Scientific Practices In The Context Of STEM Education: A Case Study In Primary Education

Achilleas Mandrikas, Constantina Stefanidou, Kyriakos Kyriakou, Constantine Skordoulis
University of Athens

Abstract

The results of a STEM educational program named "The air we breathe" implemented in a primary rural school in Greece as part of a National Research Project entitled "Diffusion of STEM (DI-STEM)" are presented in this paper. The educational program deepened in air pollution and intended to foster students' eight scientific practices proposed by the NGSS. Results derived from students' pre-post test questionnaires revealed great progress in five of the scientific practices (evaluating appropriate methods and tools for collecting data, developing & using models, constructing explanations, engaging in argument from evidence and evaluating & communicating using tables, diagrams, and charts) and moderate progress in three of the scientific practices (asking questions and defining problems, planning & carrying out investigations, and using mathematics). The implications for successful STEM education in primary education are discussed.

Keywords: STEM education, primary education, scientific practices

Introduction

The term "STEM education" refers to teaching and learning in the fields of science, technology, engineering, and mathematics in an integrated way across all grade levels in both formal and informal classroom settings (Kelley & Knowles, 2016; Martín-Páez et al., 2019; Ortiz-Revilla et al., 2020). STEM education is a purely student-centered approach that fosters students' scientific and technological literacy through familiarization with everyday life problems (Du Plessis, 2018; Hathcock et al., 2014; Karakaya et al., 2020). It has been proposed as an educational reform of science education in the last two decades worldwide (Bybee, 2013; Honey et al., 2014; MacFarlane, 2016; National Research Council, 2011).
Although there is no consensus on the definition of STEM (Bybee, 2013; Hsu & Fang, 2019), many educators and policymakers promote STEM practices in classrooms (Bybee 2011, DeCoito 2014; Rosicka 2016), because STEM education offers a pedagogic approach based on project-based learning (Kelley & Knowles, 2016; Roberts et al., 2018) and prepares students for 21st century skills by engaging them in real-world problem solving (Perdana et al., 2021; Binns et al., 2016; Garibay, 2015).

Inquiry-based learning has been proposed as the most effective teaching method in science education and consequently inquiry is considered the mainstream teaching strategy also in STEM education. Since 1916 "inquiry" has been proposed by Dewey as a student-centered process in education, a view that was reinforced in 1962 when Schwab argued for "enquiry into enquiry" in science education (Tytler & White, 2019). Since then, "practical investigations that focus on the specific processes by which scientific knowledge is built through empirical evidence" (Tytler & White, 2019, p. 174) are often proposed for implementation in the science classroom. In this way, students are prepared for life and work by acquiring skills including complex problem-solving, critical and creative reasoning, collaboration, communication, and digital literacy. As a result, students through engaging in scientific practices foster their critical thinking skills and gradually become lifelong learners of science (Crawford & Capps, 2018, p. 9).

During the last decade science curricula refine and emphasize inquiry in science education in many countries. This tension has been officially declared in institutional declarations, forms or legislation in the USA through the Next Generation Science Standards (National Research Council, 2013), in the UK (United Kingdom Department for Education, 2014), in Australia (Australian Assessment, Curriculum, and Reporting Authority, 2013; Victorian Curriculum and Assessment Authority, 2015), in Israel (Barnea et al., 2010), in Singapore (Ministry of Education of Singapore, 2007), in Taiwan (Ministry of Education, 2013). In the US "Framework for K-12 Science Education" (National Research Council, 2012) and "Next Generation Science Standards" (National Research Council, 2013) the term "inquiry" has been replaced by eight "Scientific and Engineering Practices" (Crawford & Capps, 2018, p. 13), which are essential for K-12 science and engineering curriculum:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and design -ing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

These scientific practices describe and refine "inquiry" and students' progression in them at the end of secondary education should be measured as important competencies for life (National Research Council, 2012, p. 49).

After the publication of the "Framework for K-12 Science Education" a long debate concerning the use and the meaning of the terms "inquiry" and "science practices" has been developed (Garcia-Carmona, 2020; Lederman & Lederman, 2014; Tytler & White, 2019). In this frame, Stroupe (2015, p. 1034) defines scientific practices "as the learnable and valued dimensions of disciplinary work, both tacit and explicit, that people develop over time in a specific place, such as a laboratory, field station, or classroom". Garcia-Carmona (2020, p. 457) analyzes the shift from "inquiry" to "science practices" from a critical and reflective view and concludes that "the practice-based approach could be the enhanced version of that based on inquiry, and therefore to represent a complete and holistic image of science". Concerning the debate about the terminology between "practices" and "skills" the "Framework for K-12 Science Education" clearly refer "We use the term 'practices' instead of a term such as 'skills' to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice." (National Research Council, 2012, p. 30)

As a contribution to the "terminology debate" some researchers have tried to find coherent elements or dimensions of science. For example, Duschl (2008) described scientific practice and provided a description of four dimensions of science: conceptual, social, epistemic and material dimension. The "Framework for K-12 Science Education" proposes three integrating dimensions in science teaching: eight scientific practices, seven crosscutting concepts and disciplinary core ideas (Bybee, 2014; National Research Council, 2012, p. 3).

Scientific practices have been in the state of the art in recent years. It is worth noting that Science & Education hosted a special issue entitled "Scientific Practices, Epistemic Aims, and Learning Progressions" in 2018. In this special issue tensions in educational experiences, types of disciplinary practices and new perspectives on learning progressions for scientific practices have been recorded (Kelly, 2018). A variety of pedagogical and didactical terms has been recorded in the literature as relative and corresponding with scientific practice: problem-based approach, authentic experience, real-work issues, hands-on activities (see Anand & Dogan 2021; Campbell & Oh, 2015; Garcia-Carmona, 2020; Garibay, 2015; Kang et al., 2019; Martín-Páez et al., 2019; Roberts et al. 2018; Stroupe, 2015; Tytler & White, 2019). Moreover, many researchers believe that such kind of activation supports the development of students' critical thinking (Crawford & Capps, 2018; Evangelisto, 2021; Kelley & Knowles, 2016; Margot & Kettler, 2019).

However, research concerning fostering students' scientific practices proposed by "Next Generation Science Standards" (NGSS) is limited. Campbell & Oh (2015) addressed key facets of modelling instruction or design features of modeling curriculum, without emphasis on other scientific practices. Reiser, Berland & Kenyon (2012) examined in detail scientific practices of explanation and argumentation in the light of the proposals of the NGSS. After defining argumentation and explanation individually, they concluded that "The two practices depend on each other: For students to practice explanation construction, they must also engage in argumentation" (p. 6). Kang, McCarthy & Donovan (2019) investigated in what extent secondary teachers tend to incorporate scientific practices proposed by the NGSS in their science teaching practice. Analysis of classroom observations revealed that "Engaging in Argumentation" was the most successfully incorporated scientific practice (p. 788).

Arias et al. (2016) focused on four scientific practices, recording scientific observations, constructing evidence-based claims, making predictions with justification, and designing investigations, as aspects of the larger scientific practices of conducting investigations, scientific argumentation, and constructing explanations. However, they investigated how might curriculum materials could support teachers to engage students in these scientific practices. Crawford & Capps (2018) investigated what teachers need to know to engage children of all ages in scientific practices in the classroom. Although this research referred to teachers, one of the conclusions was that "engaging children in scientific practices is not an easy way to teach science" (p. 27).

In our research the fostering of the eight scientific practices proposed by the NGSS through the implementation of a STEM education program in a primary school is investigated. The implemented program entitled "The air we breathe" deepened on air pollution, a core environmental issue, intending to contribute to "human sustainability", as proposed by the NGSS (Feinstein & Kirchgasler, 2014; National Research Council, 2013).

Methodology

Research question

The research question of the present study is as follows: to what extent the STEM educational program entitled "The air we breathe" contributes to fostering primary students' scientific practices. Specifically, the research is analyzed regarding: 1. Asking questions & defining problems 2. Planning & carrying investigations 3. Evaluate appropriate methods and tools for collecting data 4. Developing & using models 5. Using mathematics (qualitative & quantitative data) 6. Constructing explanations 7. Engaging in argument from evidence 8. Evaluating & communicating data through tables, diagrams, and charts.

Sample

The research sample consists of 48 primary students (K-4 & K-5, 10 and 11-year-old students), members of 2nd Elementary School of Messini, a school located in a Greek rural area without any previous experience in STEM education. K-4 students were 28 (13 in D1 class and 15 in D2 class) and K-5 students were 20 (all in E1 class). The school participated in DI-STEM project as one of the "Research, Innovation and Dissemination Hubs" in order to get involved in STEM education through teachers' seminars and implementation of STEM activities in class. The school was chosen to participate in DI-STEM project in order to strengthen itself as a place of education for vulnerable social groups, which theoretically have fewer opportunities to get involved in modern educational research programs. Forty-eight students implemented in their own class (D1 class, D2 class, E2 class) the STEM educational program named "The air we breathe". This program included the construction of "air pollution detectors" by everyday materials, their exposure in different external locations, data recording and observing by microscope, data interpretation and presentation in diagrams. Moreover, primary students constructed "air filtering device" by everyday materials, tested its function and redesigned the filter improving the filtering effect.

Data collection

Data were collected from March to April 2023 and derived from the same questionnaire completed by the students before and after the implementation of the educational program named "The air we breathe".

Students' questionnaire consisted of 8 questions, 6 open-ended, 1 multiple choice and 1 based on student's sketch/painting. The questionnaire was structured in eight (8) categories, in accordance with the above-mentioned scientific practices proposed by the NGSS. Regarding the validity of the questionnaires, it is provided by the fact that all questions are related to eight scientific practices under consideration (content validity) and vice versa, the questionnaires include all scientific practices as they are analyzed in the NGSS. Moreover, the questionnaires are thoroughly tested by two experts, experienced schoolteachers. They both agreed on the content validity of all items (Polit & Beck, 2006).
Questionnaires were created and distributed in printed form by the authors and were completed by students under teachers' supervision.

Data analysis

Regarding the multiple-choice question, answers were sorted based on the pre-determined answers and recorded in Table 1. Percentage differences between pre & post questionnaires have been estimated and discussed. Regarding the open-ended questions, qualitative content analysis method was used to analyze the data (Mayring, 2015). The answers have been divided in three categories named "scientifically acceptable", "partially scientifically acceptable" and "unacceptable". Criteria for this division were the scientific explanation provided and the accuracy of the text given the age of the students.

Results And Discussion

Asking questions & defining problems

Students were asked to identify scientific (testable) and non-scientific (non-testable) questions among five given statements (Table 1). Although most students had correctly identified the scientific questions before the

1. The air in the village whets the appetite		2. The air in the village is cleaner		3. The air in the village has more pollen than the air in the city		4. Village air causes fewer asthma attacks than city air		5. The air in the village helps longevity	
PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
19%	13%	83%	90%	58%	92%	60%	85%	27%	23%

Table 1: Which questions are scientific (testable) and non-scientific (non-testable)? (Note: students could give more than one answers)

implementation of the STEM activities (sentences 2, 3, 4), their answers increased even more afterwards. In addition, incorrect answers (sentences 1, 5) decreased after the implementation of STEM activities.

Students' experience through "The air we breathe" seems to have reinforced their ability to recognize testable questions and thus to ask questions that can be investigated. However, there is still space to improve, because real scientific progress for students would be to answer what would happen if a variable changed, to predict reasonable outcomes based on patterns, to describe problems that can be solved. It seems that engagement in scientific investigations is a complicated procedure, a fact also ascertained by other researchers: "students' engagement in science practices is complex and multiple kinds of knowledge are needed to teachers (science concepts and principles, context, culture, nature of science, scientific practices, pedagogy, assessment)" (Crawford & Capps, 2018, p. 9).

Planning & carrying out investigations

When the students were asked before the STEM activities how they would check if "The air in the village has more pollen than the air in the city", the majority (65%) responded by formulating a general personal opinion or citing experience: "The village has more pollen than the city, because in the village there are many more flowers" (E2 class, student 3), "I guess so, because in the villages there are more flowers, therefore more pollen" (D1, st. 5), "I've seen it myself" (D1, st. 2), "My parents told me" (D1, st. 3), "I read it in the encyclopedia" (D1, st. 1), "I've read it in books" (D1, st. 10), "I know it from the internet" (D1, st. 8). Other students responded with references to instruments of observation: "...with magnifying glasses" (D2, st. 3), "... observing a flower with a microscope" (D2, st. 9), "We can check it by the number of flowers" (D2, st. 8) or they didn't answer the question at all.

After the STEM activities and after construction and use of "air pollution detectors" the vast majority of students (86%) answered correctly (Table 2) and accurately indicating the authentic experience that mediated: "I will put one detector in the village and one in the city and then I will compare them with the microscope" (E2, st. 1), "We will put detectors in different places in the city and in the village and then we will compare them" (E2, st. 1), "It can be checked with the air pollution detector" (D2, st. 11).
It is obvious that students' ability in planning and carrying out investigations to answer questions or test solutions to problems has been increased after the experience of STEM activities through "The air we breathe". Moreover, some answers imply that progress in investigation includes control of variables, use of fair test, number of trails, and collaborative work. All these elements could be considered as evidence to support students' ability for providing explanations or design solutions.

Considering this question as an introduction to problem-solving process, our findings are compatible with proposals of Crippen and Antonenko (2018), who believe that "the problem-solving process in STEM education requires authentic practices and development of collaborative skills at the cognitive and metacognitive levels" (p. 89). In addition, similar primary students' active enactment has been recorded by Kang et. al. (2019). Moreover, such progress in problem-solving of real-life issues has been characterized by Garibay (2015) as an important element of critical thinking.

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unacceptable	scientifically acceptable	partially scientifically acceptable	Unacceptable
How do you think the sentence "The air in the village has more pollen than the air in the city" can be tested?	6%	65%	29%	86%	6%	8%

Table 2. Percentages of 48 answers about planning & carrying out investigations

Evaluate appropriate methods and tools for collecting data

Students were asked to choose suitable objects and make a measuring instrument, device, experimental set-up or procedure to check whether the air in the village has more pollen than the air in the city and to depict it with a sketch or a drawing.

Before implementation, the majority of responses (67%) were very vague: "I will put transparent tape on it and see the pollution" (D1, st. 6), "I will stick a bottle on the tree" (D1, st. 9) or displayed great imagination beyond any scientific explanation: "If we take a big fan and put it inside the village, it will pull all the pollen onto it" (E2, st. 1), "With a vacuum cleaner we suck up both the air and the pollen" (E2, st. 2), "With a device that would have a thermometer" (E2, st. 17). Very few answers indicated some kind of measurement and some methodology: "We could use cardboard with an adhesive tape that the pollen will stick on it" (E2, st. 12).

An impressive conversion of responses was recorded after the implementation of the STEM activities (Table 3). The students had been involved in the construction of such devices, had placed them in suitable places, had collected traces of pollen, dust and atmospheric pollutants and observed them under the microscope, thus they were now in a position to give a scientifically acceptable answer to this question. The vast majority (81%) could list the materials, the process and the measuring instrument: "I can make a detector out of cardboard, string, a marker and adhesive tape" (E2, st. 16) (Figure 1) and in some cases also the location (Figure 2 & 3) or at least (17%) described the basic process "I hung detectors in the trees" (D1, st. 6) (Figure 4).

It is clear that students' ability in evaluating appropriate methods and selecting tools for collecting data has been highly increased after the experience of "The air we breathe". This ability also includes progress in ability of

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unacceptable	scientifically acceptable	partially scientifically acceptable	unacceptable
Make a measuring instrument, a device, an experimental set-up or a procedure to test whether the air in the village has more pollen than the air in the city (sketch)	10%	23%	67%	81%	17%	2%

Table 3: Percentages of 48 answers about methods and tools for collecting data

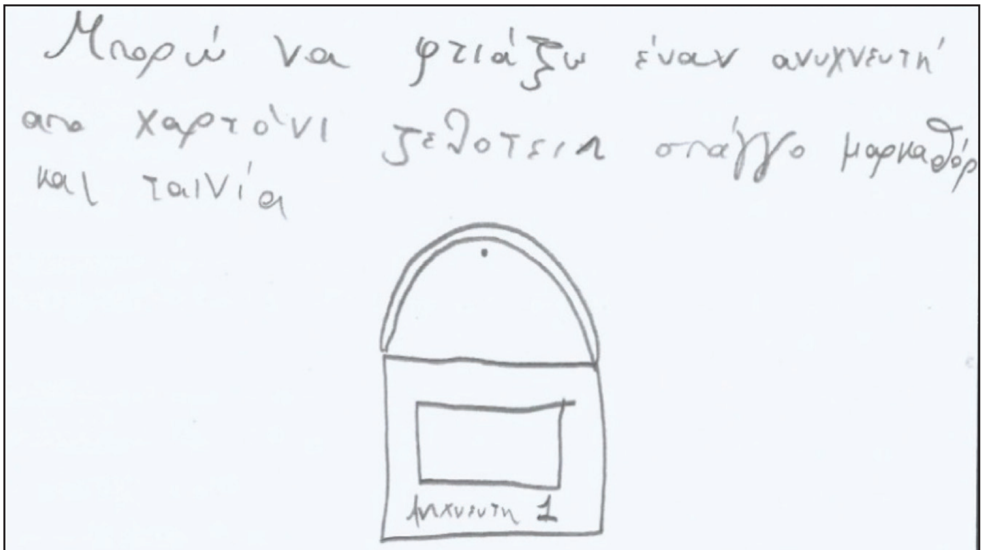

Figure 1. "I can make a detector out of cardboard, string, a marker and adhesive tape – Detector 1" (E2, st. 16)

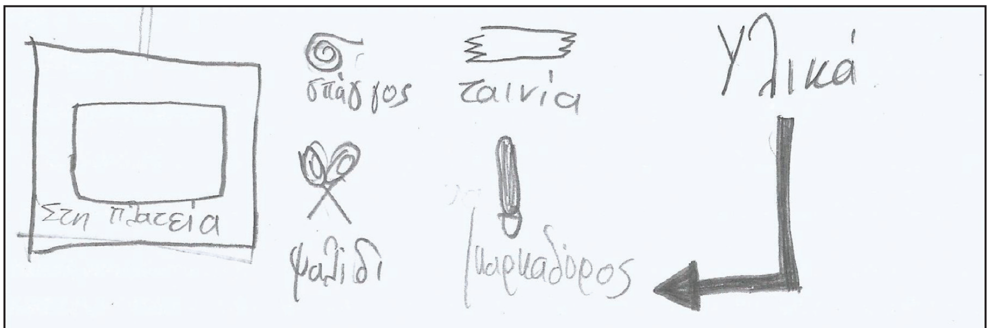

Figure 2. "String, a marker, scissors, adhesive tape (material) – In the square" (E2, st. 6)

Figure 3. "Detector 11: central square" (D2, st. 1)

Figure 4. "I hung detectors in the trees" (D1, st. 6)

making observations, taking measurements to produce data, searching for evidence to give an explanation or a design solution.

Our findings are compatible with those of Kang et al. (2018), who recorded "Analyzing and Interpreting Data" as the most enacted practices by students and teachers (p. 798). This indicates that all teachers and all students actively engaged in this practice during the lesson, exactly as in our STEM educational program, when students actively constructed their own tools, collected data from investigations, made real-time observations and comparisons between data recordings.

Asking questions & defining problems

Concerning students' ability to develop and use models, primary students were asked where air pollution detectors "show more pollution" (Table 4).

Before the implementation of the STEM activities, half of the students (48%) answered partially correctly in an intuitive way, based on personal experience and knowledge either by separating the city from the village: "The city has more pollution because there are many cars in circulation" (D2, st. 11), "I think in the city, because it has factories and a lot of cars" (D2, st. 13) or by identifying specific locations in a city: "In my opinion they would show more pollution in parking areas, intersections, gas stations and coffee shops" (D1, st. 5), "At the traffic lights" (D1, st. 10), "In the square of Messini" (E2, st. 7).

After the experience of the STEM activities, almost all students (92%) answer correctly and provide an adequate explanation: "I think it will have more pollution on the road, because there are a lot of cars passing by" (E2, st. 1), "Where there are many cars, i.e. at the traffic lights of Messini because [there are] exhausts and exhaust gases" (E2, st. 9), "In the central square, in factories, in ports and at traffic lights" (D2, st. 1).

Prior knowledge and estimation ability was obviously increased through STEM collaborative activities including authentic measurements, comparisons of findings, microscope detection, and discuss for explanations. In this way, students built a model to test cause and effect relationships based on the analogy "more pollutants in the air mean more pollution in the location". Although these relationships among variables were evident, students fostered their ability to check for frequent and regular occurring events, to describe phenomena, to make predictions about what would happen if a variable changes, to describe an occurring scientific principle, and to explain interactions concerning the functioning of a natural or designed system. Final students' answers were improved in such extent, that we could suppose that in some cases students could test or compare more than one model of "air pollution detectors" to determine which better meets criteria for success.

Students' progress in developing and using models recorded in our sample satisfies Campbell & Oh (2015)

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unacceptable	scientifically acceptable	partially scientifically acceptable	unacceptable
If you had air pollution detectors available, where do you think they would "show more pollution"?	29%	48%	23%	92%	8%	0%

Table 4. Percentages of 48 answers about developing & using models

suggestion for "pedagogies for transforming scientific practices of modeling into students' experience" (p. 125) implying that this transformation was successful through "The air we breathe".

Using mathematics (qualitative and quantitative data)

A question asking students to judge the importance of quantitative and descriptive data appeared to be difficult for them to answer (Table 5).

Before the implementation of "The air we breathe" none of the students' answers could be characterized as scientifically acceptable, while 44% were unacceptable. These include blank answers, "I don't know" answers and answers without any meaning: "It is important, because there is a lot of pollution in this area" (D1, st. 4), "This area has a problem" (D1, st. 9), "I think it's important" (D2, st. 10), "...if we find garbage on the beach...you smell it and you don't feel good" (E2, st. 15).

The majority of responses (56%) were partially acceptable including those agreeing to the significance of all data without further explanation: "I think quantitative and descriptive data both help" (D2, st. 1), "I think it is very important to know the type and amount of pollutants" (D2, st. 9), "It matters how many there are, but also what their shape is" (E2, st. 2), "It matters how many pollutants it has, but also what we smell" (E2, st. 11) and those that only explain why quantitative data is important: "It is important because in this area there is a lot of pollution and it has a problem" (D1, st. 6), "It is important, because if we measure a lot of pollutants, we understand that there is a problem at that point" (D1, st. 12), "It matters how much" (E2, st. 5).

After the implementation of "The air we breathe" 29% of the answers were correct: "They are both very important, because the quantitative ones show us how many there are, while the descriptive ones show us what kind they are, which can be dangerous for humans" (E2, st. 5), "Both quantitative and descriptive data are important, because with descriptive it shows us the shape and size, but also with quantitative it shows us how much there is. Both are crucial for our health" (E2, st. 19).

The majority of students (65%) still gave partially acceptable answers including those who agreed with the importance of all data without further explanation: "They are important to see what we breathe" (D2, st. 12), "They are very important because they can cause us something inside our body" (E2, st. 10) and those mentioned only in the quantitative data: "They are important, because this way we know the amount of pollutants present in each area and what we breathe" (D1, st. 4), "They are very important, because you can see the quantitative data" (D2, st. 11).

Although completely scientific acceptable final answers were not derived from students' majority, the final not scientific acceptable answers clearly diminished. Thus, it seems that students made some progress in deciding if qualitative or quantitative data are appropriate for measurements, but there is still space for improvement. Students' ability to organize simple data sets, to compare data collected by different groups, to reveal patterns that suggest relationships, to measure, estimate and compare quantities, and to analyze and interpret data improves their ability to use logical reasoning, mathematics, and computation to address scientific and engineering questions and refine problems and design solutions. It is doubtful to conclude that all these abilities were cultivated through the STEM education program titled "The air we breathe", but we believe that a positive start has been made.

Participants of the research made a positive shift towards the use of qualitative and quantitative data in the design of an investigation. Nevertheless, since their written answers were not cross-referenced by interviews (see for example Kelley et al., 2021), we cannot make general conclusions about using mathematics ability, when in other research students have clearly declared that they have learnt a lot about mathematics through STEM activities (Roberts et al., 2018). However, answers in another research concerning teachers' pedagogical content knowledge and confidence in the NGSS implementation, revealed remarkably low score in scientific practice of "Using Mathematics and Computational Thinking" for both knowledge and confidence (Kang et al., 2018), that means this is not an easily achievable scientific practice.

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unacceptable	scientifically acceptable	partially scientifically acceptable	unacceptable
Air pollution devices give data numerically, that is, they measure the number of air pollutants in each area where you place them. However, they also provide descriptive data, such as the shape of air pollutants. How important do you think quantitative data is and how much descriptive data? Explain.	0%	56%	44%	29%	65%	6%

Table 5. Percentages of 48 answers about using qualitative and quantitative data

Constructing explanations

The students gave significantly improved answers to a question that tested the ability to construct explanations for an everyday problem: why do white clothes spread for many hours on a balcony in a big city turn a gray tint? (Table 6)

Before the implementation of STEM activities, only 40% of the students could give a fully scientific answer: "White clothes turn gray because pollutants stick to the clothes" (D1, st. 1), "The clothes have a gray tint because the exhaust gases and smoke from the street get on them" (D2, st. 9), "Because in this area, there is probably a lot of pollution" (E1, st. 15). Another 40% of students gave partially acceptable answers based on prior general knowledge: "Maybe someone lit a fire and the pollution turned them gray" (D2, st. 7), "Because of the smoke" (D2, st. 2), "Because of the wind that raises dust" (D2, st. 16), "Because the rain having exhaust gases goes down on them" (E2, st. 11), "They must have lit a fire and the ash went on the clothes or from the pollution" (E2, st. 16). There was also a 23% of completely wrong answers: "Because it's a very civilized city, so they change color and turn gray..." (D1, st. 6), "Clothes have a tint of air" (D2, st. 4), "Because it's too much time in the sun" (D2, st. 12), "... if the clothes are wet they take on a color, while if they are dry they take a different color" (E2, st. 10).

After the implementation of STEM activities the fully scientifically acceptable answers almost doubled (73%): "In the center of Athens there are too many cars, so more pollutants that stick to clothes" (D1, st. 5), "This is due to pollution and exhaust gas" (D2, st. 7), "There are particulate matters on the clothes" (D2, st. 13), "... they turn gray from environmental pollution, smoke, exhaust gases etc" (E2, st. 15). In addition, the completely incorrect answers almost disappeared, while the partially accepted answers were limited to 23%: "Maybe there is dust and the dust gets on the clothes" (E2, st. 8), "It is because the polluted air containing dust, paint, gravel creates a gray color" (D2, st. 10), "Because the air we breathe is dirty" (D2, st. 14).

In general, students' ability for constructing explanations and designing solutions has been improved in great extent and this is due to the use of evidence through "The air we breathe". Primary students had the opportunity to construct their own "air pollution detectors", to take measurements, to make observations, and to seek patterns of air pollutants in their local environment. These authentic activities contributed to students' ability to construct or support an explanation, to design a solution to a problem, to compare multiple solutions to a problem, and to assign criteria and constraints of the design solution.

Although we did not interview primary students, we consider their final answers as written evidence that strengthen four examples referred by Reiser et al. (2012) that illustrate students' meaningful engagement in explanation and argumentation: arguing for prediction, reconciling competing explanations, building consensus from multiple contributions, and critique leading to clarified explanation. In other words, students' ability to construct explanations after the implementation of "The air we breathe" has been refined, deepened and elaborated.

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unaccept able	scientifically acceptable	partially scientifically acceptable	unaccept able
Some of your friends who live in the center of Athens told you that when they spread outside white clothes and leave them for many hours, when they pick them up they have a gray tint. How can you explain this fact?	40%	37%	23%	73%	23%	4%

Table 6. Percentages of 48 answers about constructing explanations

Engaging in argument from evidence

Another question asked students to make a claim about the merit of a problem solution providing appropriate procedure and evidence. The question was how to determine between two cities of different sizes where the air pollution is more intense (Table 7).

Before the implementation of the STEM activities, 44% of the students gave completely wrong answers either by answering "I don't know" or by formulating a conclusion that was not based on a research process: "In the center of Kalamata, the pollution is greater than in the square of Messini" (E2, st. 6), "It is more intense because it is a bigger city than Messini, so it has worse oxygen" (E2, st. 18), "I wouldn't agree with him" (D2, st. 8), "Our friend's opinion is correct" (D2, st. 10).

As partially acceptable considered 33% of responses, which either were repeating a process that the students saw written in a previous question of the questionnaire: "I will go to Kalamata, spread clothes and see if they turn gray" (D2, st. 7) or intuitively indicated the use of a measuring instrument: "I'll check with a device I made" (E2, st. 19), "We can put an air pollution detector in the city center" (E2, st. 16), "We'll put gas devices of pollution in the center of Kalamata" (D1, st. 7)

The correct answers reached up to 23%, a percentage that increased impressively to 79% after the implementation of STEM activities: "We will put detectors in the square of Messini and detectors in the center of Kalamata. Then we will compare" (D1, st. 12), "I would go and put a detector in both places, after a few days I would go and see the contaminants that each detector picked up and I would draw my own conclusion" (D2, st. 10), "I would put pollution detectors on both cities and then compare them with a microscope" (E2, st. 2). Partially correct answers

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unaccept able	scientifically acceptable	partially scientifically acceptable	unaccept able
A friend of yours claims that in the center of Kalamata the air pollution is more intense than in the square of Messini. What would you do to ascertain whether your friend's opinion is correct?	23%	33%	44%	79%	19%	2%

Table 7. Percentages of 48 answers about arguments from evidence

diminished to 19% and completely incorrect answers almost disappeared.

There is no doubt that students' ability in engaging in argument from evidence and especially in using data to evaluate claims about cause and effect was highly increased after the implementation of "The air we breathe". The primary students of the sample can propose a procedure to check estimation, opinion, argument or scientific question and also can construct an argument with evidence, data or a model. Despite their young age, through such STEM activities, students gradually develop further abilities, like comparing and refining arguments based on evidence, reasoning based on research findings, providing and receiving critiques from peers about a proposed scientific procedure, explanation or problem solution.

As mentioned above, Reiser et al. (2012) examined in detail scientific practices of explanation and argumentation through four examples. Although their research has quantitative characteristics, we discerned such elements in our students' responses. For example, the answer "I would put pollution detectors in both cities, measure amounts of pollutants and then compare them under a microscope to get a proper view" (E2, st. 3) testifies that this student can precisely describe the process through which an accurate result can be tested, probably emerged by consensus between different aspects or contradictable observations. Moreover, our findings can confirm these of Kang et al. (2019), who found that "Engaging in Argumentation" was the most successfully practice incorporated by secondary teachers in their science teaching practice.

Evaluating & communicating data through tables, diagrams, and charts

The last question of the questionnaire intended to record students' ability to obtain, evaluate, and communicate information in the form of tables, diagrams, and charts (Table 8) by asking students what elements they think are necessary to have in a graph presenting their research.

Before the implementation of "The air we breathe" half of the students (52%) could not give scientifically acceptable answers at all: "I believe the elements will be the city and the village" (D1, st. 4), "I think in the city there will be 20 pollutants and in the village 5 pollutants" (D1, st. 6), "The air in the city is very dirty" (D2, st. 10), "The flowers, the bees, the wind, the pollen" (E2, st. 7), "There are more flowers in the village" (E2, st. 17), "It's the exhaust gas, the garbage, the people, a lot of movement, etc." (E2, st. 18). Some of the answers suggest that the students misinterpreted the question as either asking them to make a general comparative conclusion about air pollution or to list the main environmental problems of the area, which could be graphed after measurements of appropriate parameters.

Partially acceptable answers were given by 42% of the students: "Pollutions, exhaust gases, carbon and other various bad air substances" (E2, st. 9), "How much pollen is in the air, how cold the air is" (E2, st. 2), "Essential elements in the chart will be numbers, words and lines" (D2, st. 1), "Necessary elements in the graph will be the numbers and two lines" (D2, st. 4), "... the numbers, quantities and names we have to find their quantities" (D2, st. 9), "I think the graph should have city, village and quantity of pollutants" (D1, st. 5). From these responses it is inferred that the students indeed had an intuitive view of what is depicted on a graph, but they could not describe it precisely.

QUESTION	PRE-TEST			POST-TEST		
	scientifically acceptable	partially scientifically acceptable	unacceptable	scientifically acceptable	partially scientifically acceptable	unacceptable
You decide to present the results of your research "The air in the village has more pollen than the air in the city" by making a graph. What elements do you consider essential to have in your graph?	6%	42%	52%	73%	25%	2%

Table 8. Percentages of 48 answers about evaluating & communicating data

After the implementation of "The air we breathe" scientifically acceptable answers reached 73% of the sample: "The elements I consider necessary are on the horizontal axis the city and the village and on the vertical axis the amount of pollen" (D1, st. 1), "It will has the numbers on the vertical line and the places where we put the detectors on the horizontal line" (D2, st. 11), "Chart title and vertical sides, including Pollen, Village, City (E2, st. 5), "I consider it necessary to have the title of the graph and vertical sides (pollen in village and city)" (E2, st. 10), "On my graph it will be pollen and below will be town and village, title name and vertical sides (pollen - village, town)" (E2, st. 15). In addition, partially scientifically acceptable answers were given by 25% of the students, while unacceptable answers almost disappeared.

It is obvious that STEM activities implemented by the primary students highly improved their ability to communicate scientific and technical information in written formats, including tables, diagrams, and charts. This ability includes other important abilities, like combining information in written text with that contained in corresponding diagrams, comparing data appearing in various complex texts and reliable media, summarizing scientific and technical ideas and describing how they are supported by evidence.

Previous research concerning teachers' confidence in the NGSS teaching recorded very low scores in "Obtaining, Evaluating, and Communicating Information" (Kang et al., 2018). In a newer study the same researchers concluded that "teachers frequently engaged their students in orally communicating their findings to others" (Kang et al. 2019, p. 806). So, our findings based on "The air we breathe" and revealing great students' progress in this scientific practice imply that students increased their ability to present data not only orally but also by diagrams.

Conclusions And Teaching Implications

Much of the literature on STEM has referred either to its introduction into education for reasons that serve the working needs of industry and technology (Du Plessis, 2018; Garibay, 2015) or in its differences with inquiry-based education (Bybee, 2013; Martín-Páez et al., 2019; Rosicka, 2016). Less research has been done on how to introduce STEM into the curriculum of primary and secondary education either in the form of integrated courses (English, 2017; Kelley & Knowles, 2016; Ortiz-Revilla et al., 2020) or as interdisciplinary lessons (Hsu & Fang, 2019; Margot & Kettler, 2019). There is even less research that investigates the way to implement a STEM program in young students, which are the appropriate teaching tools and the most efficient educational techniques.

Our research belongs to this last category and refers to primary education, where students' scientific knowledge is naïf or confused and their capabilities relatively limited. Nevertheless, it seems that the topic of air pollution through the "The air we breathe" STEM program piqued students' interest and motivated them to action in the form of specific activities at the local level. The students were asked to build "air pollution detectors", place them in various locations in the city, collect them after a reasonable period and observe them with the help of a microscope, so that they can draw reliable conclusions. This process included similar elements of other research which explicitly referred to problem-based learning (Roberts et al., 2018; Kang et al., 2019), project-based learning (Anand & Dogan, 2021), real-world problems (Du Plessis, 2018; Garibay, 2015; Hsu & Fang, 2019), authentic experience (Stroupe, 2015; Crippen and Antonenko, 2018), evidence-based claims (Arias et al., 2016) and hands-on activities (Anand & Dogan, 2021; Kang et al., 2019; Roberts et al., 2018).

In our case, by implementing "The air we breathe", we did not intend to participate in the terminology debate, but we insisted to students' answers in order to emerge their progress in the acquisition of the eight scientific practices proposed by the NGSS. According to students' answers it seems that students' abilities increased in great extent in five of these practices and in moderate extent in three of these practices. Great progress has been noted in a) evaluating appropriate methods and tools for collecting data, b) developing & using models, c) constructing explanations, d) engaging in argument from evidence and evaluating e) communicating using tables, diagrams, and charts. Moderate progress was recorded in a) asking questions and defining problems, b) planning & carrying out investigations c) using mathematics.

From one hand, students' early age (K-4, K-5) and lack of previous experience in STEM activities could justify the relatively moderate progress in three scientific practices. From the other hand, the same reasons could justify students' high scores in five scientific practices, as a first experience, unique educational process and pure opportunity to extent the established curriculum of science education. As an experience, "The air we breathe" consisted of a rich and meaningful learning environment that forced students to confront against a real-world problem. As an educational process, "The air we breathe" promoted outdoor education and fostered concrete abilities that struggle in the typical classroom. As an opportunity, "The air we breathe" was a chance to primary students to investigate their local environment and to make decisions and proposals for sustainability.

We think that students' progress in the eight scientific practices proposed by the NGSS is due to three reasons. First, the innovative character of the STEM educational program, meaning that students for the first time in their school life participated in a structured procedure including real-world problem solving, construction of tools, measurements, calculations and formulating of accurate conclusions. Second, the "diffusional" character of the STEM educational program, meaning that teachers implemented "The air we breathe" had previously educated as learners themselves by experts of STEM education and had introduced to scientific practices. Third, the supportive character of the STEM educational program, given that experts of STEM education continuously supported teachers by providing the measurement tools, application instructions and communication through a digital hub.

Thus, implications for successful STEM education in primary education are teacher education in STEM approach, provision of tools and continuous guidance by experts, problem-solving process, appropriate transformation of scientific knowledge, set of measurements and estimation of data, authentic experience, and hands-on activities. Furthermore, in our case the environmental orientation of the educational program "The air we breathe" has positively contributed to its successful implementation by encouraging students to study their local environment.

However, there are numerous limitations to our research which don't allow the generalization of findings and conclusions. The sample is limited and concerned only one elementary school and the program was implemented in a rural area. Even if questions of the questionnaires were open-ended, interviews did not refine students' answers. These limitations also give suggestions for further research, for example the implementation of "The air we breathe" in a wider audience, in a greater city or among cities of different size. Furthermore, the use of some interviews could cross students' answers and deepen their progress in scientific practices.

Nevertheless, the environmental core of "The air we breathe" delivered an appropriate chance to introduce STEM in primary education. Students engaged in search and solution of a local environmental problem going through all the stages of scientists' work, a procedure that is not surely occurring in typical teaching of science in class. The outdoor enactment, the construction of original measurement tools, and the use of technological instruments functioned as positive experiences that improved student engagement and contributed to noteworthy acquisition of scientific practices. So, "The air we breathe" was an authentic workplace for an innovative learning experience promoting hands-on activities that successfully engaged primary students in STEM education.

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Ethics Statement

The present study is conducted as a non-interventional study with minimal or no intrusiveness, aiming at mapping students' improvement on scientific practices, without including any personal data. Ethical approval was waived under the decision of the Regional Directorate of Primary and Secondary Education (in Greece) since during the design and implementation procedures were followed to ensure ethical standards regarding the anonymity of the participants, parents' consent and password protected data storage.

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Achilleas Mandrikas has been a primary school teacher since 1987. He holds an MA in Science Education (2006) and a PhD in Environmental Science Education (2010), both from the National and Kapodistrian University of Athens. Among 2009-2018 he was a School Advisor in primary education for the Hellenic Ministry of Education. Among 2018-2023 he was an Educational Coordinator on Education for Sustainability in the 6th Regional Centre of Educational Planning of Attica, Greece. In parallel, he also lectures undergraduate and postgraduate students in the Department of Primary Education of the National and Kapodistrain University of Athens on environmental science and environmental education.

Constantina Stefanidou is a physicist who has a PhD in Science Education from University of Athens. After a long period of teaching science in secondary education, she now has a position in the Department of Education at Athens University in the field of pre-service teachers' science education. Her research and publications are on STEM Education and didactics of science, focusing on historical and philosophical perspectives as well as conceptual difficulties and their relation to model-based teaching and learning and informal science education. She participates in international conferences and science communication actions. She is a member of the European Science Education Research Association (ESERA) and the International History Philosophy and Science Teaching (IHPST) Group.

Kyriakos Kyriakou is a chemist who has a PhD in Science Education from the National and Kapodistrian University of Athens (2014). He is Principal at a Night School in Athens. He also lectures undergraduate students in the Laboratory of Didactics and Epistemology of Science and Educational Technology, and in Physics Laboratory classes of Department of Primary Education of the National and Kapodistrian University of Athens (2006-2021). His recent publications are on didactics of science, focusing to model-based teaching and learning. His research interests include science education, history and philosophy of science and science communication.

Constantine Skordoulis is Professor of Epistemology and Didactical Methodology of Physics in the Department of Primary Education, National and Kapodistrian University of Athens. He is the Director of the Laboratory of Science Education and Educational Technology and Head of the Postgraduate Studies Program "STEM Education and Educational Robotics Systems". He has studied Physics at the University of Kent at Canterbury, UK and worked as a visiting researcher at the Universities of Oxford and Groningen. He is Co-Editor of "Almagest / Journal for the History of Scientific Ideas" (Brepols, Brussels) and member of the Editorial Boards of international journals (Journal of Critical Education Policy Studies, Advances in Historical Studies, Journal of Interdisciplinary Social Science etc). He is an Effective Member of the International Academy of History of Science and has served as the Secretary of the Interdivisional Teaching Commission of the International Union of History and Philosophy of Science (2007-17). His research interests include History of Science, Science Education and STEM Education from a critical perspective.