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# Curriculum development for student agency on sustainability issues: An exploratory study

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Despite unprecedented global challenges to the environment, research show that many young people are pessimistic about their ability to address these challenges. This paper explores one approach designed to guide middle-school teachers and their students to develop and practice agency about sustainability issues: *via* a curriculum that challenges students to solve problems by analyzing real-world data and developing scientific arguments, as a basis for engaging in activism. The paper begins with an overview of the United Nation's Agenda 2030, its Sustainable Development Goals (SDGs), the related aims of Education for Sustainable Development (ESD), and a review of what is meant by student agency. Next, the goals and design features of a curricular initiative, "Speak to Me in Numbers," are presented with a brief presentation of two units, each based on a different SDG. The paper's research questions are (1) How were the design features of the curriculum perceived by the teachers? and (2) What were the preliminary outcomes of the curriculum in terms of student and teacher argumentation skills and student activism? To address these questions, we present an exploratory study: observations and comments from in-service teachers and participating students regarding preliminary outcomes of the curriculum that might be related to the development of student agency. In our concluding discussion, based on these findings and relevant literature, we suggest that a promising pedagogy to strengthen student agency on sustainability issues is a data-driven pedagogy that focuses on the development of scientific argumentation, mathematical thinking and activism.

KEYWORDS

**education for sustainable development, data-driven pedagogy, argumentation, activism, student agency, sustainable development goals (SDGs)**

## Introduction

The world today faces global challenges that include complex environmental, social, and economic issues. Nearly 800 million people live in hunger (Von Grebmer et al., 2016), and 1.2 billion live in extreme poverty (Suresh et al., 2015). More than half of the world's agricultural land is overexploited, undermining the livelihoods of over 1.5

billion people (United Nations [UN], 2011). Climate change affects human well-being everywhere, and even threatens basic human survival in certain regions. Countries and islands may be flooded due to rising sea levels. Unprecedented droughts or changing precipitation patterns are expected to result in migrating populations.

## The United Nation's sustainable development goals

To address these and other complex global challenges, the UN Council adopted the resolution "Transforming Our World: The 2030 Agenda for Sustainable Development" (United Nations [UN], 2015), adopted by close to 200 countries and based on the 17 Sustainable Development Goals (SDGs).

The roots of the SGDs initiative lie in a shared global vision for a better future economically and socially. Sustainable home for the planet and for present and future generations (Halisçelik and Soytas, 2019). The SDGs have been designed with the intention of having them achieved by 2030. The primary responsibility for monitoring and testing achievement is at the national level.

## Sustainability education and environmental citizenship

What is the United Nations' vision for how the world can achieve the 17 SDGs by 2030? According to the UN, achievement of each of the SDGs objectives is dependent on the collaboration of each country's local civic organizations, along with its educational system (e.g., Lidstone et al., 2015). Educators, students and teachers, business professionals and members of civic associations are all important stakeholders and players in the process of achieving each country's SDG goals (Blanco-Portela et al., 2017). Thus, these ambitious goals are only a common reference point. Their achievement needs to take into account each country's social, environmental and economic capital, including its educational system, on both the national and local levels (Svanström et al., 2012).

The effort to translate the UN's SDGs into sustainability education was undertaken by UNESCO in its Education for Sustainable Development (ESD) initiative. The vision of UNESCO is that ESD: empower learners of all ages with the knowledge, skills, values, and attitudes to address the interconnected global challenges we are facing, including climate change (Mandler et al., 2012), environmental degradation, clean water (Mandler et al., 2014), loss of biodiversity, poverty, and inequality. Learning must prepare students and learners of all ages to find solutions for the challenges of today and the future. Education should be transformative and allow us to make informed decisions and take individual and collective action to change our societies and care for the planet (UNESCO, 2019).

Another effort to educate the world's youth to address global sustainability challenges relates to the emerging field of Environmental Citizenship, defined as the responsible pro-environmental behavior of citizens who act and participate in society as *agents of change* in the private and public sphere on a local, national, and global scale, through individual and collective actions in the direction of solving contemporary environmental problems, preventing the creation of new environmental problems, achieving sustainability and developing a healthy relationship with nature (Hadjichambis and Reis, 2020).

This emphasis on the developing the agency of citizens–including students–is reinforced by Dobson (2010), who defines Environmental Citizenship as "pro-environmental behavior, in public and in private." This behavior is driven by a belief in the fairness of the distribution of environmental goods, in participation and in the co-creation of sustainability policy. Thus, Environmental Citizenship relates to the active participation of citizens in moving toward sustainability.

## Student agency and activism

As seen in the approach of both the UN's Education for sustainable development and the field of Environmental Citizenship, one of the main objectives of sustainability education is the development of student agency. What is meant by this concept?

The concept of "student agency" is a complex multidimensional concept that has recently emerged in pedagogical discourse. According to the OECD, there is no global consensus on the definition of this concept. In fact, student agency is perceived and interpreted differently in different countries; in some cultures, there is no direct translation for the term. Nonetheless, student agency is central to the OECD Learning Compass 2030, where it is defined as "the capacity to set a goal, reflect and act responsibility to effect change. It requires the ability to frame a guiding purpose and identify actions to achieve a goal. It is about acting rather than being acted upon; shaping rather than being shaped; and making responsible decisions and choices rather than accepting those determined by others" (OECD, 2019).

Student agency relates to the development of an identity and a sense of belonging. When students develop agency they rely on motivation, hope, self-efficacy and a growth mindset (the understanding that abilities and intelligence can be developed) to navigate toward well-being. This enables them to act with a

sense of purpose, which guides them to flourish and thrive in society (OECD, 2019).

The concept of student agency is informed by Bandura's theory of human agency (Bandura, 2001). In social cognitive theory (SCT, Bandura, 1986), agency "is present in the ability of people to regulate and control their cognition, motivation, and behavior through the influence of existing self-beliefs (i.e., self-efficacy). SCT considers the self-as-agent to encompass four core features of human agency–intentionality, forethought, self-reactiveness (self-regulation), and self-reflectiveness (self-efficacy)." (Code, 2020). It is also important to note that environmental hope is linked to agency thinking (Kerret et al., 2020).

How to develop student agency? According to the OECD (2019), the process implies relationships with others.

Parents, peers, teachers, and the wider community influence a student's sense of agency, and that student influences the sense of agency of his or her teachers, peers and parents–a virtuous circle that positively affects children's development and well-being. Thus, "co-agency," often referred to as "collaborative agency," implies the influence of a person's environment on his or her sense of agency.

Research and development efforts to develop and measure the multidimensional aspects of student agency are emerging. Efforts to develop student agency in regard to sustainability issues have included youth-led action projects focused on individual and collaborative change in both formal and informal educational contexts (e.g., Trott, 2020). In regard to the evaluation of student agency, a questionnaire tool that has been developed is described by Code (2020) and a number of qualitative research to evaluate students agency have been reported (e.g., Lehtonen, 2015).

A related construct to student agency is activism, a term that traces its roots to the writings of the early sociologists (e.g., Parsons, 1937) who understood activism as social action directed to achieving a common communal goal. Whereas student agency reflects the development of a long-term personal identity and taking initiative, with the capacity to act responsibility to effect change, activism reflects the engagement in short-term activities that require collective action aimed to achieve a common good. We understand these two terms to be complementary: one relates to the development of a student's personal initiative while the other relates to action collectively taken to effect a change in the student's local environment.

In our study, we were interested in knowing to what extent, if any, an innovative interdisciplinary curriculum called "Speak to Me in Numbers" develops student agency relating to global sustainability challenges, where activism is a design feature to help develop student agency. In the following sections, we present the design features of the curriculum and how they were expressed in two curricular units. Next, we present the study's methodology, the data and findings, leading to a discussion about the relationship between the curriculum's design features and possible outcomes, including the development of student agency.

## Design features of the "Speak to Me in Numbers" curriculum

Design features are "guidelines expressing the goals for the learning outcomes, the classroom activities and the teaching strategies" (Jiménez-Aleixandre, 2007). Each unit in the "Speak to Me in Numbers" curriculum is based on several design features:

1. A Sustainable Development Goal (SDG),
2. Data-based challenges requiring the use of mathematical literacy to address them,
3. Student construction of evidence-based scientific arguments, and
4. A concluding student activism activity.

In this exploratory study, we applied a design-based research approach by collecting continuous feedback from the participating teachers and students. In the paper we will present the design features and preliminary evidence collected that relates to the curriculum development process.

### A sustainable development goal

Each of the "Speak to Me in Numbers" units is based on one of the United Nation's Sustainable Development Goals (SDSs). The SDGs chosen as topics for the different units were chosen because they can be well-integrated into a ninth-grade enrichment program. Each SDG has many important objectives. An effort was made to focus the curriculum on those objectives that are most relevant to the students and that can be well-integrated into the science syllabus, e.g., objectives that relate to the carbon cycle, acid-base solutions, and alternative energy sources. In some cases, science content was included in the units that is not part of the regular science syllabus.

### Data-based challenges requiring the use of mathematical literacy to address them

After an introduction to the relevant SDG, students receive relevant data–presented in graphs or data tables that relate to a particular problem or challenge. By performing a mathematical analysis of the data, students reach data-based

conclusions and make data-based arguments. It is important to note that the mathematical knowledge and skills needed for this analysis are not new for the 9th grade students, but that the applications of the knowledge and skills to the context of sustainability issues are new. This approach can be characterized by the term "mathematical literacy" which can be understood as an individual's capacity to formulate, employ and interpret mathematics in a variety of contexts (Istiandaru et al., 2018). Such contexts include personal, societal and scientific contexts (Tabach and Friedlander, 2008; OECD, 2022).

## Student construction of evidence-based scientific arguments

The data-based challenges are the foundation for another design feature of the curriculum: the construction of evidence-based arguments (Osborne et al., 2004; Simon et al., 2006). In this way, the curriculum fosters a classroom culture of argumentation discourse regarding sustainability issues.

While the research literature provides many different ways to define what is meant by a scientific argument (e.g., Driver et al., 2000), we have adopted the Toulmin model of argumentation (Toulmin, 1958), as described in greater length in section "Students and teacher data-based argumentation skills" below.

The general goals that incorporate characteristics of an argument focus on empowering students to speak and write science, as well as supporting their connection to science communities and developing epistemic criteria for evaluating knowledge. Studies dealing with arguments relating to the understanding of scientific epistemology have found that students need to be in teaching-learning contexts in which they make explicit epistemic decisions in order to understand scientific methods (Mork, 2005). In the "Speak to Me in Numbers" curriculum, the student construction of evidence-based arguments focuses on "how we know what we know" regarding specific sustainability issues, as the basis for understanding "what we know" regarding those same issues.

## A concluding student activism activity

At the end of each unit, the students are challenged to plan and carry out an activism activity. This activity is also data-driven and challenges the students to make a plan to "take action," based on the data. These activities are usually set in the context of the students' local environment. This activity causes the students both to take action regarding a specific sustainability issue, as well as to "speak in numbers," i.e., in a manner that improves their scientific and mathematical skills, organizes their thoughts, builds good scientific arguments and creates awareness for the need to change in their immediate environment.

# The processes of curriculum development and implementation

Given the above four guiding design features, the curriculum was developed and implemented by an interdisciplinary staff of content specialists from the sciences (particularly chemistry and biology) and mathematics, along with several teachers of these disciplines for middle school students.

In the curriculum development process, the staff first chose a science-rich SDG on which to focus (e.g., SDG 3: Good Health and Well-Being). Next, the science content specialists outlined the relevant science principles and concepts (e.g., health issues involving the COVID-19 pandemic and virus). Afterward, both the science content and mathematics content specialists looked for data that could be analyzed by middle school students, in order to develop evidence-based claims involving the relevant science principles and concepts. Given these data sets, activities were developed, focusing on the application of mathematical knowledge and skills by these students in the context of the SDGs. It is important to note that the relevant mathematical knowledge and skills were already known to the middle school students. The emphasis was on students developing mathematical literacy (OECD, 2022). As part of the development process, science and mathematics teachers on the staff tried out the activities with their students, feedback was provided, and necessary changes were made in the activities.

In the curriculum implementation process, the project staff first led Professional Development (PD) courses for middle school teachers in the areas of science, as well as mathematics; the main goal of these courses was to familiarize the teachers with the content and pedagogy of the curriculum.

After the teachers completed the PD course, those who implemented the program participated in a Professional Learning Community (PLC) (Vescio and Adams, 2015). In this PLC, the teachers shared their questions and difficulties regarding the implementation of the "Speak to Me in Numbers" curriculum, as well as suggested solutions and successes. Meeting regularly in an atmosphere of mutual trust (Waldman and Blonder, 2020), the teachers were able to develop their practice and their visions of the relevant Pedagogical Content Knowledge (PCK), a concept initially understood as "the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9).

In the next section, we will briefly describe two of the curriculum's units and discuss how these design features are expressed in each unit.

## Expression of the design features in the program

Below we describe, from the point of view of the program's developers, how the four design features described above found expression in the program, in two of its units that relate to the Sustainable Development Goals (SDGs): (1) Good Health and Well-Being (SDG 3) and (2) Life Below Water (SDG 14).

### Good health and well-being (SDG 3)

The goal of this SDG is "to ensure healthy lives and promote well-being for all at all ages" (United Nations [UN], 2015). The worldwide COVID-19 pandemic provided a real-world context to help students better understand the complex situation around them. For example, concepts common in news items, such as "flattening the curve" and "exponential growth," need to be explicated in order for students to understand them and act accordingly.

The unit of SDG3 begins with a news article describing an experts' prediction of the number of COVID-19 cases about a month into the future. At first glance, this prediction seems exaggerated. Students need to decide whether this is the case or not, based on their analysis of the data, using an Excel spreadsheet. As part of this assignment, students learn about how an epidemic spreads and the meaning of exponential growth. In this way, students develop their critical thinking and mathematical skills to develop evidence-based arguments.

Next, students learn about the concept of "orders of magnitude" while investigating the size of the Corona virus and how this size relates to more common objects. This activity is used to help students assess the relative protective effectiveness of different types of masks, to stop the spread of the virus. Students watch a news video that addresses the costs and benefits of different types of masks. Students observe Scanning Electron Microscope (SEM) images of different types of masks (see **Figure 1**) to estimate the different sizes of the spaces between the fibers and combine all the different sources of information in the activity to draw their conclusions about the preferred mask.

The students then analyze data from 10,000 people who were tested for COVID-19; these data include different symptoms and health outcomes associated with each person. Students use the "CODAP" application[1] to examine the large data sets from confirmed COVID-19 cases to evaluate different arguments about what symptoms predict COVID-19 infection. The unit concludes with an activism activity challenge: Students are asked to analyze data regarding different "activity centers" (restaurants, museums, businesses, etc.), leading to policy recommendations for opening up the economy, after a lockdown. They draft a letter to policymakers based on this analysis. Teachers can decide on another activism scenario depending on the class they teach, as happened in the cases presented below (see section "How the program promoted student activism").

### Life below water (SDG 14)

The goal of this SDG is "to conserve and sustainably use the oceans, seas and marine resources for sustainable development" (United Nations [UN], 2015). The unit based on this SDG relates to the negative consequences of human activities that involve the oceans. At the beginning of the unit, students are asked if they think is it important for them to know what is happening in the oceans because, after all, most students don't live next to them. Why should they care?

Next, the students are exposed to graphs that connect carbon dioxide emissions with ocean acidification. They come to the conclusion that an increase in the concentration of carbon dioxide causes the pH level to decrease, thus increasing ocean acidity. Students also examine how different predictions of carbon dioxide levels may cause different ocean acidification levels, leading to negative consequences for marine life. (This activity about the effects of atmospheric carbon dioxide is connected to another unit in the curriculum, Climate Action, SDG 13).

In the activity that follows, the students learn about The Great Pacific Garbage Patch, a collection of plastic debris in the Pacific Ocean (Plastic Ethics, 2018). Based on real data, they estimate its size (about 1.6 million square kilometers) and learn about ways in which plastic waste at sea can be treated. They do so while learning about Boyne Slatt, a Dutch entrepreneur who was first exposed to the problem of ocean plastic waste as a teenager on a diving vacation, and decided to take action by setting up a company that uses boat interceptors to remove this plastic.[2] Next, students analyze graphs that help them understand the relationship between macro-plastics and micro-plastics in the ocean and how the forecast of a reduction in sea macro-plastic waste does not necessarily result in a similar decrease in micro-plastics.

What are the implications of micro-plastics on marine life? Students address this question by relating to data in a scientific paper (Mattsson et al., 2017); they analyze a graph showing that a high concentration of micro-plastics causes greater and faster mortality of *daphnia* (a small planktonic crustacean), causing harm to the marine food chains (**Figure 2**). They are asked to draw conclusions and contemplate what would have happened if the starting point of the experiment had been different (i.e., with a different concentration of micro-plastics and a different initial number of daphnia) based on their earlier

1 https://codap.concord.org/

2 https://theoceancleanup.com/about/

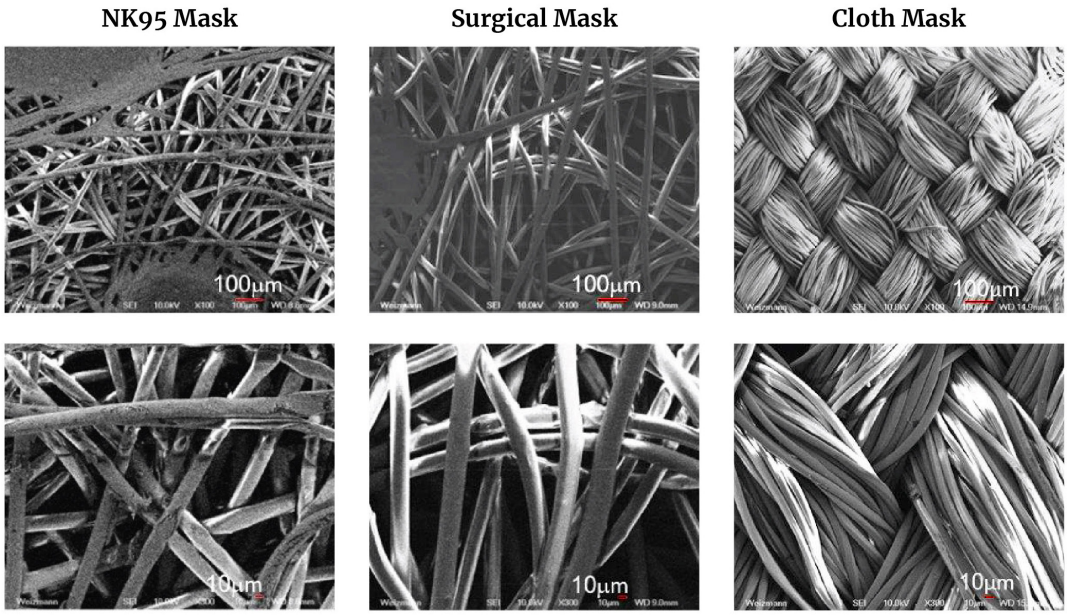


FIGURE 1
Example of question from unit on "Good health and well-being" (SDG 3). Question and accompanying illustrations of three main types of masks on the market for public use, taken from a Scanning Electron Microscope (SEM) and depicting the surface of the masks on the micrometer scale.

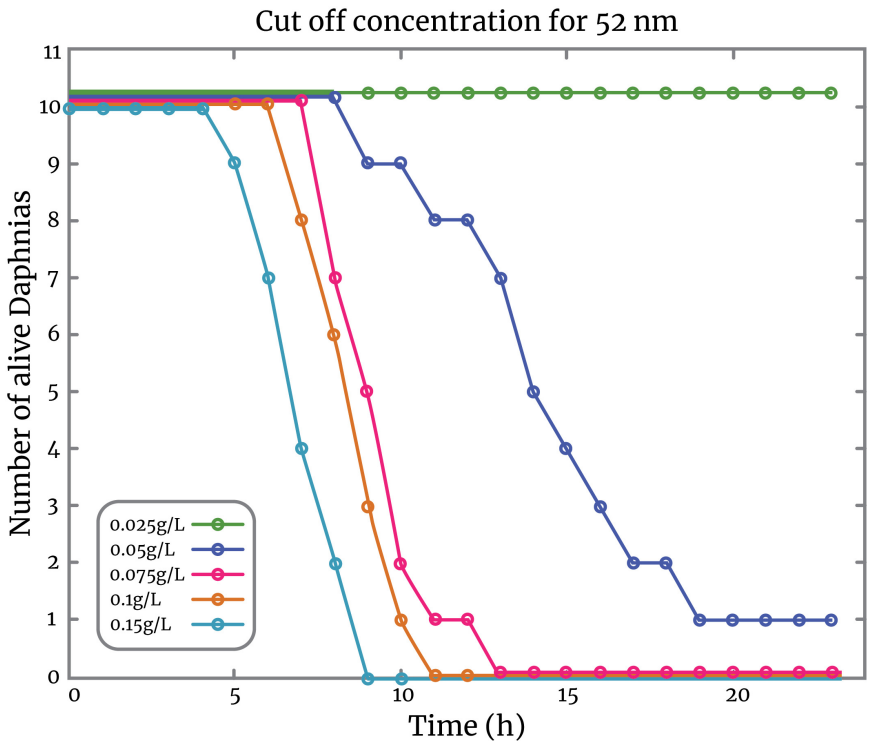


FIGURE 2
Example of question from unit on "Life below water" (SDG 14). Based on research presented in a scientific paper (Mattsson et al., 2017), students learn about the effect of micro-plastics on the marine food chains.

data analysis. Subsequently, students are asked to think about "real life" consequences of micro-plastics in the oceans.

In the following activity, students are exposed to the concept of "the tragedy of the commons" (Hardin, 1968) by working through a simulation of overfishing. In a playful game-playing atmosphere, the simulation challenges students to examine various goals related to the survival of the fish population, the survival of the families dependent on this food source, and their respective economic gains. Students link their conclusions from the simulation to the real-world of commercial-scale marine fishing.

The activism challenge for this unit deals with the issue of plastic packaging for various consumer products. Students analyze data diagrams and conclude that most plastic waste comes from packaging. They use mathematical skills to calculate the different surface areas that can enclose the same volume and conclude that some packaging shapes use less plastic than others, for the same volume. Based on this knowledge, they are asked to examine the plastic packaging of products at their local supermarket and make recommendations for how to change the packaging, in order to reduce the amount of plastic used.

In summary, the above presentation of the two units illustrates how the curriculum's design features were expressed in these units in the "Speak to Me in Numbers" curriculum. Specifically, the SDGs provide a broad and productive context in which students (a) are exposed a given sustainable issue and to data-based challenges which require the use of mathematical thinking to address them, (b) construct evidence-based scientific arguments, and (c) use the knowledge and skills from them in addressing a concluding activism activity challenge that involves their local environment.

# Methodology

The two guiding research questions of the exploratory study were:

(1) How were the design features of the curriculum perceived by the teachers?
(2) What were the preliminary outcomes of the curriculum in terms of student and teacher argumentation skills and student activism?

In order to answer this question, we will present the perspectives of teachers who went through the PD and implemented the program in their classrooms. **Figure 3** presents how this article is organized, in terms of the agents of the curriculum: curriculum developers, teachers, and students.

We presented the design features that guided the curriculum developers, in building the program's units, and we provide examples of two different units that were presented as part of the teachers' PD. In the results section, we will present the reflections of the teachers relating to the curriculum's design features. In addition, teacher argumentation skills before and after the PD will be analyzed along with development of the students' argumentation skills before and after the program. Finally, interviews conducted with two teachers concerning their students' activism will be presented and analyzed.

## Population

In 2020, the program was implemented as part of a 30-h professional development (PD) course. About 80 9th grade teachers of science and mathematics participated in the course. In this study, which was an exploratory study, we chose the appropriate population for each aspect we wanted to investigate. We present evidence from reflections of one PLC comprising 18 teachers who implemented the program in their classes. In addition, we selected representative arguments of these teachers and their students. We also interviewed two teachers who implemented the program in their classrooms and reported to us about the activism activities that were raised at the initiative of their students.

## Limitations

The main limitation of the current research is that most of data rely on teachers, as windows into their students' learning. In future studies, we plan to collect more data from the curriculum's participating students, in order to further test and refine the resulting model. Another limitation is that the data collection on student agency occurred soon after the students completed the program. In the future in order to determine to what extent student agency is maintained, we suggest investigating this outcome also at a later date.

## Research tools and data analysis

### Teacher reflections about the program's design features

After completing the PD course and implementing the program in their classrooms, the teachers in the PLC provided their reflections on the program, how they understood the program's design features and how the program was received by their students.

The teachers were asked to answer the following questions:

- What are the differences between the teaching of the program "Speak to Me in Numbers" and the regular science teaching in your class? For each difference you point out please give an example.

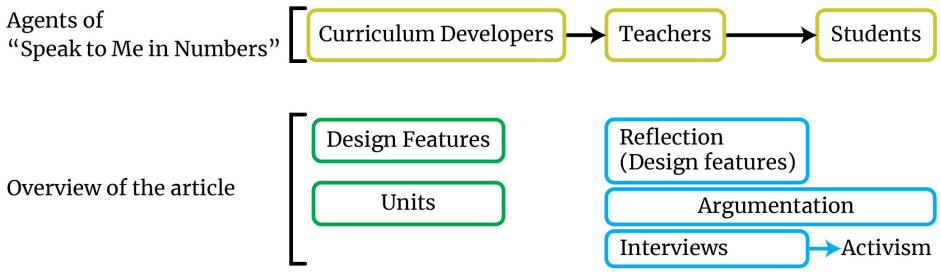


FIGURE 3
Agents of the program and article overview.

- How did the course make you think differently about issues you already knew?
- What do you think about the use of arguments during science lessons? And to what extent did the tasks you performed during the training promote the use of argumentation in your teaching?

The reflections were analyzed by applying a top-down approach according the design features of the program (similar to Dorfman and Fortus, 2019). After grouping the teacher statements according to the design features we looked for emergent categories for each feature. The first author conducted the described qualitative analysis and received feedback from the co-authors. The discussion continued until the authors reached a consensus. In the results, we describe the categories and provide examples of each.

## Students and teacher data-based argumentation skills

Before beginning the PD course, teachers were asked to answer this question: "There is a claim that the human use of plastic products affects marine organisms. Do you agree or disagree? Provide an explanation for your answer." Teachers were also asked to answer this question after the PD course.

In addition, students were asked before and after the program the following question: "There is a claim that masks don't help to protect against the COVID-19 virus. Do you agree or disagree? Provide an explanation for your answer."

In both cases, by comparing these two answers, we were able to analyze the change in students' and teachers' argumentation skills. The arguments were examined using the Toulmin model (Toulmin, 1958; Osborne et al., 2004; Katchevich et al., 2013). Each of the arguments was analyzed in terms of the presence or absence of key components in this model, i.e., claim, evidence (or data), warrant, backing, and scientific explanation, defined as follows:

A claim is a conclusion whose merits are being established by the argument.

Evidence (or data) is facts that are presented as grounds for the claim.

A warrant is a principle, provision or chain of reasoning that connects data to the claim.

Backing is additional support, justification, and reasons to back up the warrant.

A scientific explanation is an explanation of a phenomenon based on principles of science.

The task of making a data-based argument required the students and the teachers to make connections between claims, supporting evidence, warrants, backing, and scientific explanations.

It is important to note that we chose our examples about changes in argumentation skills, in order to support what we found to be representative of teachers and their students. However, given our small sample size, we did not conduct a rigorous study regarding these changes.

## Teacher interviews about student activism

Semi-structured interviews were conducted by Zoom with two teachers (Fontana and Frey, 1998). The interviews took place 6 months after teachers completed the PD course and after they implemented the curriculum in their classrooms. The goal of these interviews was to collect their perspectives regarding their students' activism and to understand how they felt the curriculum's design features were expressed, specifically in regard to the transformation process students underwent to become change agents.

The teacher interview included the following questions:

1. Can you describe the activism activity your students performed?
2. Who initiated the activism activity? Who led the activity?
3. How were the content and skills of the unit expressed in the students' activism activity?
4. Did your students add content or skills beyond what was included in the unit?

The interviews were analyzed in a top-down perspective according the design features of the program (Dorfman and Fortus, 2019).

# Results

Below we first present data relating to how the design features of the curriculum were perceived by the teachers after they implemented the program. Afterward, we present data about the outcomes of the implemented curriculum and discuss to what extent student agency was part of these outcomes.

## How did the teachers perceive the design features of the curriculum?

For each design feature we identified different categories that shed light on teachers' perceptions. **Table 1** shows the teachers' perceptions about the four design features: (1) the context of the SDGs, (2) using data and developing high-level mathematical skills (3) developing argumentation skills, and (4) a concluding student activism activity.

The teachers' reflections provide some important insights. First, the teachers felt that the SDGs topics were relevant and important to learners as well as to themselves. The program integrates environmental topics and associated values. Second, the teachers appreciated the program's integration of mathematics and science, as well as the importance of mathematics in understanding and solving authentic problems. They noticed the effect that this approach had with their students, i.e., students were more convinced by working with the data and were not likely to forget the results. Third, teachers thought that the development of evidence-based scientific arguments is important not only for scientific thinking but also in everyday life and that it also leads to the development of critical thinking. Lastly, in regard to the design feature of concluding each unit with a student activism activity, teachers felt that this activity promotes student initiative on many levels (the classroom, school, community, and society). Another perspective on this design element, *via* teacher stories of student activism, is presented later in this paper.

## What were the outcomes of the implemented curriculum and to what extent was student agency part of these outcomes?

### How students and teachers develop their data-based argumentation skills

As described above, students were asked before and after the learning the program to respond to the claim that deal with Good Health and Well-Being (SDG3) "There is a claim that masks don't help to protect against the COVID-19 virus. Do you agree or disagree? Provide an explanation for your answer."

Before learning the program, it was noticeable that most of the students did not substantiate their claims:

> *"No, I disagree [claim]. The masks reduce the option of contagion if people continue to wear them [claim]"*

> *"No, I disagree [claim], because the masks help by preventing the spread of air of the COVID-19 patient [claim]"*

After learning the program, students responses to the claim were more evidence-based, as illustrated by the following examples:

> *"No, I disagree [claim], the Centers for Disease Control and Prevention highlighted the need to wear the mask continuously. The masks provide maximum protection when they are snugly fitting around the face. It is known to us. During a single sneeze, as many as 3,000 droplets can be spread from the infected person's mouth. Some people are concerned that the virus will spread through droplets that are spread while talking, therefore it is recommended to wear a mask to reduce the spread of the contagion." [data + warrant]*

We can see that the structure of the argument written by the student changed. It is now based not only on an opinion but rather on new data and information obtained during the study of the unit. In this example, the student brought forth evidence and figures from the material taught in the unit, and based her claim on them. Below is another example.

> *I do not agree [claim]; I base my claim on what I discovered during the course when we learned about different types of masks. For example, "N95" masks cover the nose and mouth and prevent the transmission of the coronavirus, which is about 0.1 microns in diameter [data]. This way the masks contribute to the protection against viruses and infections, as these masks consist of several layers that prevent the entry of small particles like the coronavirus. There are other types of masks, such as woven cloth masks, which are considered among the least effective masks in protecting against Corona. This is because of gaps between the fibers of the cloth masks that are about 44 microns wide and about 22 microns long, which allow the coronavirus to enter easily through them. Therefore, I prefer to use the N95 mask, and I encourage my family and friends to wear it to protect them from infection." [Backing + warrant]*

This example illustrates how the student's argument improved. The student does not base his knowledge only on what is "learned in class" but puts the data into use, and bases his argument on the analysis he performed as part of the tasks. Finally, the student even indicates what is his preferred

choice in light of the findings he came across during the course of the unit.

Similarly, we found out that the teachers also learned to substantiate their claims. In the context of SDG14, teachers were asked before and after the PD program to respond to the claim that "Human use of plastic products affects marine organisms". Teachers were asked if they agreed or disagreed with the claim; they were also asked to provide an explanation for their answers.

At the beginning of the PD, it was noticeable that most of the teachers did not substantiate their claims, and when they did, their reasoning was poor and not based on concrete data:

> *"Yes, I agree that (plastic) waste causes the death of marine organisms.[claim]"*

> *"I agree. [claim] The use of plastic products increases the amount of waste and toxic substances that harm life in the water."*

> *"Plastic waste in the oceans causes pollution and affects the organisms that ingest poisoned water. Moreover, fish and other marine organisms often feed on the plastic products and suffocate."*

It can be seen that the teachers' responses to the claim made after the PD were more evidence-based than were their responses before it. More specifically, after the PD the teachers used more arguments based on data processing to justify their claims, as can be seen in the following examples:

> *"The claim that the use of plastic products negatively affects marine organisms can be examined on two levels: (a) Laboratory studies, such as an experiment that examined the effect of different concentrations of microplastic on the survival of Daphnia placed in these solutions. In these experiments, the big advantage is isolating variables. In this case, it can be seen that microplastics have a great impact on the survival of Daphnia.* [claim + data + warrant] *(b) Measurements and testing of phenomena that exist in nature (in vivo). These studies have a great advantage because one can actually see the effect of the plastic (macro or micro) on the number of marine organisms that survive in different regions. There are certain locations around the globe where plastic pollution is particularly high. Immediate improvement at these locations can lead to a global change in ocean life. We must pay attention to everyone's plastic waste. Paying attention also means limiting the use of consumable plastics, and dealing properly with existing waste sites. Scientific and technological thinking, as well as encouragement and education for such thinking, can bring about a variety of solutions. Producing many ideas about how to improve the way we live will make an impact on everyone and on all the interrelated links that make up the ecological balance."* [data + warrant + conditional argument]

In this example, it can be seen that the teacher used data analysis which he had performed during the PD. He noted the data that were presented to him, which he analyzed in the context of the effect of the microplastic concentration on the Daphnia, and also their effect on the whole food chain. In addition, the teacher indicated the conditions under which there may be a change in this trend and what it requires of us in this context [conditional argument]. Below is another example.

> *"I agree with the claim that the use of plastic products affects aquatic organisms* [claim]. *We saw in an experiment that they examined the effect of the concentration of microplastics in water on the Daphnia population. As the microplastic concentration increased the Daphnia died earlier and at a faster rate. The size of the Daphnia population affects the entire food web, as Daphnia is part of the microplankton and many animals feed on it. Consequently, the effect travels up the entire food chain. There are also other marine organisms affected by microplastic."* [warrant + backing]

In this example as well, it can be seen how the teacher uses the data and its analysis in order to substantiate her claim. In addition, she explains the context and how it harms not only the Daphnia themselves but the entire food network.

From these teachers' answers we can see that their experience of data analysis in the PD was significant for them, since they addressed the same question more in depth, while using more argumentation components and moving away from the intuitive answers they had before the PD. They based their answers on the data they had analyzed in the PD course. In addition, some teachers added terms and conditions in order to strengthen their claims. So apart from the scientific knowledge they gained, they also improved their skill of argumentation.

To sum-up the program's influence on the development of argumentation skills, a pre-post study showed that the teachers' arguments regarding sustainability issues after the Professional Development course were stronger and more evidence-based than before it. We have presented examples of how both teachers and students have improved their argumentation skills, given Toulmin's model. From what we have seen, this change is representative for all teachers, but not for all students; however, as mentioned in the methods section, we cannot make a rigorous claim to this effect, given our small sample size.

## How the program promoted student activism

Two teachers who participated in the PD and taught the program in their classes were interviewed in order to provide their insights regarding the student activism activity. We first

present a summary of their descriptions of the activity, as conducted by their students, and then analyze these stories in terms of their common components (Table 2).

Annie, a ninth-grade science teacher taught the SDG-3 unit (Good Health and Well-Being, in the context of the COVID-19 pandemic) in a class of gifted science students. Annie's students initiated their own activism activity after they conducted the original activism activity that was part of the program (i.e., to draft a letter to policymakers, based on data-based arguments from the unit, regarding how the economy should be opened after lockdown. See the description of the unit above.). Her students said that they learned a lot and gained a new understanding of how the pandemic spread and how they can act responsibly. They said there is no reason the other students in school should not learn what they did and told her that they wanted to do something, in this regard. They asked Annie to present what they had learned to all the students in their grade level in order to promote their good health in the context of the COVID-19 virus. After consulting with the school science and mathematics coordinator, Annie suggested that she prepare a PowerPoint presentation for this purpose. However, her students asked that they prepare their

TABLE 1 Analysis of the teachers' perception regarding the design features.

| Design feature | Perception | Example quote |
|---|---|---|
| 1. The context of the SDG | a. The topics of SDGs are relevant to learners. | "It connects the learner to previous experience and knowledge, the learner's needs, her emotional world, skills, hobbies and occupations, and needs as an individual and part of society. For example, students usually will not acquire the information provided in the unit on COVID-19." |
| | b. The program integrates environmental topics and associated values. | "The program summons challenging, intriguing, and interesting content, messages and ideas tailored to the learner." |
| | c. The SDG topics were important to the teachers as well as to the students. | "The course made me think differently about the importance of integrating environmental topics and values into teaching…to understand how important sustainability and its long-term effects are." |
| 2. Using data and high-level mathematical skills | a. Teachers appreciated the program's integration of mathematics and science. | "In this program for the first time I saw a real integration of mathematics and science. It is a new field to me, and I think it is very interesting and needed." |
| | b. Teachers felt encouraged to integrate mathematics skills into their science classes. | "The course certainly encouraged me to think differently about how I incorporate math into my science classes. Before, I would shy away from math and just mention it as a side note, but now I am more confident in discussing the mathematical elements that underlie scientific ideas. For example, when I teach about bacterial culture and the growth curve…I would usually call the steep part of the curve "exponential growth" and move on. Now I can discuss what an exponential curve is, what are its properties and so on." |
| | c. Teachers commented on the effect that this approach had on the students. | "Dealing with numbers and high-level mathematical skills creates an effective student, as the student can be involved using numbers as opposed to being provided with the information as "ready-made.""" |
| | d. Students are more convinced by working with the data and are not likely to forget the results. | " I think it is worthwhile to let students calculate and deal with numbers, rather than just talk about trends, because when we analyze data we will help students understand the issue or curve better, more deeply and in a well-established manner. When the student has data in the form of numbers, it convinces them of the answer…. Without numbers, the student is not one hundred percent convinced, and then the information is not assimilated well and may quickly be forgotten." |
| | e. Mathematics is important in understanding and solving authentic problems. | "The course highlighted the important role of mathematics in understanding and solving authentic problems (e.g., how to deal with global warming), using mathematical skills and tools." |
| 3. Developing argumentation skills | a. Development of argumentation skills is important. | "This is an important skill that students must acquire, to learn how to provide their arguments with opinions based on data-based explanations. This ability gives students the skill to present a reasoned position. I instruct many students to accompany their hypothesis, conclusion or argument with a scientific explanation and reasoning. Although I encourage students to use this skill, there is no doubt that the various discussions and activities during the course made me pay more attention to this point in order for students to have the ability to have a scientific discussion." |
| | b. Developing argumentation skills is important not only for scientific thinking but also in everyday life. | "The program is built in part on developing argument-building skills. I think this is an essential skill to develop in students…I think it is an important skill to teach as it helps in many aspects of life. If you know how to build an argument that is logically based and relies on objective data, then you can reach a higher level of thinking in each area…It is very important that students know how to build arguments and know how to provide answers to issues that they do not always agree to or accept." |
| | c. Argumentation skills lead to the development of critical thinking. | "Students often tend to approach different topics intuitively and do not exercise critical thinking. I find it difficult for students to reason or substantiate their position…I remember a lesson where something was said in the media, and the PD coordinators told us that what the media is saying is not always true. Suddenly I had to change my perception and formulate an argument that goes against what was told in the media. That was really significant and important for me." |
| 4. Developing student activism | a. Activism promotes student initiative on many levels. | "The program encourages learners to be involved in the classroom, school, community and society and promote an exemplary society." |
| | b. The activism has crossed the boundaries of the classroom and affects the behavior in daily lives | "Today in our private home, our children are careful not to throw any plastic waste (or cardboard) in the trash but to collect and recycle. We also make sure to turn off unnecessary lights in the house and so on." |

TABLE 2 Analysis of the components of the student activism activities.

| | Annie (SDG-3) | Jasmin (SDG-14) |
|---|---|---|
| Summary of the student activism activity | Students presented lessons to other students in the school, in order to develop their awareness about the importance of wearing masks to prevent COVID-19 infection. | Students wrote letters to stakeholders, requesting that they address the problem of plastic waste in their town. They also calculated the weight of disposable plastic used during the month of Ramadan. |
| Components of the activity | | |
| Initiation of the activity | Students initiated the activity and developed the activity content independently. | The teacher initiated the activity. However, students chose the recipients of the letter and developed its content to support their request. |
| SDG knowledge | Students applied knowledge, skills and resources from the unit. | Students applied knowledge, skills and resources from the unit and added additional resources. |
| Data-based argumentation skills | Students adjusted the level of the SDG knowledge and the level of argumentation to the level of the students they taught. | Students conducted additional calculations, relating to the amount of plastics used by city residents during the Ramadan celebrations, in order to better support their arguments. |

own presentation, claiming that they had a better understanding of the background of the other students. In their presentation, the students presented data and resources from the unit. In addition, they selected material in science and mathematic according to the different grade levels of each class. For example, the probability questions regarding the protection provided by mask-wearing were presented only to ninth graders and not to younger students. In addition to the unit's content and skills, they emphasized critical thinking skills in regard to being critical while watching news on TV or while reading newspapers, even when the person being interviewed is famous or an expert. The activity was conducted *via* Zoom to all the classes in the school. Each of the lessons was conducted to one class by two students, in the presence of the class homeroom teacher. The school's principal and vice-principal visited all the classes and were exposed to the activism activity. Annie received positive feedback from the school teachers and the school's management staff, who wrote about the activity in the school magazine. Annie also received positive responses from the parents of her students.

Jasmin taught the SDG-14 unit (Life Below Water). The students modified the activism activity as suggested in the original unit (i.e., to make recommendations for changing the packaging of products in order to reduce the weight of the plastic used, by applying mathematical skill and the knowledge students learned in the unit). They decided to address the problem of plastic waste in their town by writing letters to a variety of stakeholders: the city's mayor, the head of the sanitation department of the municipality, the school principal and a local kindergarten teacher. In their letters, the students described how each of these people could contribute locally in their town to the solution of a global problem. In order to convince these stakeholders to lead efforts to reduce and recycle disposable plastics, the students decided to connect the challenge to the everyday lives of the people living in their town. The activity was conducted during the month of Ramadan, when every evening Muslims celebrate the end of the Ramadan fast with a family feast. In this feast, many families use as great deal of disposable plastic cups, plates, and cutlery. The students also decided to calculate the weight of disposable plastics used in each house, in the school, in the city, and in the whole Muslim population around the word, during the month of Ramadan. In their letters to the above influential people, the students suggested what they should do in their roles to make a change. For example, the head of city's sanitation department should place collection cans for recycling in different locations in the town and the school principal should prohibit the use of non-recyclable plastics in the school cafeteria. Jasmin described how the unit and the student activism activity influenced her students. She said that she has taught the topic of polymers more than 10 years. In the past, her students usually knew how to solve related problems and received high grades but they tended to forget what they learned after the exam. In contrast, her students this year kept talking about the topic even at the end of the year; they discussed the influence of their letters and compared their respective contributions to influence their families and friends. Jasmin summarized that this time her students will not forget what they learned about polymers.

To sum-up the teacher interviews and the student activism activities, the students integrated their SDG knowledge and data-based argumentation skills to initiate projects that demonstrated their agency in making sustainability-related changes in their immediate environment. More specifically, students in Annie's classroom decided to teach other students in their school about what they had learned about how the COVID-19 virus spreads and what can be done about it. Students in Jasmine's classroom engaged in the unit's activism activity relating to plastic and added their own initiative: to write letters to influential people in their town, asking them to use their influence to limit the use of non-recyclable plastic there. Students also calculated the weight of disposable plastic used by residents of their city during the month of Ramadan, to better support their arguments.

## Discussion

Given the many sustainability issues facing the world, one of the pressing challenges of education today is how to develop the responsible pro-environmental behavior of

students to act and participate in society as agents of change (Dobson, 2010; Lidstone et al., 2015). This imperative is underlined by the finding that many students around the world are worried and pessimistic about the state of the environment and about their ability to make productive changes regarding these issues (Pihkala, 2020). For example, a recently survey of 10,000 children and young people in 10 countries showed that 59% were very or extremely worried and 84% at least moderately worried about climate change and government responses to climate change (Hickman et al., 2021).

The purpose of our study is to explore how a specific pedagogical approach, organized around four design principles, can help students develop and practice their agency about sustainability issues. The study's guiding questions are (1) *How were the design features of the curriculum perceived by the teachers?* and (2) *What were the preliminary outcomes of the curriculum in terms of student and teacher argumentation skills and student activism?*

In the following paragraphs, we address these questions in light of the study's findings and suggest several implications.

The curriculum's design features, according to the teachers, had several student outcomes. First, the SDG topics were relevant and important to the students. Second, the data-based challenges and the need to use mathematical thinking to address them, led students to be more convinced about their conclusions and less likely to forget them. In addition, the emphasis on developing evidence-based scientific arguments developed the students' critical thinking skills; a related finding was that the teachers' argumentation skills were stronger and more evidence-based, as a result of their Professional Development course. Finally, the student activism activities promoted student initiative; this finding was reinforced by the teacher interviews about two concluding student activism activities.

Based on these findings, we suggest that the structure of the program's units contributes to the development of student agency in two stages, each of which relates to the program's design features. In the first stage, students develop their self-efficacy (an aspect of student agency) by successfully (a) solving challenging problems that relate to a sustainability issue (*via* the SDGs), using mathematical skills to analyze the data, and (b) developing data-based scientific arguments. These mastery experiences (Britner and Pajares, 2006) promote the students' self-efficacy belief about their ability to address environmental challenges. In the second stage, when engaged in the concluding student activism activity, students apply their knowledge and skills, developed in the first stage, to make a sustainability-related change in their immediate environment. We suggest that in this two-stage process, students develop their agency about sustainability issues.

As demonstrated by the teacher interviews on student activism, each unit's concluding student activism activity has two possible forms: guided activism and open activism. In guided activism, the teacher initiates and guides the activism activity, as presented in the program; the students can make their own choices within this context. In open activism, students create their own initiative in their immediate environment. We have chosen these terms in parallel to similar terms relating to inquiry in science learning, i.e., guided inquiry and open inquiry (Domin, 1999; Sadeh and Zion, 2009). These two forms of student activism are not mutually exclusive. In fact, in the classrooms of both Annie and Jasmine, the students engaged in both guided activism as well as open activism.

In both forms of student activism, argumentation plays a central role. It is interesting to note that there are two basic approaches for argumentation: scientific and social (Osborne et al., 2004; Simon et al., 2006). Scientific arguments have the goal of understanding a phenomenon, based on supportive scientific data. Social argumentation, in contrast, has the goal of convincing others to accept a particular position and can use other types of support, such as an appeal to authority. It is interesting to note that in both student activism initiatives presented in this paper, the students' scientific arguments were used as a basis for their social arguments. In the case of Annie's classroom, her students tried to convince other students in the school about how the COVID-19 virus spreads and how to behave in response, based on the data-based scientific arguments they developed while learning the SDG 3 unit. In the case of Jasmine's classroom, the students tried to convince influential people in their town to limit the use of non-recyclable plastics, based on the data-based scientific arguments they developed while learning the SDG 14 unit. Thus, we can see how the development of data-based argumentation skills can support the development of student activism and agency.

We can also observe how developing mathematical literacy, within the context of addressing sustainability challenges, also can contribute to the development of student activism and agency. This is not only because these skills are necessary in order to develop scientific arguments. Another reason appears to be connected to the concept of "productive struggle" in mathematics; such struggle occurs when teachers include opportunities for students to attempt solving problems that target concepts that are new to them, rather than limiting those opportunities to tasks with familiar skills (Hattie and Zierer, 2017). When this happens, by trying to solve difficult problems, by making mistakes and learning from them, and at the same time being supported by their teachers to endure and to debate possible ideas and solutions, student agency is developed (Warshauer, 2015; Boaler and Dweck, 2016). In this way, we suggest that students developed agency also by engaging in "productive struggle" with mathematical problems in the Speak to Me in Numbers curriculum.

Nevertheless, the concept of agency is complex. According to the authors of *Children as Agents in Their World*:

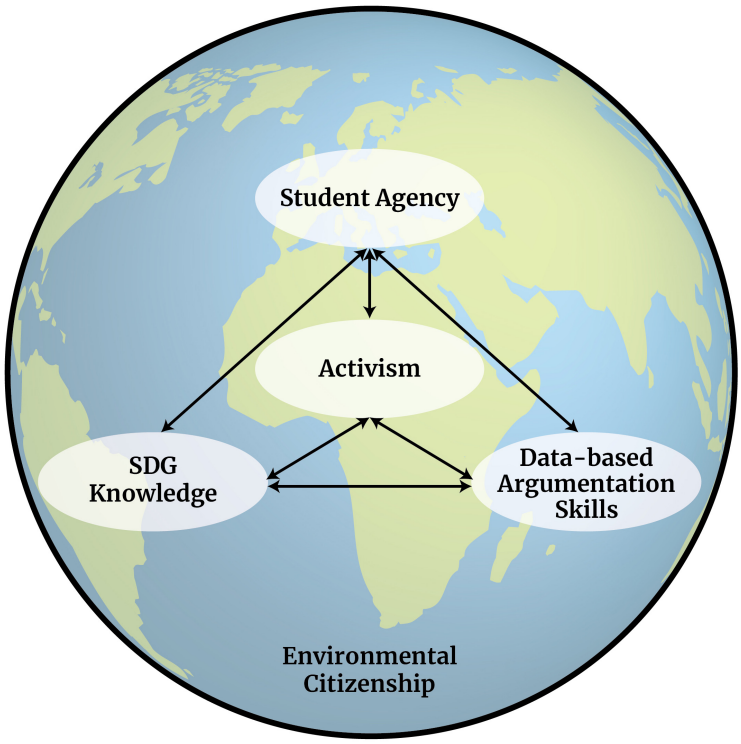


FIGURE 4
A model to develop data-based student agency on sustainability issues.

". . .agency can mean different things to different researchers. The term agency is used to label a range of phenomena or processes, a fact which confounds drawing conclusions about how agency manifests itself, by whom and in what context. However, it seems clear that agency is expressed in very different ways by different children in different settings. . . It also varies according to their own attitudes and expectations about their position in the world, their understanding of their immediate context and their anticipations of their future" (Greene and Nixon, 2020).

The authors also point out that there are many individual differences in dealing with agency, such as age, gender, genetic inheritance and contextual sources of difference, such as social class and geographical location.

Given this complex view of agency, along with the results from our study, we suggest that the development of student agency was promoted by the teachers. In other words, both the students and their teachers engaged in "co-agency." This was an unexpected result, but we feel that the study's results necessitate this conclusion. The students did not develop their agency alone, but in tandem with their teachers. This is how the concept of "co-agency" is understood, i.e., as the "interactive, mutually supportive relationships–with . . . teachers, the community and with each other–that help students progress toward their shared goals" (OECD, 2019). As a result of the "Speak to Me in Numbers" curriculum, both the teachers and the students developed their argumentation skills and their abilities to justify claims based on mathematical data and skills. Below, we will continue to discuss "student agency" by using these words, though we understand this concept to be closer to the concept of "co-agency" between students and teachers.

The research literature shows that the development of student agency regarding sustainability issues can vary among students, based on similar individual differences regarding their pessimism about the environment. Within this context, it is interesting to note a significant difference between two types of environmental pessimism: (1) pessimism about the general state of the environment; and (2) pessimism about being able to do anything about this problem (Sheppard, 2006). It is quite possible, and perhaps desirable, for students to have a realistic view about the general state of the environment, (that may involve some pessimism) while developing their agency regarding their ability to act to improve the situation, starting in their immediate environment. In this way, their agency will be a vehicle for offsetting their ecological anxiety by propogating hope, understood as "the belief in the possibility of a better future" (Kelsey, 2016).

Based on the findings of this exploratory study, along with the related literature discussed above, how might student agency on sustainability issues be developed? We address this question by first recalling that student agency, according to social cognitive theory (Bandura, 1986, 1997), is the ability of students "to regulate and control their cognition, motivation, and behavior through the influence of existing self-beliefs (i.e., self-efficacy)" and that it is composed of intentionality, forethought, self-regulation and self-efficacy (Code, 2020). The findings suggest that teachers of the "Speak to Me in Numbers" curriculum connected its four design principles to aspects of student agency, as related to sustainability issues: (1) The focus of the curriculum on the UN's Sustainable Development Goals (SDGs) was relevant to students, hence supported their motivation for learning about these issues; (2) The data-based challenges requiring the use of mathematical literacy to address them developed student efficacy in making data-based arguments regarding sustainability; (3) Student construction of evidence-based scientific arguments led to their critical thinking about sustainability issues; and (4) the concluding activism activity promoted student initiative-taking about sustainability on many levels: the classroom, school, community, and society. In addition, looking at the related literature, we suggest that student "productive struggle" with difficult math problems, the development of teachers' co-agency, and the students' experience of "doing something" about the sustainability issues they studied (despite possible environmental pessimism), *via* both their guided and open activism activities, also contributed to the development of student agency regarding sustainability issues.

In order to further develop student agency relating to sustainability issues, we suggest the following model (see **Figure 4**). The foundation of this model is the concept of Environmental Citizenship and its goal to promote "the responsible pro-environmental behavior of citizens who act and participate in society as agents of change" (Hadjichambis and Reis, 2020).

In this model, we suggest that a mutual and dynamic relationship exists between three pedagogical processes: developing SDG knowledge, developing data-based argumentation skills and developing student activism. Each of these processes (that constitute the model's inner triangle) contributes to and reinforces the others. In addition, each process contributes to the development of student agency on sustainability issues (located at the apex of the model's outer triangle).

Two other variables that reflect this type of agency are the development of a pro-environmental set of values and environmental hope. Studies have shown that if people do not have a pro-environmental set of values, they will choose not to engage in pro-environmental action. For example, in a 3-year controlled study, subjects were given feedback devices designed to help them monitor and modify their home energy use. The results showed that only those with environmental values used and derived tangible benefits from these devices, while people without these values did not (Puntiroli and Bezençon, 2020). Another variable that predicts pro-environmental action is environmental hope. People with environmental hope (1) believe in their own capacity to generate different pathways leading to the goal of protecting the environment ("pathway thinking") and (2) have the motivation to use these pathways to achieve that goal ("agency thinking") (Kerret et al., 2020).

In conclusion, our study suggests a promising pedagogy to strengthen student agency on sustainability issues *via* a data-driven pedagogy that focuses on the development of scientific argumentation, mathematical literacy, and activism. We call for future studies to investigate to what extent this proposed model can develop student agency on sustainability issues as well as pro-environmental values and environmental hope with students and teachers alike.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by IRB-Weizmann Institute of Science. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

SRa, RB, and SRo contributed to conception and design of the study and wrote sections of the manuscript. AS-B, SRa, and RB contributed to the data collection and analysis. All authors contributed to manuscript revision, read, and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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