021). Lastly, knowledge construction instead of rote learning was the focus of the assessment as students must collaborate for their group requirements and they must individually demonstrate a deep understanding of science-related issues in view of course content. Student-student interaction in an online environment through giving collaborative learning tasks can facilitate higher levels of thinking by recognizing that knowledge takes place within a social context (Hussin et al., 2019), while student-content interaction through assigning reflective tasks can similarly foster higher levels of thinking by emphasizing the contribution of meaning-making in effective learning (Ertmer et al., 2011; Safitri et al., 2019).

Self-directed planning and monitoring are also transferable skills that are necessary for carrying out a scientific inquiry. They, as Mun et al. (2015) describe, "refer to an individual's capability to use cognitive resources actively in order to regulate one's own thinking and improve [the] capability to understand" (p. 1746). These transferrable skills help individuals to decide when they need further information, what data they need, and whether they understand the gathered information (Choi et al., 2011).

In this study, self-directed planning and monitoring improved among students after taking *Science, Technology, and Society* within six weeks during the first year of the pandemic probably because of the nature of remote learning, which demands greater responsibility among learners for their learning. Specifically, asynchronous learning warrants independence and self-regulation, while synchronous learning necessitates connectivity, interaction, and collaboration (Garrison, 2003). Such findings reflect how the students were bound to take control of their learning by being proactive and autonomous as teaching abruptly shifted to an online setting during the pandemic. Similar to the study of Maphalala et al. (2021), these students were challenged by the extraordinary circumstances to adopt learning strategies that would help them navigate through remote learning within the context of a pandemic.

The other dimensions of the Global Scientific Literacy Framework, however, were not further developed among the students in this study due to several reasons. First, the six weeks allotted for the online course offering may not be enough for the students to acquire the other dimensions of scientific literacy. Second, cognitive overload could have taken place as there were plenty of learning materials to go through over a short period. Third, the pandemic is not an ideal context to learn. Fourth, some students may have not adapted well to the abrupt shift from in-person classes to remote learning. Fifth, there could have been more collaborative tasks to promote social presence in an online setting.

Conclusion

Scientific literacy has become imperative in this age of I.R. 4.0. The COVID-19 pandemic, however, has challenged the acquisition of scientific literacy among students as the delivery of science education has suddenly shifted from in-person classes to remote learning. Nevertheless, this mixed methods study showed that there could still be a gain in scientific literacy despite the constraints on science education by the pandemic. An improvement in systematic thinking and information management as well as self-directed planning and monitoring among the students can account for such an increase in scientific literacy. Students became better at systematic thinking and information management possibly because of the course design wherein elements of student-teacher interaction, student-student interaction, and student-content interaction were purposively included in the teaching-learning process that takes place in an online setting. The very nature of remote learning that requires students to be more responsible for their learning, on the other hand, can explain why there was an improvement in their self-directed planning and monitoring. The role of teachers as facilitators of learning within the context of adverse situations, such as pandemics, is therefore crucial as they map out and implement course design and they offer instructional as well as psycho-emotional support to students, who must adjust to the unfamiliar terrain of remote learning. Findings from this study can offer valuable insights for science educators and higher education institutions on how to ensure quality education when using remote learning during pandemics and other adverse situations.

Recommendations

Several recommendations for future research are listed below in view of the limitations that were encountered in this study. First, the constructs used for scientific literacy in this study were confined to the theoretical framework suggested by Choi et al. (2011) and Mun et al. (2015). Other studies may consider other theoretical frameworks in measuring and evaluating scientific literacy. Second, this study only offered observations and explanations on the acquisition of scientific literacy during the latter part of the first year of the pandemic. Additional studies may be needed to better understand the development of scientific literacy among students during the early months of the pandemic and throughout the remainder of this public health crisis. Third, the study participants volunteered to take part in this research and may not represent other students within and outside the examined university. Future studies may benefit from carrying out probability sampling and investigating multiple educational institutions. Fourth, this study only yielded a 10% response rate to the online surveys despite the researchers repeatedly sending out email notifications. It also garnered more female participants than males. Asking the teachers to remind their students about the surveys, giving incentives to the respondents, and assuring the students of the anonymity of their responses and the practical usefulness of these responses are some of the strategies that other studies may employ to increase the survey response rate. Lastly, the study participants came from classes handled by different teachers. Their learning experiences during the pandemic may therefore vary. Future studies may find it useful to use analysis of covariance to account for the difference in teachers.

Acknowledgment

This research study was made possible through a grant from the Ateneo Research Institute of Science and Engineering (ARISE).

References

Almamuri, A.H., & Shaalan, F.A.H. (2021). Systematic thinking among university students. *Turkish Online Journal of Qualitative Inquiry, 12*(3), 3792-3803.

Braun V., Clarke V., Hayfield N., & Terry G. (2018). Thematic analysis. In P. Liamputtong (Ed.), *Handbook of Research Methods in Health Social Sciences* (pp. 1-18). Springer.

Braund, M. (2021). Critical STEM literacy and the COVID-19 pandemic. *Canadian Journal of Science, Mathematics and Technology Education, 21*(2), 339-356. https://doi.org/10.1007/s42330-021-00150-w

Choi, K., Lee, H., Shin, N., Kim, S.W., & Krajcik, J. (2011). Re-conceptualization of scientific literacy in South Korea for the 21st century. *Journal of Research in Science Teaching, 48*(6), 670-697. https://doi.org/ 10.1002/tea.20424

Dovgyi, S., Nebrat, V., Svyrydenko, D., & Babiichuk, S. (2020). Science education in the age of Industry 4.0: Challenges to economic development and human capital growth in Ukraine. *Scientific Bulletin of National Mining University*, 2020 (1), 146-151. https://doi.org/10.33271/nvngu/2020-1/146

Edmonds, W.A., & Kennedy, T.D. (2017). *An Applied Guide to Research Designs: Quantitative, Qualitative, and Mixed Methods*. SAGE Publications, Inc.

Ertmer, P.A., Sadaf, A., & Ertmer, D.J. (2011). Student-content interactions in online courses: The role of question prompts in facilitating higher-level engagement with course content. *Journal of Computing in Higher Education, 23*(2), 157-186. https://doi.org/10.1007/s12528-011-9047-6

Garrison, D.R. (2003). Cognitive presence for effective asynchronous online learning: The role of reflective inquiry, self-direction, and metacognition. *Elements of Quality Online Education: Practice and Direction, 4*(1), 47-58.

Han, Q. (2020). Introduction: The COVID-19 pandemic calls for the strengthening of scientific culture. *Cultures of Science, 3*(4), 223-226. https://doi.org/10.1177/20966083211003343

Hussin, W.N.T.W., Harun, J., & Shukor, N.A. (2019). Online interaction in social learning environment towards critical thinking skill: A framework. *Journal of Technology and Science Education, 9*(1), 4-12. https://doi.org/10.3926/jotse.544

Krajcik, J.S., & Sutherland, L.M. (2010). Supporting students in developing literacy in science. *Science, 328*(5977), 456-459. https://doi.org/10.1126/science.1182593

Krueger, R.A. (2015). *Focus Groups: A Practical Guide for Applied Research.* SAGE Publications, Inc.

Maphalala, M.C., Mkhasibe, R.G., & Mncube, D.W. (2021). Online learning as a catalyst for self-directed learning in universities during the COVID-19 pandemic. *Research in Social Sciences and Technology, 6*(2), 233-248. https://doi.org/10.46303/ressat.2021.25

Melinda, S., & Sa'ud, U.S. (2022). STEM in science learning in the era of the Industrial Revolution 4.0. *International Conference on Elementary Education, 4*(1), 779-785. http://proceedings.upi.edu/index.php/icee/article/view/2055

Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J.M., Ramírez-Montoya, M.S., Navarro-Tuch, SA., Bustamante-Bello, M.R., Rosas-Fernández, J.B., & Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers & Electrical Engineering. 93*(1), 107278. https://doi.org/10.1016/j.compeleceng.2021.107278

Moraes, E.B., Kipper, L.M., Kellermann, A.C.H., Austria, L., Leivas, P., Moraes, J.A.R., & Witczak, M. (2022). Integration of Industry 4.0 technologies with Education 4.0: Advantages for improvements in learning. *Interactive Technology and Smart Education*. Advanced online publication. https://doi.org/10.1108/ITSE-11-2021-0201

Mun, K., Shin, N., Lee, H., Kim, S.W., Choi, K., Choi, S.Y., & Krajcik, J.S. (2015). Korean secondary students' perception of scientific literacy as global citizens: Using global scientific literacy questionnaire. *International Journal of Science Education, 37*(11), 1739-1766. https://doi.org/10.1080/09500693.2015.1045956

Organisation for Economic Co-operation and Development. (2019). *PISA 2018 Assessment and Analytical Framework.* OECD Publishing. https://doi.org/10.1787/b25efab8-en.

Reddy, D. (2021). Scientific literacy, public engagement, and responsibility in science. *Cultures of Science, 4*(1), 6-16. https://doi.org/10.1177/20966083211009646

Roth, W.M. (2003). Scientific literacy as an emergent feature of collective human praxis. *Journal of Curriculum Studies, 35*(1), 9-23. https://doi.org/10.1080/00220270210134600

Persic, A., Beigel, F., Hodson, S., & Oti-Boateng, P. (2021). The time for open science is now. In S. Schneegans, J. Lewis, & T. Straza (Eds.), *UNESCO Science report: The race against time for smarter development* (pp. 12-16). UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000377433.locale=en

Safitri, H., Hamidah, I., & Setiawan, W. (2019). The preliminary study of learning interaction in physics concepts for developing e-learning to promote students' critical thinking. *Journal of Physics: Conference Series, 1157*(3), 032054. https://doi.org/10.1088/1742-6596/1157/3/032054

Schaber, P., & Shanedling, J. (2012). Online course design for teaching critical thinking. *Journal of Allied Health, 41*(1), 9e-14e.

Schneegans. S., & Nair-Bedouelle, S. (2021). Scientific literacy: An imperative for a complex world. In S. Schneegans, J. Lewis, & T. Straza (Eds.), *UNESCO Science report: The race against time for smarter development* (pp. 17-19). UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000377433.locale=en

Shi, W.Z. (2022). Understanding the nature of science through COVID-19 reports. *Nature Human Behaviour, 6*(3), 311. https://doi.org/10.1038/s41562-022-01303-z

Stewart, D.W., & and Shamdasani, P.N. (2015). *Focus Groups: Theory and Practice*. SAGE Publications, Inc.

Tsang, J.T., So, M.K., Chong, A.C., Lam, B.S., & Chu, A.M. (2021). Higher education during the pandemic: The predictive factors of learning effectiveness in COVID-19 online learning. *Education Sciences, 11*(8), 446. https://doi.org/10.3390/educsci11080446

United Nations. (2020). *The Sustainable Development Goals report 2020.* https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf