POLAR★STAR

ROADMAP
Showing the way to innovative learning

POLAR STAR

**Guiding the way towards STEAM
through contemporary science
and innovative learning approaches**

Roadmap: showing the way to innovative learning

Contents

"Students act, and when they act, they learn better."
Polish teacher

"I learned that we can solve problems if we think well."
Portuguese Student

"Not all students want to save the world and love geography, but everyone can sort rubbish."
Polish teacher

"I learned my students are curious in general. They can work in small groups and are willing to help each other. When motivated, they can do science research by themselves."
Polish teacher

"I learned a lot about the environment and space"
Spanish student

"I was suprized that the activity we did was so much fun."
Irish student

"My favorite part was noticing problems in our environment and thinking about solutions for them by myself."
Finnish student

"I really loved that idea I had after all!"
Greek student

"I learned my students learn more through interaction. They get excited when they can apply the knowledge they acquire to everyday practices."
Cypriot teacher

"My favorite parts was finding creative solutions."
Irish student

"I liked the people's positive reactions and the experience itself, I had a good time with friends and teachers "
Portuguese student

"So, I can choose any subject I want? Any subject I like? Wow!"
Greek student

Dear teacher,

We couldn't be happier to present to you our POLAR STAR roadmap! This book encompasses all the work we have done during the past three years, in an effort to continue offering teachers solutions that will help them bring innovation and state-of-the-art practices to their school class. To us, teachers are the silent heroes that have the privilege and responsibility to shape students' minds and help them grow into individuals fully equipped to find their own way into an increasingly volatile and rapidly changing world. As you are our heroes, we wanted to make sure that the work we did in POLAR STAR is meaningful and helpful to you. To that end, during our three-year journey we worked with as many of you as possible and we were happy to involve teachers in every aspect of the project. What you will read in this book has been co-designed with advisor teachers and pilot tested in schools across Europe.

Browsing through this book, you will learn about our methodology which we originally started designing during the PLATON project and we have completed in POLAR STAR. Using this methodology, you will be able to teach the required content while developing students' key competences through means that are closely related to students' everyday life and contemporary societies. Strong emphasis is also given on personalizing the learning process, formative feedback and the promotion of horizontal connectedness across learning disciplines through interdisciplinary episodes of learning.

In this book you will also find a set of activities on Arctic research and Space exploration. Students often believe contemporary science to be completely disconnected to their needs and the world. Also, they are often found to believe that they are not fit to following scientific careers and they dismiss them for being too difficult, complicated, or impossible to pursue. Our activities will help your students obtain a clear understanding of the strong bond between science, technology and society, develop an appreciation of what science and technology offers to the world and most importantly cultivate the idea that scientific careers can be exciting, rewarding and that they are 'there for the taking' by boys and girls alike.

We hope you enjoy reading our roadmap and that it will inspire you to use POLAR STAR with your students!

Yours sincerely,
The POLAR STAR team

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POLAR STAR in a nutshell

POLAR STAR brings together state-of-the-art learning pedagogies and combines them with exciting activities that focus on contemporary science, thus helping teachers to introduce STEAM successfully in their class. At the same time, the project focuses on the development of students' key skills and competences as well as deepening their knowledge of fundamental science principles, increasing their appreciation of science and technology and their role in today's society.

See the Polar Star project website for details on the project, materials and partners >>

You can also find a general introduction to the project in video form. >>

Background and heritage

The partners of POLAR STAR have been working together for several years on designing innovative pedagogies and state-of-the-art educational materials. POLAR STAR is the result of this long collaboration and was designed to continue the work that parts of our team started in previous projects. In 2013, partners worked together during the Go-Lab project focusing particularly on interdisciplinary learning, inquiry learning and educational activities that use online labs. POLAR STAR partners, working together with other partners of the Go-Lab team, produced the "Big Ideas of Science", an interdisciplinary set of core science ideas that, in their totality, describe our world, the Go-Lab inquiry cycle, a student-centred learning

approach for teaching science and a large pool of science activities which focused on using online labs.

On finishing Go-Lab in 2017, we moved on to design the PLATON project which aimed to take our work a step further. In PLATON our team used the "Big Ideas of Science" to introduce to schools an interdisciplinary organization scheme of the science content taught to help students identify the connections between what they are taught in school and the "Big Ideas of Science". The main outcome of this work was the 3D interdisciplinary map of Science Ideas. PLATON also gave us the "Inquiry Under the Microscope" toolkit which aimed to offer an alternative approach to inquiry

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This way is easier! I managed to understand what an energy transformation is."
Portuguese student

learning. This toolkit breaks down inquiry to its components and introduces them as a set of individual practices which teachers can take up at any given moment during their everyday teaching or during long-term projects to work following the principles of scientific inquiry. Finally, PLATON delivered an assessment methodology, a set of 18 science activities and 5 long-term projects.

In 2019, PLATON passed on the torch to POLAR STAR. In this project we completed our methodology for interdisciplinary and transdisciplinary learning. Building on the 3D interdisciplinary map of Science Ideas from PLATON we designed additional components to our methodology to facilitate deeper learning processes, help increase students' knowledge retention and help them picture concepts within different contexts. With these additions we completed our approach to interdisciplinary learning which we call "Science as a Whole". Working on transdisciplinary learning, our team modified the Go-Lab and PLATON inquiry approach and extended it to cover additional disciplines. This part of our methodology we call 'STEAM education". POLAR STAR also refined the assessment tools previously designed and added new ones which aim to assess students' skills development.
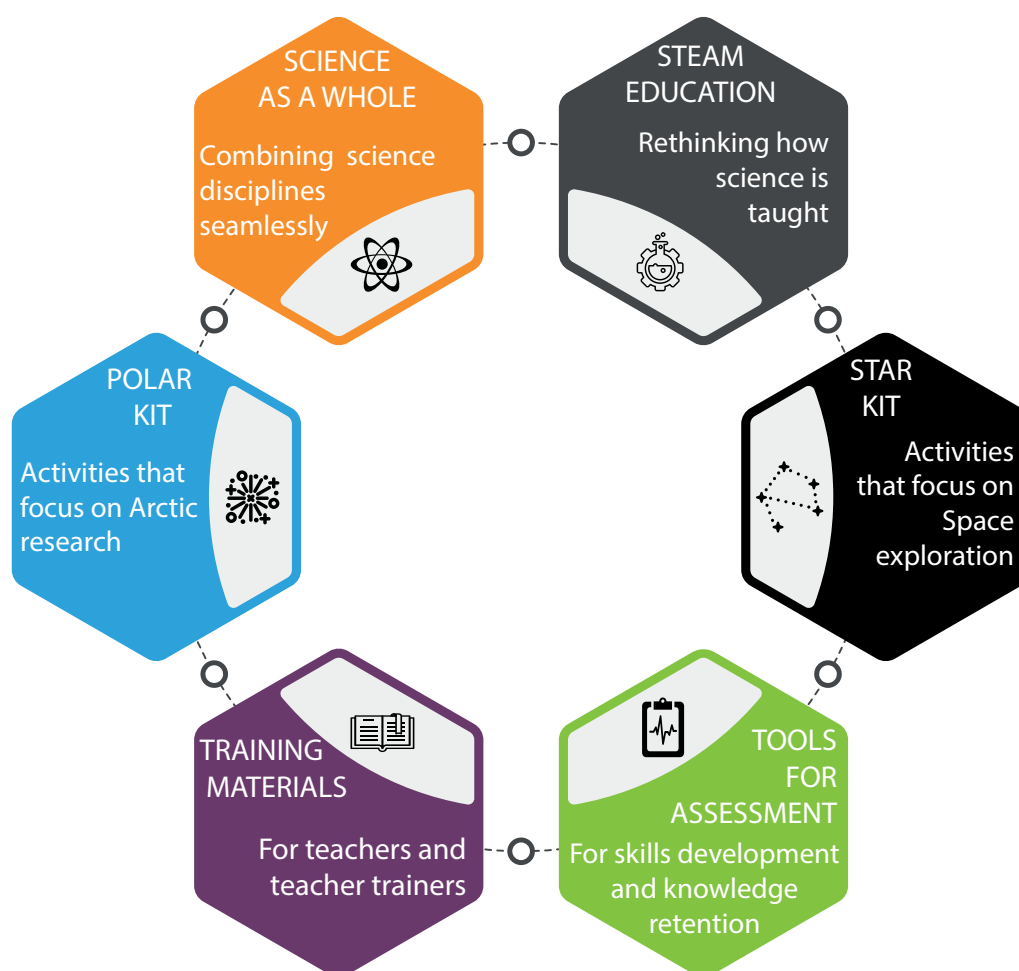
The key elements of POLAR STAR

"The most interesting thing for me was the different approach to science"

Polish student

Overall, our methodology is designed to make meaningful interventions on multiple levels of the teaching process. Its two strands are complimentary to each other and focus on different parts of the teaching process. Firstly, "Science as a Whole" focuses heavily on **'What'** we teach our students. With "Science as a Whole' we aim to help teachers prioritize the content they teach based on importance and give meaning to each concept they introduce. In other words, we help them reflect upon **where** to focus and **why** when it comes to content. Secondly, "STEAM education" focuses on how to deliver content by making it appealing and interesting, by connecting it to contemporary science achievements and everyday life while following a student-centred approach. Thirdly, our assessment tools facilitate teachers to assess students' progress and skills development not only through traditional methods but also using innovative tools that encourage self-assessment, self-expression through art and most importantly the idea that assessment is there to help students evolve rather than judge them.

Finally, unlike Go-Lab and PLATON, when it comes to educational activities, POLAR STAR focuses specifically on space exploration and Arctic research, aiming to increase students' appreciation of science through carefully designed and focused activities that involve scientific research domains that are appealing to children, teenagers and adults alike.

> **"I was surprised by how interesting the topics were."**
> **Finnish student**

The key elements of POLAR STAR

Even though POLAR STAR introduces a seamless methodology for teaching science, its building blocks can still be introduced progressively as standalone elements. Teachers can start from any given element of the project and use it as a standalone set of materials. At any given point, teachers can choose to integrate additional elements to their teaching practice. This way, POLAR STAR gives the freedom to teachers to choose whichever materials they wish and dive into the project to the degree they feel comfortable. Overall, our project has three dimensions: a) teaching methodology, b) educational content and c) support tools. Each of these dimensions includes two elements. Our teaching methodology includes the "Science as a whole" and the "STEAM education" elements. Our educational content includes the "POLAR kit" and the "STAR kit" of activities.

> **"It surprised me that Chemistry is incredible!"**
> **Portuguese student**

Finally, POLAR STAR offers a set of support tools which includes our set of assessment tools and teacher training materials. Training materials include two separate workshops, one for each of the methodology strands, to help teachers get acquainted with our materials and use them to their full potential. To bring the two parts of our methodology together, we also have designed a merged workshop, which introduces both strands together following the Design Thinking approach. This workshop aims to help you and your colleagues prepare your lessons/activities/projects and/or a whole school year plan based on the POLAR STAR interdisciplinary and transdisciplinary methodology.

An important element of the project was the feedback and ideas we received from the POLAR STAR Advisors. More than 40 teachers and educators from all over Europe helped us to make the activities meaningful to them and applicable in their classroom. In this way, we ensured that the content is compatible with the needs of different countries and the material matches the curriculum of different countries.

Training materials >>

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POLAR STAR Methodology – Science as a Whole

Prelude

As mentioned above, the work on our interdisciplinary learning approach started by producing the "Big Ideas of Science" set to be used as a reference system during the Go-Lab project. The "Big Ideas of Science" are:

Energy can neither be created nor destroyed. It can only be transformed from one form to another. The transformation of energy can lead to a change in state or motion. Energy can also be converted to mass and vice versa.

There are four fundamental interactions/forces in nature. Gravitation, electromagnetism, strong nuclear and weak nuclear forces. All phenomena are due to the presence of one or more of these interactions. Forces act on objects and can act at a distance through respective physical field, causing a change in motion or in the state of matter.

Earth is a very small part of the universe. The Universe is comprised of billions of galaxies, each of which contains billions of stars (suns) and other celestial objects. The earth is a small part of the solar system with the Sun in its centre, which in turn is a very small part of the Universe.

All matter in the Universe is made of very small particles. They are in constant motion and the bonds between them are formed by interactions between them. Elementary particles as we know, form atoms and atoms form molecules. There is a finite number of types of atoms in the universe which are the elements in the periodic table.

On very small scales, our world is subjected to the laws of quantum mechanics. All matter and radiation exhibit both wave and particle properties. We cannot simultaneously know the position and the momentum of a particle.

Evolution is the basis for both the unity of life and the biodiversity of organisms (living and extinct). Organisms pass on genetic information from one generation to another.

Cells are the fundamental unit of life. They require a supply of energy and materials. All life forms on our planet are based on this common key component.

Earth is a system of systems which influences and is influenced by life on the planet. The processes occurring within this system influence the evolution of our planet, shapes its climate and surface. The solar system also influences Earth and life on the planet.

Science as a whole ▸▸

The 3D Map of Science Ideas designed in the PLATON project
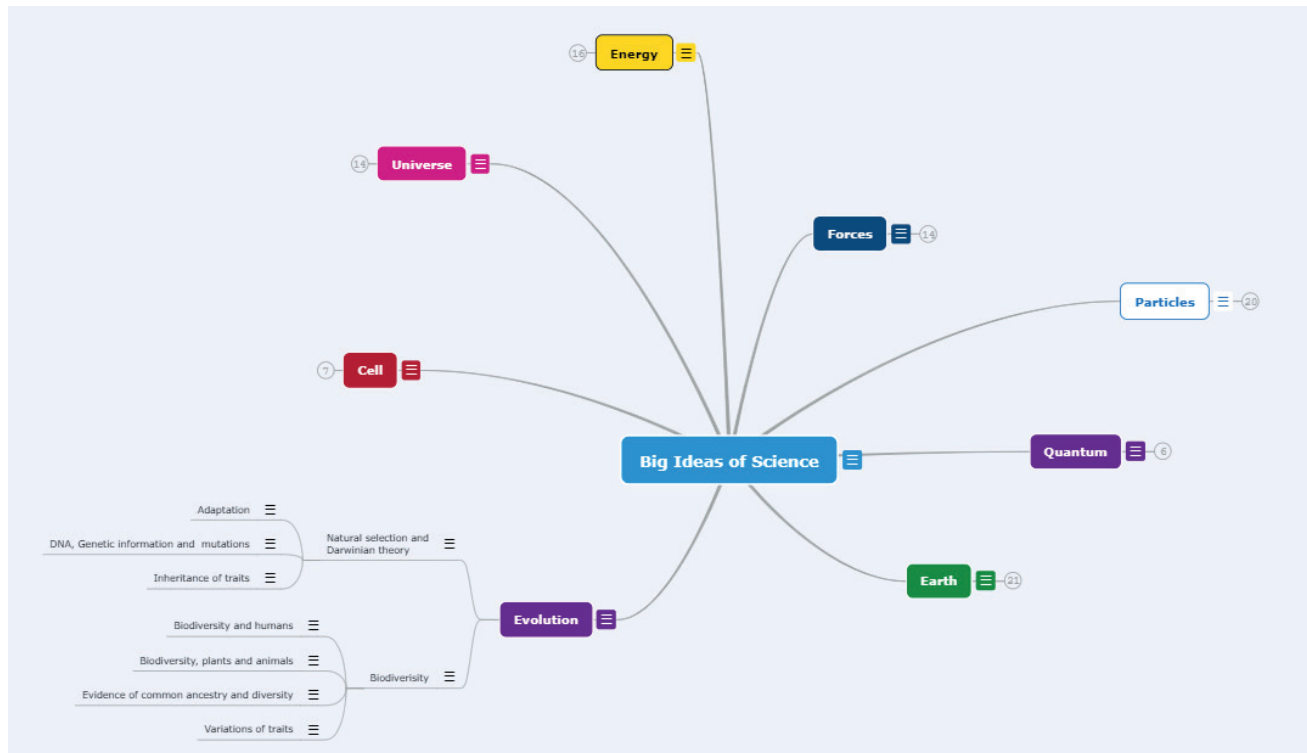
Even though the "Big Ideas of Science" were widely accepted by the teachers, through our work with them, we found that a bridge was missing between these broad and relatively abstract core concepts and the smaller concepts students learn in detail during science classes. To that end, our team designed what we teasingly call a 'curriculum-proof curriculum'. We call it that because it encompasses all the basic science ideas students are taught over their school years organised in an interdisciplinary way. It is 'immune' to curriculum changes; it can be used with students of all ages and in schools of countries with different approaches to science education. Our curriculum-proof curriculum was produced during the PLATON project and it is the 3D 'Interdisciplinary map of Science Ideas'. This 3D Map essentially breaks down the eight Big Ideas of Science to 21 smaller ideas, which we call Intermediate Ideas and these Intermediate Ideas are then broken into 86 smaller ones, which we then called "Small Ideas of Science" and we now call "Basic Ideas of Science". The 3D 'Interdisciplinary map of Science Ideas' is based on the concept of the Big Ideas of Science and aims to act as an organisation scheme for concepts and principles that goes beyond

3D 'Interdisciplinary map of Science Ideas' ▶▶

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My favourite part was conversations with my classmates. Sharing my opinions and point of view expands others' thinking. When others also share their opinions and points of view, my own thinking expands.

Finnish student

traditional curriculum organisation and allows students to identify the connections between what they learn in different disciplines as well as to everyday life. This map can help teachers introduce any given stand-alone subject using an interdisciplinary approach as well as make connections to subjects that are also discussed in other disciplines in collaboration with other teachers. It is our experience so far that teachers tend to find many more connections between topics than those suggested, so these are just a starting point to each teacher's discovery.

The 3D Map of Science Ideas was the starting point of our work in POLAR STAR and it was used on different levels to address important questions...

Two important questions

Students often feel overwhelmed with the number of things they must learn during science classes at school, and they cannot seem to be able to find any benefit to what they are learning. As a teacher, surely, you would agree that it is not unusual to spend a long time teaching your students certain concepts and principles only to find out that soon after they have completely forgotten what you had been talking to them about. Questions like 'Who cares?' or 'Why do I have to learn this?' are often found on the lips of students, causing disappointment and frustration to their teachers. These circumstances and students' resentment towards science classes have multiple implications not only in the short term but also in the long term. Students' failing interest in science classes leads to fewer youngsters following scientific careers and less scientifically literate young citizens. This failing interest stems from the fact that students do not find meaning in what they learn during science classes, they do not feel inspired or intrigued and they cannot seem to be able to find connections between what they learn in school and the world out there. This sullen situation leads to two important questions: What is really important to teach? How do we increase students' knowledge retention?

Both these questions are closely related to a problem many teachers around the world face: Overloaded curricula. The number of concepts to teach is so great that it inevitably leads us to wonder what really is important for students to learn and what could potentially be left out. In addition, it looks inevitable that students will likely forget most of what they learn, as they are asked to learn (memorise) a great deal of information in a relatively short time.

What is really important to teach?

So, when thinking about the science curricula of different grades, how do we distil what is really important? Among all the concepts students are taught over their school life, which are the core concepts that constitute the foundations of how the world works (isn't that one of the main reasons why we teach science in schools)? Do these core principles receive the attention they deserve? Is there enough time allocated to their communication? To what depth are they taught and in how much detail should the students know them? Even if students are taught these concepts, would they be able to understand that these are the core concepts and why they are so important?

The POLAR STAR team has been working for many years on these very same questions aiming to give concrete answers. From our research, it is evident that what teachers could really use is a set of core ideas of science, which as a whole describe how the world works in a nutshell. The

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My students increased their appreciation about the role of science in contemporary societies and ability to make connections between natural phenomena."
Greek teacher

Students from Cyprus detecting microplastics in home products

fundamental nature of these core concepts is such that they naturally appear in science curricula, regardless of the possible changes in school curricula over the years, or the different curricula of different grades. Thus, teachers can use them as a reference system, one they can always use in class, no matter what they teach their students, to make connections and give them the bigger picture.

"I learned science is everywhere!"
Finnish student

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So many things make sense now!"
Cypriot student

How do we increase students' knowledge retention?

Retention is all about being able to remember things. Knowledge retention involves the process of being able to recall knowledge and use it within different contexts. It is closely linked to processes for deepening students' learning. Let us start by focusing on the simplest part of the question: How can we increase someone's ability to remember things? How can we help our students move what they learn from their working memory to their long-term memory? Are there
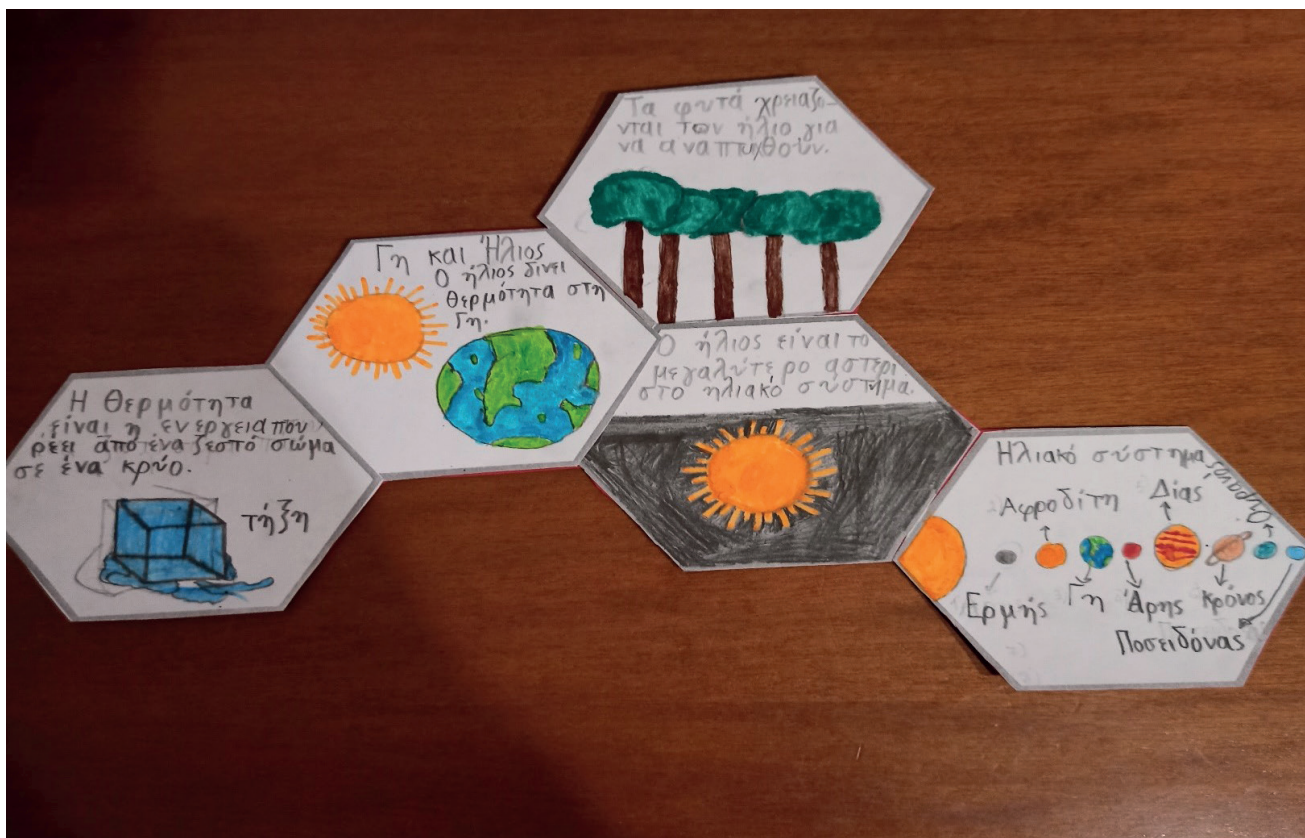
A Greek student's map based on the Sun

any 'tricks' we can deploy to help our students do this? Now let us think about the main problem: How can we use these 'memory tricks' in a meaningful educational context?

Three complimentary answers

The two questions discussed above, **What is really important to teach?** and **How do we increase students' knowledge retention?** are closely linked. When it comes to curriculum content, it is imperative for a teacher to be able to prioritise and identify the gravity of each concept taught and where it fits into the bigger picture (our world). Teachers need to be able to discern between the fundamental concepts that require more attention and others that could be viewed as secondary. In other words, a teacher needs to be able to tell what is really important for students to learn and what 'they could live without'. Knowing what is really important to teach will also indicate when a teacher should focus more on increasing students' knowledge retention. If every single piece of knowledge is addressed

with equal priority then 'what is really important' will no longer stand out or be treated with the attention it requires.

In POLAR STAR, our answer to the question 'What is really important to teach' (as far as science education is concerned) is what we call 'The Big Ideas of Science'. 'The Big Ideas of Science' is the set of core concepts discussed above. It is a set of crosscutting science ideas that go beyond science disciplines and to their total, describe our world in a nutshell (see more below). Our answer to the question 'How do we increase students' knowledge retention?' is by giving multiple meanings to each concept, both related to natural phenomena and related to students' lives. Thus, to address the two questions discussed above and improve the way science is taught in class, POLAR STAR offers three methods that are meant to be used jointly:

A. Keeping the bigger picture in mind
In POLAR STAR we view all science concepts taught to students not as standalone entities but as a part of a bigger meaningful knowledge struc-

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After several hours of work, they wanted to spend more time on the activity, so they tried to fool me by hiding all they had done and telling me it was all wrong and they had to start all over again. Seeing my students trying to keep a straight face to convince me was hilarious!"
Greek teacher

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My students developed their critical thinking skills. They improved their writing and verbal skills. They started to combine elements from different science disciplines. They were happy to collaborate and help each other. They gained self-confidence as far as working on scientific subjects is concerned."
Greek teacher

ture, in which every concept has a certain place. That structure allows students to connect each concept taught to other related ones and most importantly connect it to bigger and wider concepts that encompass it. Through this knowledge structure, students can start from small standalone concepts and follow a knowledge path to bigger and more abstract concepts that always lead them to the core fundamental concept behind the starting concept. Every time students learn something new, before moving on to learn the next concept, they can take some time to reflect on the concept at hand and try to find its place within that knowledge structure and identify the core concepts behind it. If that process is done systematically, and students keep going back to the same knowledge structure again and again, then surely in the end, the chances of them being able to recall the core concepts are much higher. Overall, this technique of always linking each concept to core concepts that encompass it, aims to increase the knowledge retention of students as far as core concepts are concerned through a systematic revision.

"It has surprised me how science is important for everyday life."
Portuguese student

B. Present each concept within different contexts

Think about actors starring in movies. If we watch an actor starring only in comedy movies, then we only know a bit about their talents. We are most likely to also consider such actors to be a bit 'one-dimensional' since we think comedies are all they can do. But we can't really tell how good such an actor really is. If, however, we see the same actor in different movies; dramas, sci-fi, action movies etc. only then are we able to get a more complete idea of how talented that actor is and begin to appreciate their work.

Following that analogy, each concept is not a standalone entity; it plays a role in multiple phenomena, and it is related to other concepts taught in the same discipline or in other science

disciplines. If students learn about a concept isolated from the related phenomena and other related concepts, then students miss out on the opportunity to truly understand the power of that concept. Thus, in POLAR STAR we place a lot of emphasis on linking each concept taught to a) other science concepts; b) related natural phenomena; c) Technology and Engineering achievements (contemporary and older) that this concept is related to. That way, students are offered plenty of opportunities to understand the true role of each concept not only in the natural world but also in addressing the needs of societies throughout the eras. This way we aim to give the students a meaningful way of assessing the importance of each new concept they learn, give meaning and increase their appreciation of what they learn and ultimately increase their appreciation of science.

C. Personalised learning

Emotion is an important factor when it comes to storing memories. This is why students' memories and experiences are of great importance when it comes to effective learning. Linking what students learn to personal experiences and memories adds an emotional aspect to the learning process, which could increase knowledge retention. With this in mind, we strongly believe that designing student-centred activities and assigning roles to students that are tailored to their personal learning styles and preferences is essential to increase students' ability to learn through experience and happy memories. However, such projects usually can be carried out only a handful of times throughout a school year. Thus, on top of school projects, links to memories and experiences also need to be done during everyday lessons. Linking what is taught to personal experience can happen during different phases of the learning

process. For example, it can be done when introducing a concept, to anchor the new subject to something already familiar to students, or during the reflection phase.

Linking what is taught to personal experiences, also has another significant role - that of identifying misconceptions based on the misinterpretation of phenomena and experiences. By discussing students' personal experience connected to the subject at hand, teachers are in position to spot underlying misconceptions and correct them.

"I acquired some information that allowed me to understand events that had already happened to me."

Portuguese student

The "Science as a Whole" rationale

The "Science as a Whole" part of our methodology aims to help teachers introduce interdisciplinary learning in their class and address two main challenges, namely: "What are the core concepts students should learn?" and "How to increase knowledge retention?". At the same time, it also aims at giving meaning to what students learn and thus increasing their appreciation of science and its role in our loves.

The POLAR STAR "Science as a Whole" methodology focuses on four key points and making four different types of connections during their lessons:

The Bigger Picture

Focusing on what is important: Connect each concept taught to its parent Big Ideas of Science.

Linking each concept taught to the Big Ideas of Science helps students build a meaningful structure of knowledge. In addition, the more students use the Big Ideas of Science as their reference system, the more familiar they become with them. Thus, when all other knowledge fades away, the Big Ideas of Science are more likely to remain.

For each concept, the link to the Big Ideas can be done during the wrapping up part of the learning process.

Emotion

Personalized learning: Connections to students' everyday lives, their memories, experiences, and interests.

Personal experiences and memories can be a powerful tool in the learning process. Linking them to the concepts taught can greatly increase knowledge retention as students link concepts to their personal experience. Thus, not only are concepts given meaning through examples and meaningful contexts, but their importance is also increased for students due to their own experiences. Such connections can also help tackle misconceptions that could be built on the wrong interpretation of our own experiences.

Like "Action", "Emotion" connections can be useful to introduce the concept in an interesting way at the beginning of the lesson, or during the reflection phase to facilitate deeper learning. Hands-on activities can also facilitate personalized learning.

Action

Presenting concepts within meaningful context: Connections to natural phenomena, Technological and Engineering achievements.

Connections to natural phenomena, technological and engineering achievements allow teachers to present concepts within meaningful contexts that enable students to understand the role of each concept in nature and our everyday life. This way, teachers can increase students' appreciation of science and knowledge retention through tangible examples and real-life challenges.

Such connections can be made in many different parts of the learning process. Using such a connection can be useful to introduce the concept in an interesting way at the beginning of the lesson, or during the reflection phase to facilitate deeper learning. Related hands-on activities can also be related to such connections.

Review

Revisit each concept in relation to others: Connections to other science concepts taught in the same or other disciplines.

Linking concepts taught in the past with concepts introduced at a given lesson is an ideal way to revisit past knowledge, refresh student's memory and build meaningful connections between concepts which can demonstrate the interrelated nature of science disciplines and that of nature in general.

Such connections can be introduced during the recalling past knowledge phase of a lesson, during experimentation as well as reflection.

Overall, the four types of connections presented can help teachers achieve the goals mentioned above. They can be made during any part of lesson based on the teacher's judgement. POLAR STAR offers a complete training guide (presented in the Training Materials chapter) to help teachers integrate these elements in their teaching practices. Our team has also designed the necessary tools to support teachers in introducing our methodology in their classes.

Brief
Description

Are there in
other
concepts
related to it?

What's
the Bigger
picture?

Concept
learned

Any personal
stories
or
experiences?

Do you know
any
phenomena
related to the
concepts?

Where do
you find
this concept
in everyday
life?

The knowledge hive

"Science as a Whole" tools for teachers and students

"Science as a Whole" methodology offers you the rationale and tools to make your lessons more interdisciplinary during everyday teaching. Even though the Science as a Whole methodology can be quite extensive and detailed, its application in class can be done using two simple tools: The knowledge hive and the knowledge map. These two tools can be used at any given moment and particularly at the end of each chapter or whenever the teacher concludes a particular section. They can be assigned as homework activities or in-class activities depending on time availability. Our team has developed these tools both in printable and digital format.

"I am now more open to work creatively in class"
Polish teacher

As our methodology is about interdisciplinary learning, it is evident that these tools are apt for use when teaching any science subject. Since in many countries, especially in secondary education, different science disciplines are taught by different teachers, collaboration among them is important. Getting all the science teachers at a school on the same page and helping them synchronize their classes is also a very important aspect for successful interdisciplinary learning. The knowledge hive and the knowledge map are two tools that can help teachers coordinate and have a common overview of the students' acquired knowledge.

The knowledge hive

Essentially, the knowledge hive is a fact sheet that students are asked to fill in after the teaching of a particular subject is complete. The questions included in the hive are designed so that students are prompted to reflect on the concept they learned based on the three aspects of our

methodology and the key connections mentioned above: a) Keeping the bigger picture in mind, b) Present each concept within different contexts and c) Link each concept to the related natural phenomena, technology and engineering achievements and d) Personalized learning. These questions aim to encourage the student to think about the bigger picture, about other concepts related to the one under discussion, phenomena in which it plays a role, where we meet this concept in everyday life and if they have any personal experiences that are related to it.

> **"The inspiration hive had an extraordinary effect on my students. In fact, I had never seen them so enthusiastic to do something. It was extraordinary. I was already expecting their engagement, but their reaction overcame my expectations"**
> **Portuguese teacher**

You can ask your students to fill in the knowledge hive after you finish teaching a particular subject.

The hive can be filled in in class or as homework, and if time allows it, there can be a follow up discussion where students exchange information. Students can use the 3D 'Interdisciplinary map of Science Ideas' or the Science WAND (presented below) to draw inspiration when filling in the hive. As a teacher we encourage you to complete a knowledge hive before starting to teach a subject. During your teaching you can use the information you added in your hive as inspiration for your students or in different stages of your lesson to serve different goals. For example, you can use a personal experience, or a technology product related to the subject at hand as introduction. A discussion on personal experiences or from everyday life can also help you identify underlying misconceptions. Or, you can design a short experiment or demonstration based on a related phenomenon and use it with your students during the experimentation phase. In the spirit of promoting inclusion and diversity as well as multiple means of expression, we also advise to encourage your students to fill in the hive not just using words but with drawings and any other element inspiring to them, such as: writing poems or stories, adding pictures, tactile materials, or anything else they like.
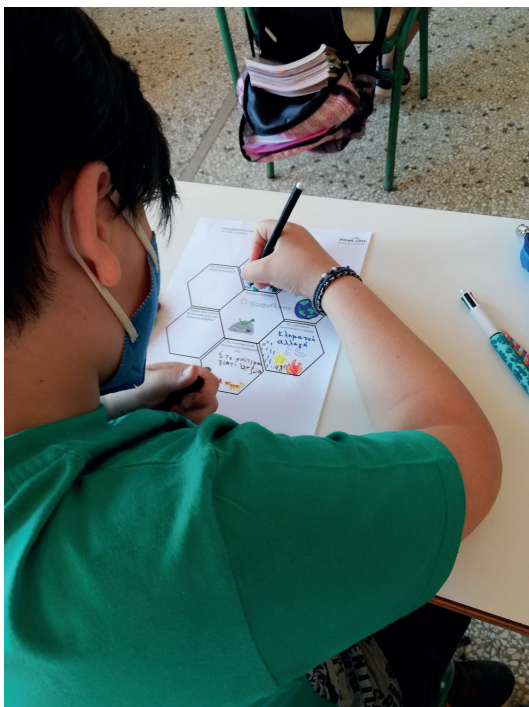
Student from the primary school of Agia Varvara in Greece adding drawings to his hive.

Student's hive from the primary school of Kanalia in Greece.

The knowledge hive can also have an additional use for teachers. As, for every concept taught, students are invited to use the hive to depict information based on their own understanding of the concept on multiple levels, that makes it a very useful formative assessment tool as well. Be reviewing students' hives, a teacher can elicit a lot of important information in addition to the students' level of understanding. The hive can communicate information about what excites the students, what kind of information impresses them, hidden misconceptions, personal moments and experiences that are important to them, as well as their ability understand multiple contexts in which a concept may be present.

The knowledge map

With this tool we invite students to create their own personal knowledge maps. These maps are the students' personal knowledge structures, built based on connections between concepts that help them place each concept they learn within a broader meaningful context. By doing this activity, students have yet another chance to engage in a personalized learning experience. Students create their maps based on their own

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Do you like my drawings? So, are we doing science now? We should do this again."
Greek student

understanding of how important each concept is, and which are the connections between concepts worth remembering. The shapes, colours and overall presentations of the maps can differ widely from student to student thus demonstrating in an apt way how differently each student goes though the learning experience.

The original inspiration for designing the map came from a very popular board game, the 'Settlers of Catan'. One of the reasons behind its success is the creative way the board of the game is determined. Instead of having a fixed game board, in Settlers of Catan, in order to make the game board, players are provided with five different types of tiles. Tiles are arranged randomly at the beginning of every game to make the board of the game. Thus, as the arrangement of the tiles changes every time, the strategy of the game also changes. That allows the game to be very diverse in terms of strategies and provides players with endless different boards to play with.

"Curiously, I have noticed that the misbehaviour situations in my class have been reduced in comparison to previous years"
Portuguese teacher

To put this idea, initially inspired from a board game, in an educational context our team used two more valuable tools; storytelling and personal geography. Children have an innate love of stories. Stories create magic and a sense of wonder at the world. They teach us about life, about ourselves and about others. They promote a feeling of well-being and relaxation and can increase children's willingness to communicate thoughts and feelings. Stories encourage active participation, increase verbal proficiency and encourage the use of imagination and creativity. Finally, through story telling students are encouraged to collaborate and enhance their listening skills. Personal geography is an artistic expression of a person's personality, thoughts, feelings, dreams, aspirations, anything else is important to that person. It is an artistic way to self-reflect

"The moment I felt most proud came after we completed the activity with the inspiration hives and all students got to see what their classmates had created. I was observing them exchange positive feedback; they were coming to me to tell me how much they loved their peers' hives and discussing their ideas. They collaborated impeccably and the students who lack confidence in presenting their work benefited a lot. They had fun, they felt very happy with their hives and indeed earned a lot from the activity. They described their experience as 'perfect'!"

Greek, teacher

or express oneself. Personal geography can help students to discover the value of what they learn through an artistic expression while it promotes self-reflection and a deeper realization of the impact of each learning experience. Using the ideas mentioned above, we invite students to make their own map, using hexagon tiles, each of which has the name of a concept written on it. At the end of each chapter, students are invited to take tiles with the names of the concepts discussed and place them on their map. Students can place their tiles so that concepts that have a connection are placed one next to the other. Students can make cluster of concepts, connect them based on what is important to them and tell stories based on the knowledge derived. Here is an example of such a map along with the students' presentation.

"I was surprised I liked everything, I think the fact that we can do practical activities is very interesting, educational and fun."

Portuguese student

As the school year progresses and more tiles are added to the map, students begin to see in a tangible way, the number of different concepts they have learned, they get to revisit them, review the connections between them and imagine different ways of connecting them. Students can always go back to their maps and rearrange tiles based on new knowledge and by deciding which connections they want to depict. Possibilities are endless and students create unique maps according to their own notion or even create collaborative ones.
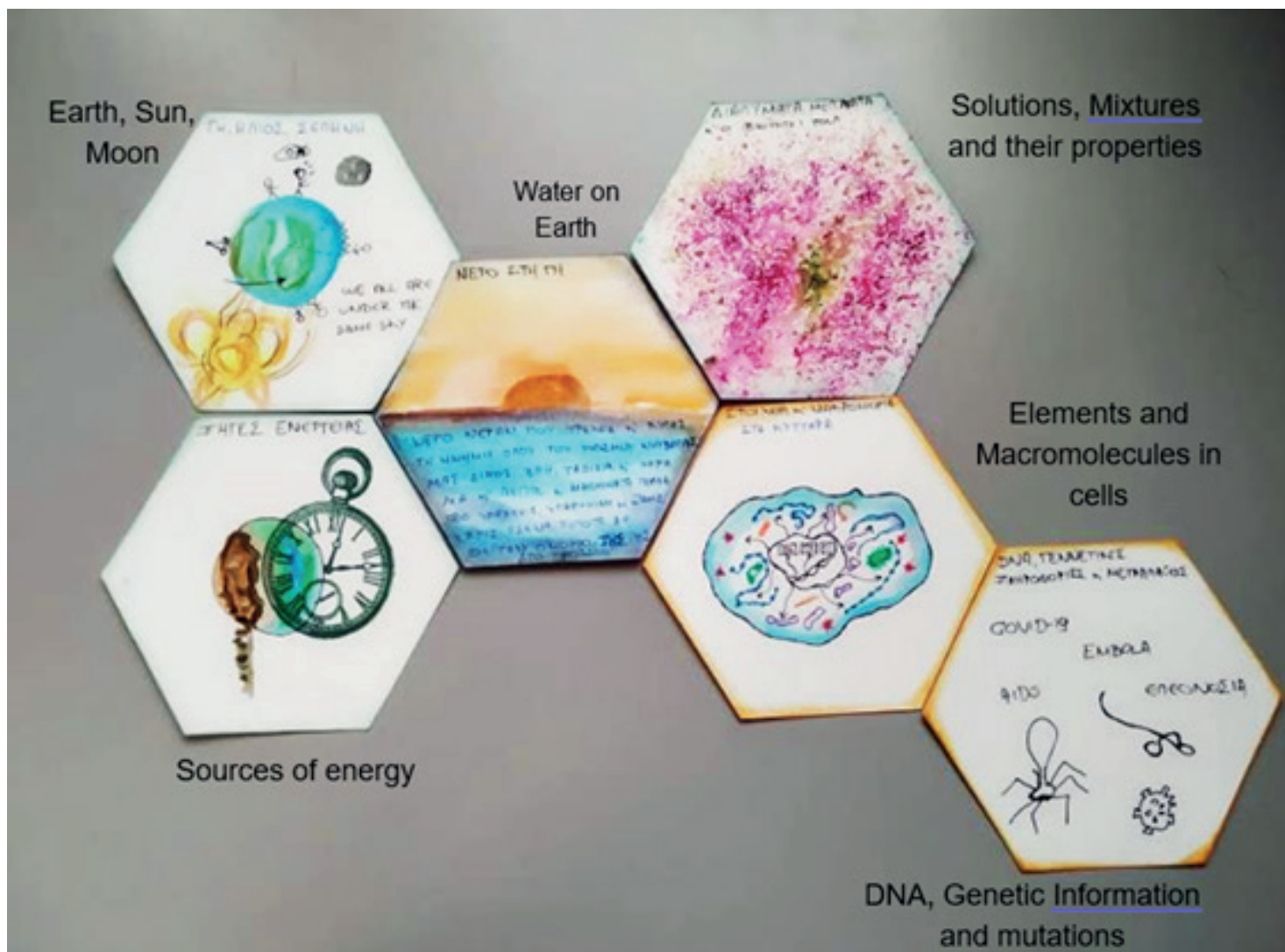
Can you explain how you placed the tiles together?

"I've placed 'Water on Earth' in the heart of my map as it is the source of all life. It is everywhere in nature and plays a pivotal role in countless processes on Earth, from Tides to the function of organisms. Tides and moving water can be a source of clean energy to help us counter the exploitation of fossils. Water rich in elements is in our cells and the key ingredient of life. At the same time however, more than 884 million people do not access to clean water to drink which makes them suffer from multiple diseases."

Can you make a story using these tiles?

"I'd like tell a story about a water droplet. The droplet makes a journey around the planet. The journey begins when the droplet falls from the sky in the form of rain, it travels around the world through streams and ocean currents, going through hydraulic power plants and then moving on become part of solution in a lab that becomes a malaria vaccine. The droplet is inserted through the vaccine to a human and travels in the cells where it observes the wonders of cell functions. The journey ends back where it started with the droplet travelling back to the clouds only to set off to a new journey."

Students can use blank tiles for each concept making a representation on their own, however, our team also designed tiles with eight different colours, one for each Big Idea. For each concept, the colour of the tile depends on the parent Big Idea. That way, while making their maps, students will get to mix concepts under different Big Ideas which is also a visual way of demonstrating the universality of science concepts and their interdisciplinary nature. Students can also choose to place the knowledge hive of each concept under the respective tile to keep all the information together. To place the tiles and design their maps, students can use different materials. They can use large sheets of paper, foam boards or anything else that suits your needs. If you collaborate with other science teachers, students can use the same map for all science classes and add tiles of concepts from every science discipline.

Teachers building knowledge maps during a training event
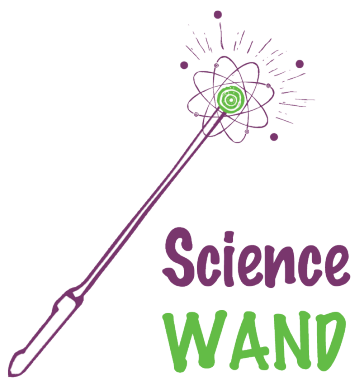
Science WAND

The Science WAND

As presented above, the knowledge hive and the knowledge map are two tools which can be printed out and given to students. However, our team has also designed a tool to make them available in digital format. The digital tool allows students and teachers to fill in their knowledge hives and design their knowledge maps in digital format. We call this tool **The Science WAND** (inspired by the phrase **W**andering **A**long **N**ature's **D**imensions). Teachers can request a new classroom and each student can have his/her own space in the tool. Students can register using a username and password, but no e-mail or verification is required. Teachers have the overview of their class through a dedicated dashboard, view their students' work and reset their passwords if needed.

Students in Spain working in their knowledge maps

Students can create their own knowledge maps and fill in their knowledge hives. In the digital format, the knowledge hive also gives users pre-set information under each section using a "View information" switch. Students can drag concepts from the list on the left of the tool and drop them on the map canvas. Concept tiles can be moved around and rearranged freely. By clicking on a tile on the map its knowledge hive appears. Concepts are divided in 8 groups based on the Big Ideas of Science and each has

Knowledge map from a student at the Primary school of Kanalia, Greece

Science WAND

BIG IDEAS OF SCIENCE | ABOUT | VIEW TUTORIAL | VIEW BASIC IDEAS CONNECTIONS | SAVE | LOGOUT

The big bang theory and the timeline of our universe

Scales of our universe

The origin of the elements

Elementary particles

Structure of atoms and isotopes

Properties and categorization of elements, the

Biogeology   View Information

Brief Description
The bigger picture
Everyday life
Related concepts
Personal stories
Importance

CLOSE

View of the knowledge map and hive in the Science WAND tool

a different colour. The concepts under the same intermediate idea have the same symbol. Using the buttons on the top users can have access to the 3D map of Science Ideas, a tutorial and information about the tool.

In the digital version, the team added on more feature which allows users to easily view the connections between concepts. In this view, all concepts appear in a circle and connections are depicted as lines between the tiles. By hovering over a tile, the user can see the name of the concepts and those connected to it. By clicking on the tile, the concepts and all its connections appear in the middle of the circle. By hovering over a line, the user can read the connection between the two concepts. In the pre-set view, users can only view the connections they added themselves while filling in the respective section in the knowledge hive. A "Show all connections" switch allows users to see all connections available in the tool by default.
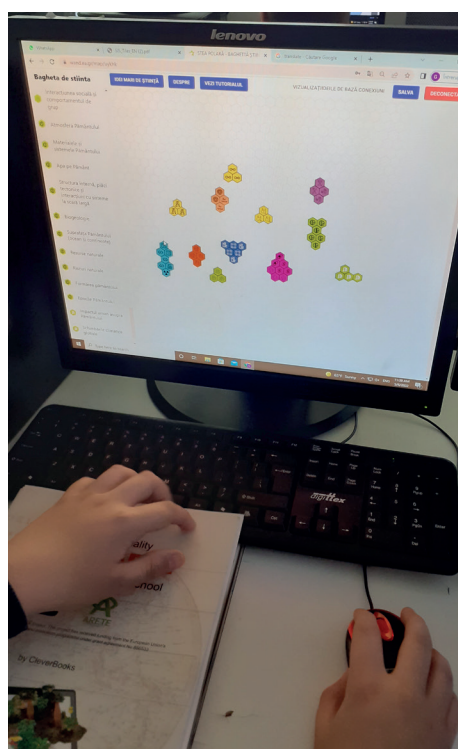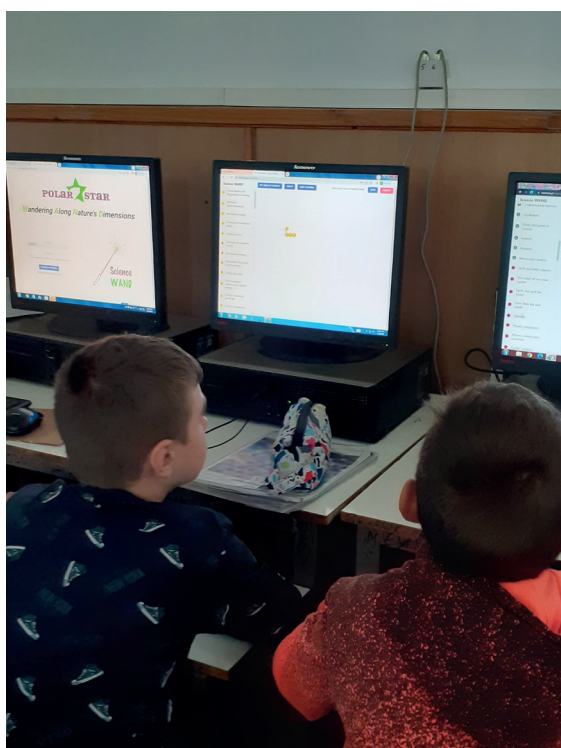
Students from the Secondary School I.A. Bassarabescu in Portugal working with their Science WAND
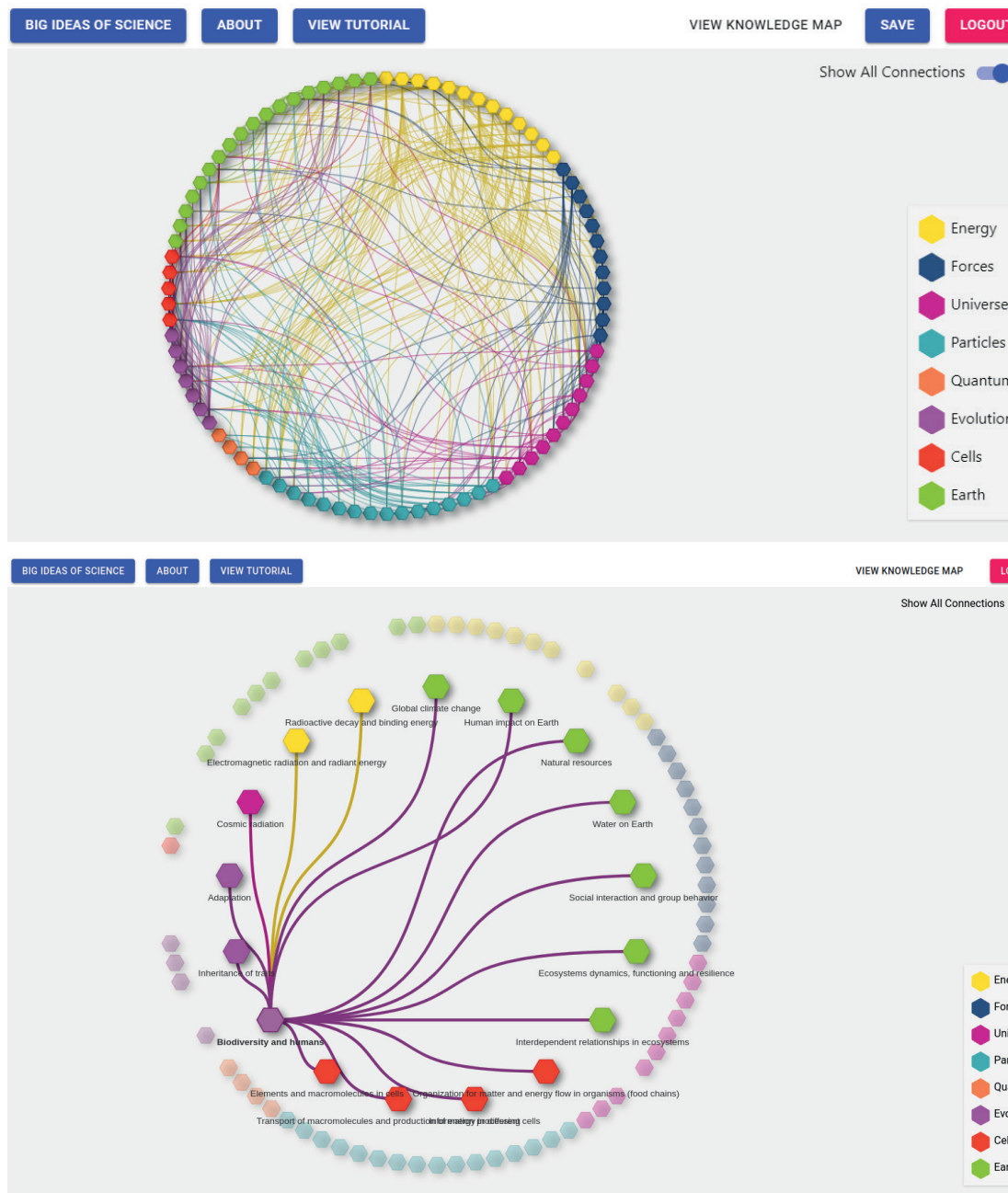
The Science WAND tool shows not only the knowledge map a student has built, but by changing the view it is possible to visualise all the connections they have made between the different concepts. It can show all connections at once, or the connections of a specific concept.

All information added to the system is saved and accessible when re-entering using the same credentials. This way, the WAND can be used by students throughout the school year. All concepts and their accompanying information are available in English, Finnish, Greece, Polish, Portuguese and Spanish. A tutorial is also available to help new users navigate and use the Science WAND.

Science WAND >>

Science as a Whole in schools

Science as a Whole was implemented in 17 schools, in 4 countries. Implementation of Science as a Whole mainly entailed the use of the Knowledge Hive in class and having students making Knowledge maps. It was used with students of different ages, from 5th grade in Greece to 10th grade in Portugal. The feedback from all schools was overwhelmingly positive: both the teachers and the students loved doing these, and teachers said their students learned better as they got more excited. The online Science WAND tool was also used in some schools, and the feedback for this was also positive.

In Spain one school implemented the methodology with 15-16 years old students in a slightly different way. They used some activities found in the teacher training materials, such as the mystery boxes, to present how science works, as well as Basic Ideas of Science tiles. The students were very engaged and showed interest in the differ-

ent activities. The teachers also valued all the resources provided by the POLAR STAR project and its dynamic in the classroom.

The challenges with the implementation mostly had to do with the new way of doing things. It took a while for the students to understand what was expected of them, but once they did, they took to the tasks more enthusiastically than at least some of the teachers had expected or hoped for.

Students in Spain working on their knowledge maps.

78% of teachers confirm that POLAR STAR's Science as a Whole methodology has served to improve student engagement, motivation and learning efficacy.

91% of teachers confirm that POLAR STAR's Science as a Whole methodology has helped students learn more effectively, compared to traditional methodologies.

94% of teachers say that POLAR STAR's Science as a Whole methodology contributes positively to their teaching style.

3

POLAR STAR Methodology – STEAM Education

What is STEAM education?

STEAM, which stands for Science, Technology, Engineering, Arts, and Mathematics, is an educational framework for all educational levels which seeks to engage students and teachers in trans-disciplinary learning in a student-centred, collaborative and iterative environment. STEAM is more than a lesson design or a class configuration; it is a culture focused on pushing students' deep thinking while solving problems which might concern themselves, their school, and the overall community.

Why STEAM?

In the context of a STEAM setting, students gain authentic experiences through dealing with problems and being encouraged to provide solutions by employing knowledge and skills from different disciplines through innovation, creativity, critical thinking, effective communication, and collaboration. Also, STEAM as an approach to teaching and learning, has the potential to produce powerful, authentic learning opportunities for students' meaningful participation in challenging STEAM fields needed in the future work-

STEAM education ▸▸

force. In doing so, learners are equipped with the necessary knowledge and skills related to the fields of Science, Technology, Engineering, Arts and Mathematics. These knowledge and skills, which are aligned with the 21st century skills (critical thinking, collaboration, creativity, technology literacy, etc.) are integrated in teaching in ways that help students not only to understand the underlying principles, but to be able to practice and create products needed in daily life.

> **"Now I apply more frequently strategies that allow students to build their own learning"**
> **Portuguese teacher**

Our approach to STEAM education

While "Science as a Whole" focuses on the content itself (*what* we teach our students), our "STEAM Education" strand of the methodology focuses on the approach we follow (how we teach our students and deliver content). In POLAR STAR, we developed an approach in which one of the STEAM disciplines is the lead discipline that shapes the profile of the activity, while the other disciplines have a supporting role. Hence, STEAM could be Science-focused (**S**TEAM), Engineering-focused (STE**A**M) etc. The POLAR STAR STEAM toolkit offers teachers a set of different activity templates to support teachers design Science-STEAM, Engineering-STEAM and Arts-STEAM activities.

> ### "...With the methodology we also got more conversation crossing subject boundaries than normally."
> **Finnish teacher**

Technology in terms of technological achievements go hand-in hand with providing solutions to emerging challenges of societies so it is directly related to Engineering. To that end, a separate template for technology-oriented activities is not provided. Instead, the Technology-STEAM part of our toolkit focuses on the deployment of technological solutions and digital tools within the learning process. A Mathematics-STEAM template is also not provided as mathematics are inherently present in any type of activity.

> **I felt most proud about the way our students engaged themselves in discussion and exchange of ideas and their enthusiasm in disseminating the knowledge and experience acquired by the workshop to their peers."**
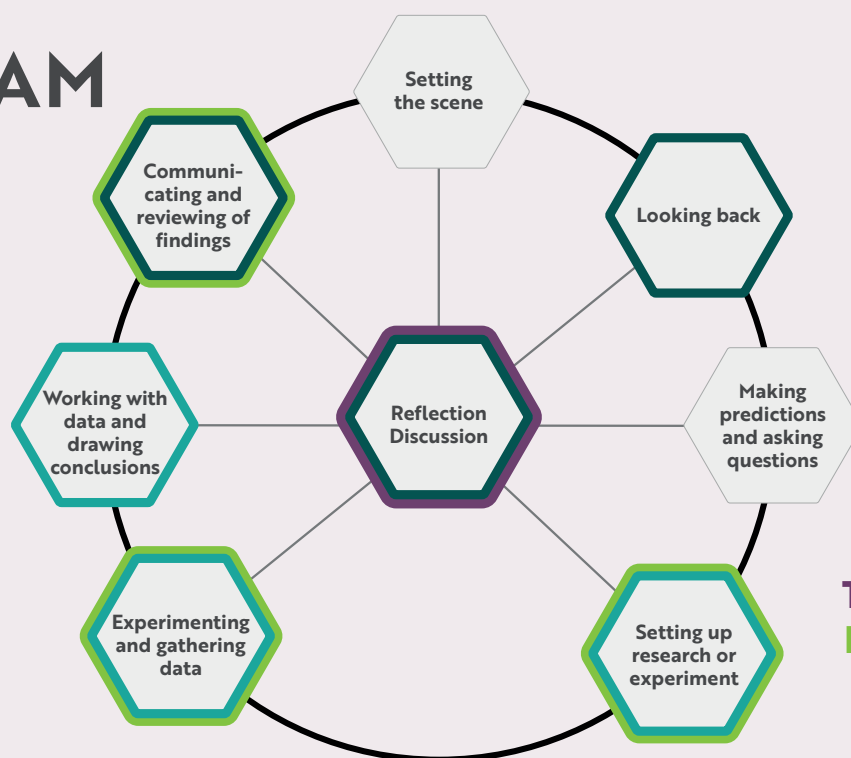> **Cypriot teacher**

But how are teachers to choose which template is the most appropriate one for what they want to design? Choosing the optimum STEAM approach lies on two factors: the subject at hand and the target audience. A teacher can choose to approach any given subject from different viewpoints, depending on its nature. To put it more simply, a teacher would need to consider, what is the 'selling point' of the subject at hand. For example, an activity around an impressive natural phenomenon like the Northern lights could be very effectively introduced using an Art-STEAM approach. In this case the other disciplines could be used by students to draw inspiration, deploy different technological tools and techniques or study in depth the science behind the phenomenon, or art-related tools/materials. On the other hand, studying impacts, could allow teachers to design an appealing Science-STEAM activity with lots of fun experiments. To support the science experiments, clear references and connections to technological applications or engineering related problems can be introduced.

> ### "I learned science can be used in many different ways in different things."
> **Finnish student**

Building activities is also closely related to the target audience. An activity may work wonderfully for a certain group of students but may not be optimal for another group. When it comes to designing activities, one size doesn't fit all. Teachers need to be able to redesign activities and choose different approaches based on their students. Some students may love doing science activities but not be interested in art-related activities and vice-versa. Likewise, the use of digital tools or hands-on activities may be intriguing for some students but not as interesting for others. To meet the needs of different target groups, teachers need to have options and be able to design STEAM activities with different formats and foci.

STEAM

Setting the scene

Communi-cating and reviewing of findings

Looking back

Working with data and drawing conclusions

Reflection Discussion

Making predictions and asking questions

Experimenting and gathering data

Setting up research or experiment

TECHNOLOGY
ENGINEERING
ART
MATH

Outline of our Science-STEAM approach

The different approaches to STEAM

The Science-STEAM approach

Scientists formulate empirically answerable questions about the phenomena they are studying, carry out research of the related literature to see what is already known, develop hypotheses that derive from their questions and the background information they obtained through research, collect data/evidence either through designing and performing experiments or using

Students from Agrupamento de Escola Tomás Cabreira in Portugal working on an activity designed using the Science-STEAM approach.

secondary data from existing databases, analyse the data and provide explanatory answers to the initial questions. This process describes the so called "inquiry-based approach", an approach that has been proposed by the science education community to denote all tasks that students are supposed to engage with while doing science in an authentic and scientifically oriented way.

Our Science-STEAM approach focuses on inquiry, in other words making an experiment to study a natural phenomenon. We suggest an adapted version of the Inquiry Cycle designed in the context of the PLATON project and adjusted to fit our STEAM education approach. You can follow this approach for investigating a natural phenomenon, while making clear references and connections to technological applications or engineering related problems. Subjects that involve engaging and impressive scientific experiments can be apt for teaching using this approach. In the figure below we indicate using different colours in which phases of the inquiry cycle the other STEAM disciplines could be embedded with relevant additions/adjustments (e.g., by using a relevant teaching practice and/or tool).

A Portuguese school used the Science-STEAM template to make a project The chick goes to school – human diversity and acceptance for mental health diversity. The inquiry also included creating an arts installation to bring awareness to mental health problems.
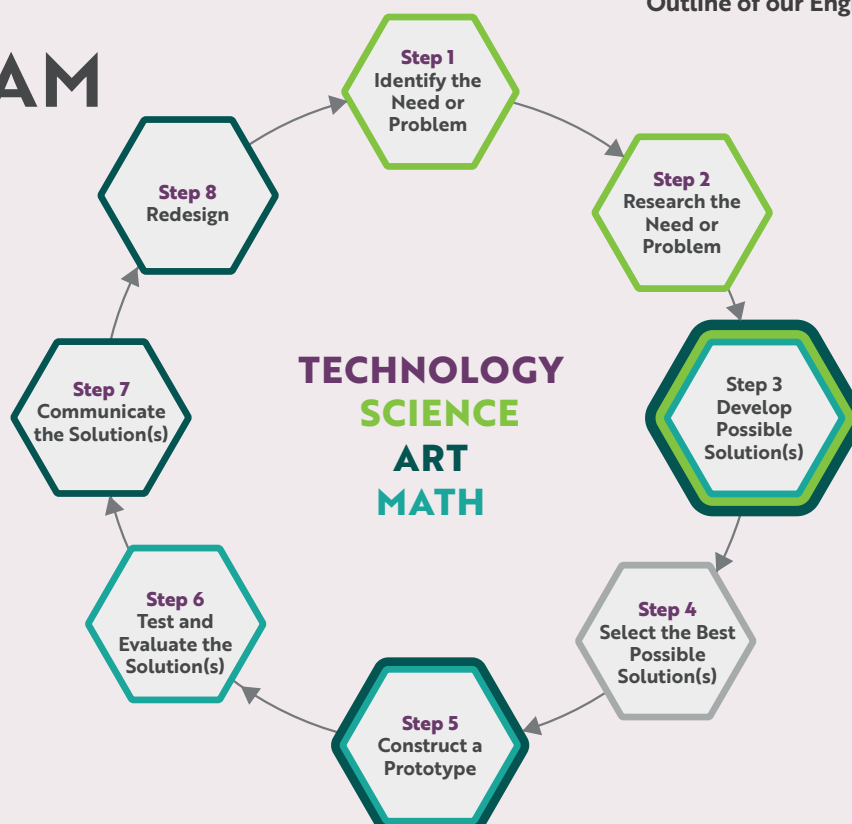
Engineering-STEAM approach

Unlike Science that focuses on studying phenomena, Engineering focuses on deploying scientific knowledge to solve problems meet the needs of people. Engineering makes use of specialized knowledge from domains like science, technology, and mathematics in solving problems that start from specific needs or desires of individuals or societal groups. For example, when there is a need to build a bridge over a river, engineers exploit their science and mathematics knowledge, the technology tools available as well as

their understanding of the engineering design process and artistic skills.

Thus, an Engineering-STEAM approach is different to the Science-STEAM approach in the sense that the focus here is to build a prototype to solve a problem. To design and implement Engineering-STEAM activities and projects, we suggest an adapted version of the Engineering Design Process which was adjusted to fit our STEAM education approach. The adapted framework offers opportunities to make connections to the other

Outline of our Engineering-STEAM approach

STEAM

TECHNOLOGY
SCIENCE
ART
MATH

Step 1
Identify the Need or Problem

Step 2
Research the Need or Problem

Step 3
Develop Possible Solution(s)

Step 4
Select the Best Possible Solution(s)

Step 5
Construct a Prototype

Step 6
Test and Evaluate the Solution(s)

Step 7
Communicate the Solution(s)

Step 8
Redesign

Students from the primary school of Panormo in Kalymnos, Greece that made a play out of the tribes' stories in the Northern Lights Arts-STEAM activity.

STEAM disciplines while students engage in the process of suggesting solutions to societal needs through designing products or services based on relevant scientific knowledge.

Arts-STEAM approach

There is art in science and there is science in art. Scientific discoveries do not emerge just from the critical and logical thinking of scientists but also from their passion, imagination, intuition and creativity, which are integral aspects of Art as well. Scientists, technology developers, engineers, and mathematicians need to innovate and solve problems creatively. Scientists and engineers try to describe and present the natural world through various means and convey it to others, an aspiration which is not detached from art. For instance, engineers use their scientific knowledge and skills to design a bridge, but they also pay attention to the aesthetic aspect of the bridge as a construct. Artists on the other hand, like scientists, utilize interdisciplinary concepts such as models, scales and patterns to present their view of the world. Scientific knowledge can also trigger a new vision to an artist which can often lead to critical judgement and discussion.

Students should be exposed to the interdependence of Art and STEM through the learning process. The same problem could lead to motivation in both subject domains and different ways of addressing that issue. The use of artistic tools (e.g., 3D modelling with the use of apps) is a way for students to be creative and visually present

Outline of our Art-STEAM approach

Drawing inspiration from STEM

STEAM

Making Art following scientific research processes

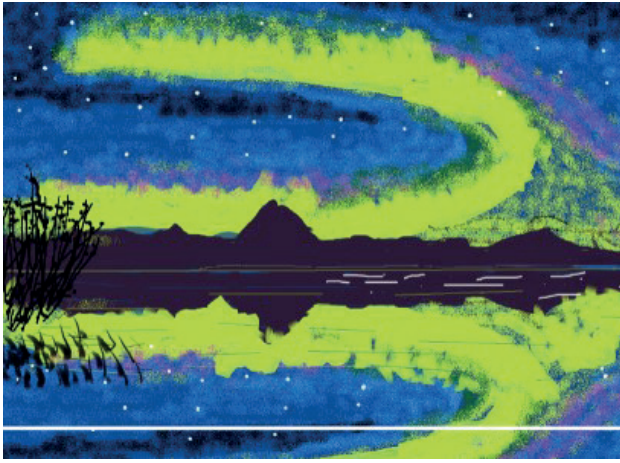Use Art to communicate science in an engaging way

Image the Northern lights using digital means Art-STEAM activity from 47th Primary School of Heraklion, Greece

their knowledge during a science lesson and/or a project. Similarly, the incorporation of scientific processes in art lessons (e.g., mathematic calculations, identification of patterns in nature) can lead to a new view of the goal of artistic expression in relation to nature and humanity. An Art-STEAM activity can follow a more open art-based format, where the other disciplines could be used by students to draw inspiration, deploy different technological tools and techniques or study in depth the science behind a particular art-related tool/ material.

Incorporating mathematics and technology in STEAM activities

In the context of STEAM education, students are expected to use their mathematical knowledge and skills during all STEAM approaches.

For instance, in the context of an engineering task, students can create several prototypes of buildings using geometrical shapes and use mathematics to create a formula with all related variables that affect the collapse resistance of the different model buildings. In doing so, they should be encouraged to think of possible alternative solutions to the problem, rather than urging them to follow a prescribed process or use a specific formula, as this is the norm that applies in traditional math teaching. As a result, a STEAM oriented task serves as a medium for promoting deeper thinking and problem-solving skills among learners.

Furthermore, during a STEAM activity a teacher can refer to related technological achievements and use them in numerous ways to reinforce certain parts of the activity and support the other elements of STEAM. For instance, technology is used by scientists to facilitate discoveries, whereas engineers utilize and design technologies, while considering scientific principles and related discoveries. In addition, the introduction of technology in education has to do with the tools that are used to facilitate the learning and teaching process. For example, engaging students with online labs can help them run experiments faster and safer, visualize abstract phenomena and models etc.

Two pictures from Escola Horácio Bento de Gouveia in which the Science-STEAM template (S.O.S Bats project) and the Art-STEAM template (recycling in the school "Gervasio can do it. What about you?") were used.

> **"I learned that my students are happier and more willing to learn. They like alternative approaches. They can draw really well. They can learn using many different methods."**
>
> **Greek teacher**

STEAM education tools for teachers

The Design Thinking (DT) guide

To support teachers in working with our multidimensional STEAM approach our team designed a guide that is apt for use from teachers of both primary and secondary education. We suggest this guide for integrating the STEAM approach in your classroom. The DT guide consists of four phases (Feel – Imagine – Create – Share) and serves as a guide when preparing your lessons/activities/projects/school year plan in the context of STEAM education.

In each phase, teachers are prompted to reflect on certain questions and use materials and tools of the project (e.g., STEAM education guide, Science WAND). To facilitate everyday teaching planning and/or the creation of STEAM projects etc. the guide is accompanied by a set of support worksheets. The guide is designed so that it can help teachers when working on their own or collaborating with other teachers from their school, in both everyday teaching and long-term projects.

Activity templates

As mentioned above our team offers three variations of STEAM teaching to support teachers in developing activities using a Science-STEAM, an Engineering-STEAM or an Art-STEAM approach on their own or in collaboration with peers. Each variation comes with a template which is divided in two parts. In the first part teachers can provide basic information about the activity, as well as relations with the other disciplines of STEAM which can be utilized during the lesson(s). The second part offers description of the actual activity which can be developed and presented based on the corresponding framework (e.g., the adapted version of the Inquiry Cycle for developing STEAM activities). A brief description of each step is provided to facilitate the design of the activity for that step by describing the process in which the class will be engaged in, as well as the related tools to be used.

List of technological tools

When designing a STEAM activity on a particular subject, related technological achievements can be referred and used in numerous ways to reinforce certain parts of the activity and support the other elements of STEAM. To find example connections between science concepts and technology products teachers can visit the Science WAND. In addition, the introduction of technology in education also has to do with the tools that are used to facilitate the learning and teaching process. Nowadays, there are numerous options available. Our team compiled a list and a mind map with suggestions of digital educational tools that could be useful to teachers (e.g., for programming activities, presentations, platforms with online labs).

I'd like to do more challenges that allow students to think about possible solutions together with the members of the community."
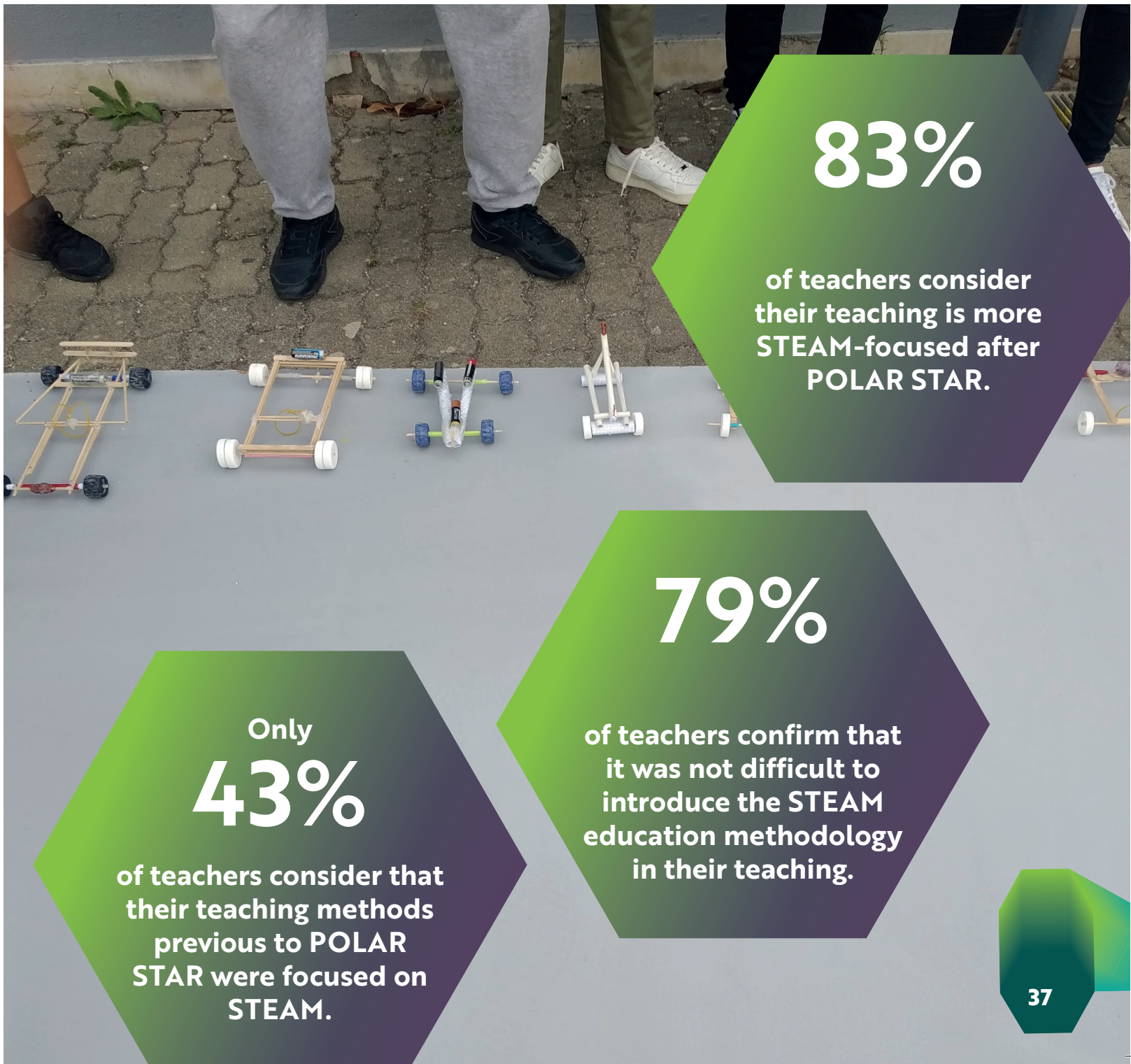
Portuguese teacher

STEAM education in schools

The STEAM education methodology and activity templates were used in 6 schools 2 in Greece and 4 in Portugal. The age range for the students participating in the implementation was 13-15 years old. Mostly this meant using the STEAM templates. The ones used in these schools were the Arts-STEAM and the Science-STEAM templates.

The Science-STEAM template was used to design an activity where the class built rockets and other scientific prototypes. The Arts-STEAM template saw many different kinds of activities designed with its help. These included building 3D con-stellations and making campaigns to increase the school community's awareness about recycling or mental health issues and acceptance of mental health diversity, the last of which also included raising a chick at the school. The activities were incredibly well liked by both the teachers and the students. In the feedback it is clearly seen that the students are learning in ways they haven't before and having more fun and getting more excited than before doing it.

An example designed using our Engineering-STEAM approach from Agrupamento Agostinho da Silva (Portugal).

83%

of teachers consider their teaching is more STEAM-focused after POLAR STAR.

79%

of teachers confirm that it was not difficult to introduce the STEAM education methodology in their teaching.

Only

43%

of teachers consider that their teaching methods previous to POLAR STAR were focused on STEAM.

POLAR STAR kit of activities

Why talk about Space and Arctic research in class?

Astronomy and space exploration have always been breath-taking subjects and a rich source of excitement for young as well as older students. The exotic celestial objects discovered by astronomers, the vastness of the universe and the endless pursuit of discovering the origins of our world are only a small sample of subjects that, despite their scientific complexity, can be transformed into simple in-class activities that can increase students' engagement and steer their curiosity, creativity and imagination. Although it may not be evident, space exploration is linked to everyday life in numerous ways, and it is a field that transcends scientific disciplines and goes beyond cultures.

"My kindergarten students designed a foldable telescope with the help of their friend "Paxi" from ESA and absolutely loved it"
Greek teacher

Many technological developments and applications of space (for example GPS navigation) are used daily by everyone, while space missions (like the Copernicus mission) play a significant role in tackling global problems like climate change. Additionally, the night sky has always been present in cultures around the world, serving different roles from inspiration for local legends to a navigation tool. Keeping in mind the idea that we are all under the same sky, astronomy and space exploration can play a pivotal role in communicating the idea of global citizenship and bringing people from different cultures together and give

them the opportunity to communicate and talk about their cultures and traditions.

"I was surprised by how big an effect climate change has."
Finnish student

Arctic science research covers a wide range of subjects, from climate change, to surviving in harsh polar conditions, and the amazing spectacle of northern lights. Arctic science, aside from being a unique field of science that intrigues students, covers a wide range of subjects, making it highly interdisciplinary in terms of concepts and phenomena that can be discussed. Thus, it is ideal to be introduced to schools to demonstrate the interdisciplinarity of science concepts and the 'Science as a whole' approach. Additionally, as many of the studies conducted under Arctic science are closely related to environmental issues, this field of science can also be directly connected to communities and our everyday lives.

The POLAR STAR kit is comprised of 10 activities which demonstrate the significant role of Arctic research and Space exploration on climate changes, environmental issues and more. They cover a wide range of subjects connected to geography, natural resources, history, social/political science and more. Our activities follow different STEAM approaches to match the needs of different target groups and to ensure the maximum impact of each topic.

POLAR Kit of activities

In POLAR STAR we designed 5 activities following different STEAM education approaches, covering important topics related to the Arctic. The topics were chosen based on school curricula and after discussing with the POLAR STAR advisors – team of teachers, who supported us during the project. They chose among 15 polar topics to find the 5 most relevant and important ones. Here are the 5 activities we designed for our POLAR kit:

Arctic research in class video ▶▶

Plastic in the Arctic
Age Range: 12-14 | Didactical Hours: up to 3 | Science-STEAM
Plastic pollution is everywhere even in the air and soil. In this activity, we talk about the different consequences of plastic in oceans, freshwater, soil and air. Students check how much plastic pollution they produce.

Northern Lights
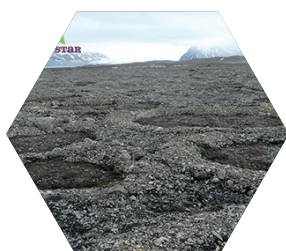**Age Range: 12-14, 14-16, 16-18 | Didactical Hours: up to 4 | Art-STEAM**
How are the Northern Lights formed? How is the auroral activity determined by the chemical composition of the atmosphere? Why do they appear mainly at the poles?

Surviving the Arctic
Age Range: 12-14 | Didactical Hours: up to 7 | Engineering-STEAM
The Arctic is a challenging environment. How do humans adapt to the extreme conditions of polar regions? Find out more about how to survive in the Arctic using traditional as well as high tech solutions.

Permafrost
Age Range: 12-16 | Didactical Hours: up to 3 | Science-STEAM
Permafrost is permanently frozen ground. It is soil, rock, or organic material that remains at 0°C or below for at least two years. How does thawing permafrost affect the Earth's climate and what are the consequences for the planet and our civilization?
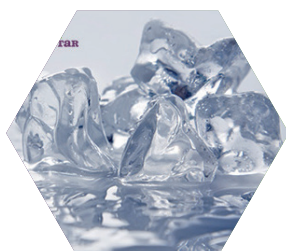
Arctic Amplification
Age Range: 12-14,14-16 | Didactical Hours: up to 3 | Science-STEAM
The warming trend in the Arctic is almost twice as large as the global average in recent decades. The loss of sea ice amplifies the warming trend because the ocean surface absorbs more sun heat than the surface of snow and ice. How does that affect the planet?

Plastic in the Arctic

Plastic found in the Arctic is a global problem – the tip of the iceberg. It is a result not only of the production and industry development but of our daily life habits as well. Plastic waste and more dangerous microplastics are found everywhere: in the oceans, ice, animals' stomachs and even snow. The influence of plastic waste on the environment is evident and alarming, but scientists are trying to estimate its impact on human's health and life.

The aim of the activity is to rethink our daily life habits and encourage all of us to make something environmentally friendly.

In this activity students find out what happens to plastic waste after it is thrown out. They follow the possible paths of the waste, and how it moves in oceans with currents if it makes its way into water. One of the most interesting parts of this activity is when students use a smartphone application - the "Beat the micro bead" - to find out if there are microplastics in the products they use every day and help replace them with products that don't contain microplastic.

The practical part of the activity – "Count your waste" experiment – raised students' knowledge about recycling necessity and awareness of plastic waste disposal.

"

I felt most proud when students' summed up their work. Sharing their knowledge about microplastic and suggestions for actions to be taken to reduce the problem of microplastic. The level of their awareness of waste segregation (which was quite poor a few months ago)."

Polish teacher

Students collecting sediments from a natural reserve and learning about Micro and Macroplastics (Agrupamento de Escola Tomás Cabreira, Portugal).

A beautiful collection of different items from the Plastic in the Arctic activity (Escola Básica das matas, Portugal)

Northern lights

Although Auroras are mostly connected with the beautiful lights seen in the Northern skies, their origin has a very interesting and fierce story to tell. In this activity, students learn about the epic battle between the Sun and the Earth and are encouraged to create their own artwork inspired by what they learn about auroras.

This activity follows the Art-STEAM approach but has a strong flavour of science to it. Students are engaged in diverse art related activities that involve creative thinking, storytelling and artistic representation. Students are invited to look at aurora images like "Ghost Aurora" and give their own impressions, draw auroras or capture them using different tools and materials, and design mood boards to tell their story. One of the most interesting parts is when students imagine that they lived near the Arctic Circle thousands of years ago and come up with folklore stories on how their tribe 'explained' the aurora phenomenon based on its tradition and characteristics.

The activity also has a scientific part during which they not only learn about how auroras are created, but most importantly they get a first-hand impression about the power of our Sun and how it affects our planet. Impressive examples that demonstrate the power of the auroras like the Carrington Event are also presented. During this event in 1859 solar activity took down parts of the US telegraph network, starting fires and shocking some telegraph operators. Northern lights was one of the most successful activities and was implemented with several age groups including very young students.

"

It was hard to keep a straight face while students presented the tribes and not burst out laughing!"
Greek teacher

Surviving the Arctic

'Surviving the Arctic' follows both the Science-STEAM and the Engineering-STEAM approach. It talks about how different species survive in the Arctic. It includes three inquiries for three different subtopics: Surviving the Arctic for a) Plants, b) Animals and c) Humans. Each of these subtopics is implemented separately, but all three subtopics come together again in the final phase. This approach allows teachers to organize the class in different ways and assign tasks according to students' preferences.

The "Plants" subtopic includes a more inquiry-based experiment during which students are expected to gather and explain data. The "Animals" subtopic is designed based on a lighter type of inquiry that focuses more on exploring using online tools. The "Humans" subtopic is an inquiry that focuses on technological achievements and carrying out

online research to find out how technological solutions help people who live in the Arctic address survival challenges. Finally, there is one optional challenge offered at the end of the activity in which students are invited to design equipment for people to survive in the Arctic.

Surviving the Arctic was one of our most successful activities and schools produced very interesting and diverse output. One school in Greece for example made their own card game, while an Irish one made their own igloo. There were also many schools in which students designed clothes for humans to survive the Arctic. Finally, after making a request, some schools participated in a webinar with a member of the expedition to the Polish station during which students learned first-hand what it is like to live in the Arctic.

"It started some interesting discussions on whether everybody needed a gun and whether you should shoot a polar bear if it was about to attack. They were also concerned about avalanches!"
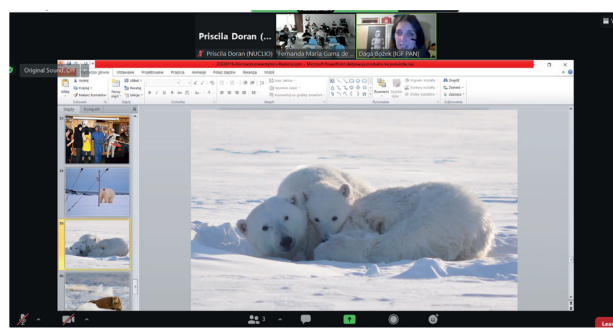
Irish teacher

Students from Robeen NS, Ireland making their own igloo.

Card game developed from students at the 6th Experimental Intercultural Primary School of Eleftherio-Kordelio in Greece

Students from Escola Secundária Jaime Moniz in Portugal discussing with a scientist that spent time in the Arctic.

Permafrost

This activity touches upon a subject which is not as common in school activities but quite important to be aware of when discussing climate change. Due to climate change, permafrost is thawing more and more and organic material that unfreezes and decomposes releases greenhouse gases into the atmosphere. In this activity, students find out why thawing permafrost accelerates climate change and becomes dangerous for the planet. They also calculate potential carbon release from permafrost compared to anthropogenic production of carbon dioxide by their country.

The activity starts with guessing what permafrost is. After learning some basic information about permafrost, they colour the contour map of the Northern Hemisphere and indicate all areas where they think permafrost occurs. The activity also involves hands-on experimentation, while in the last part students are also asked to deploy their artistic skills. Finally, students also had the opportunity to virtually visit a permafrost tunnel in Alaska.

This activity uses science to inspire students' interest in how the world works. It contains multidisciplinary concepts like climate change and feedback loops, and combines Physics, Chemistry and Geography. It also uses Mathematics, as the main task is to calculate potential carbon release from permafrost compared to anthropogenic production of carbon dioxide. The final part of the activity provides a good opportunity for adding Arts into the mix.

"

The most challenging part for us was the long-term experiment but it was also the most interesting for students."
Polish teacher

A Polish school studied how permafrost, represented by plasticine, affects plant growth.

Arctic Amplification

This activity aims at raising students' awareness about the importance of sea ice for the entire planet and familiarizing them with the concept that the changing weather patterns in the Arctic affect the weather of the whole planet. What happens in the Arctic, does not stay in the Arctic.

Students learn about albedo and the melting sea ice positive feedback loop and the likely results of reduced snow and ice cover on global temperatures. The activity contains multidisciplinary concepts, like albedo (useful for Physics, Geography), feedback loops (useful for Biology, Chemistry and Geography) and demonstrates how some factors are affecting other factors in the environment and how they are interconnected. The main emphasis is put on Science, but the toolkit contains tasks from Mathematics (calculation of sea ice extent differences), Engineering (by designing and performing the experiment) and encourages students to use Technology (by means of the online version of the toolkit and suggested ways of communication of their findings).

In this activity students get a chance to ask and research the questions they want. The students make their own hypotheses about what they think will increase or decrease the melting rate of ice, and design and run experiments to find out if their hypotheses are correct. This very open approach may be a challenge for some students. If your students have problems in designing the experiment, you may give them scenarios of experiments. For this purpose, we created scenarios of two experiments: "What happens when snow or ice become dirty" and "Does the thickness of the ice influence the melting process?", which are available for teachers.

Students from Cyprus working on Arctic amplification

"

I've learned how much different surfaces reflect light and heat back into space and that the greenhouse effect as a whole is actually different to what I had been told before. Arctic amplification was a completely new thing for me, and I hadn't understood before that the glaciers are melting so fast. "
Finnish student

POLAR kit in schools

The activities of the Polar kit were tested in 42 schools in 7 countries with multiple age groups. All activities were implemented by multiple classes and were well-liked by the vast majority.

"I liked teaching this kind of whole and coming at the subject from the perspective of different subjects. In Finland geography and physics are combined far too rarely. I did Arctic amplification, and it was well executed in the POLAR STAR project. With the methodology we also got more conversation crossing subject boundaries than normally. The students thought it was great to see how physics connects strongly to geography and life on Earth."

Finnish teacher

The most popular of the activities was Plastic in the Arctic, which according to the feedback had a profound impact on some of the students, waking them up to microplastics being a real and significant problem in the world. It was used with students from the 4th grade all the way to 8th grade. Generally, the students were very inter-
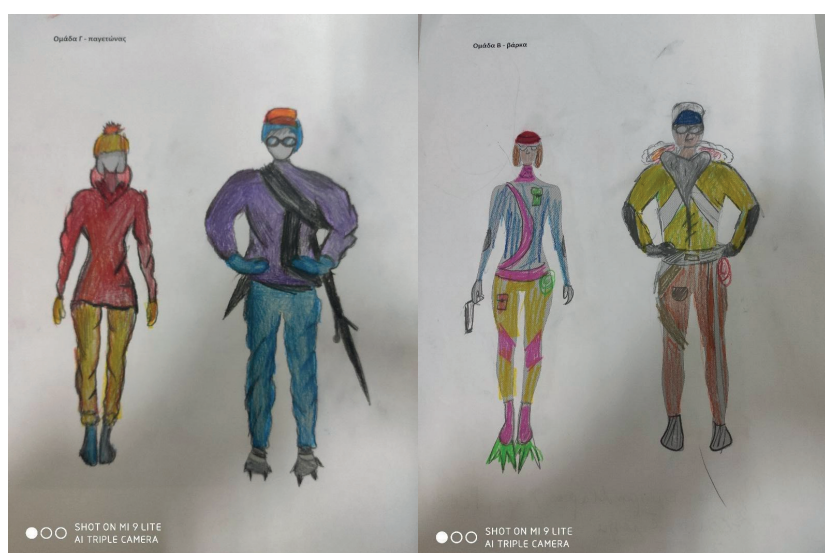
ested in the activity and highly valued exploring new areas of knowledge.

Northern Lights is the only one of the activities that got mixed reviews: most liked it, but one 5th grade teacher said it was too difficult for her 11-year-old students. On the other hand, one teacher used the activity with an even younger group of 1st graders. The teacher said that she collaborated with the art teacher and dramatized the stories of the ancient people about the aurora, making little plays out of them. This shows that while the activities might not work as they are to any age group, with modification, parts of the activities can be used with students of any age.

"The moment I felt most proud was when they discussed ways how to reduce plastic in the sea and also in their normal life."

Polish teacher

The drawings made by students show what kind of equipment for people to survive in the Arctic they have invented. Pictures are from Cyprus GCSC elementary school.

73%
of teachers believe that POLAR activities are suitable for the educational level they are aimed at.

86%
of teachers say that they would use POLAR activities in the future.

STAR kit of activities

For our STAR kit, we designed 5 activities following different STEAM education approaches, covering important topics related to Space exploration. In the same way as the POLAR kit, the topics were chosen based on school curricula and after discussing with the POLAR STAR advisors. Here are the 5 activities we designed for our STAR kit:
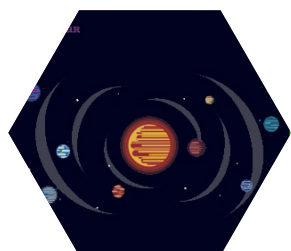
Solar System Astronomy
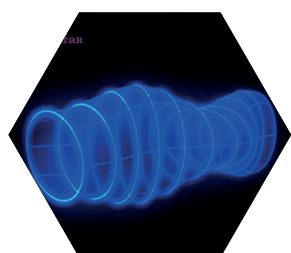**Age Range: 12-16 | Didactical Hours: up to 3 | Art-STEAM**
Mix art and science to create your own colour images from raw pictures taken by spacecraft and landers across the solar system.

Surviving in Space: Space Weather
Age Range: 13-18 | Didactical Hours: 1.5 | Science-STEAM
Follow a guide to predict space weather events and then look for aurora as evidence of these events.

Gravitational Waves
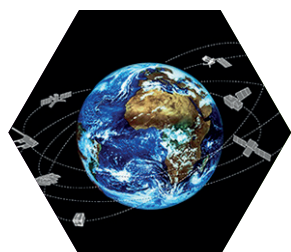**Age Range: 12-18 | Didactical Hours: 1-2 | Science-STEAM**
Detectable Gravitational Waves can be created by massive compact objects that orbit each other. Model this with everyday materials and use Tracker to carry out digital video analysis of the model to study the circular motion.

Observing the Skies
**Age Range: 10-14 | Didactical Hours: up to 3 | Engineering-STEAM**
Explore the construction of the James Webb Space Telescope and the design of its primary mirror. Consider three engineering issues and plan how to resolve them.

Earth Observation
Age Range: 12-16 | Didactical Hours: 2 | Science-STEAM
Explore Solar Radiation patterns on the Earth, using C3S Education demonstrator. Determine the effect of latitude within Europe on solar radiation patterns with this online tool.
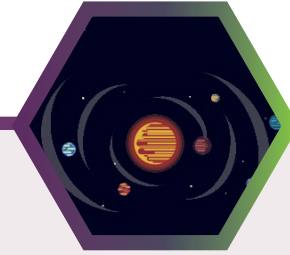
Solar System Astronomy

In this activity students mix art and science to create their own colour images from data collected by spacecraft and landers across the solar system.

Students look through raw images, mainly from the Perseverance rover on Mars and the Juno probe in orbit around Jupiter, although other available pictures will work as well. They learn how the cameras work and how images that are black and white can be processed to create colour images with a computer program. However, their images do not need to look realistic, instead, the students are given artistic freedom to create an image they like, that highlights the things they find important and tells the story they want to tell. They can consider whether they have created an art image or made a scientific image.

Once they have created their images of planets and moons, they can look for the elements of art to better understand geological processes. How do lines or circles on a planet's surface tell you about what has happened to that planet?

Students consider some of the typical pictures of the solar system and evaluate how realistic these pictures are by using mathematics to consider the size and scale of planets in the solar system.
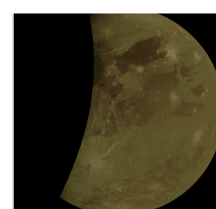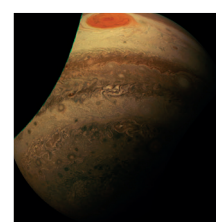
"

I valued learning about JunoCam and being able to see the images it captures."
Spanish Teacher

Students from Agrupamento de Escolas Professor Agostinho da Silva model the solar system.

Pictures from IES Fortuny Madrid, Spain. Raw images are being combined to create a colour image in GIMP-software.

Surviving in Space: Space Weather

Space weather relates to the magnetic fields, radiation and particles that are ejected from the Sun and interact with the Earth's upper atmosphere, with a range of different, some-times, devastating results. In this activity, students learn what space weather is, how it affects us and how we can predict it. They learn what kinds of things to look for on the Sun's surface that might tell us about space weather in the coming days or weeks. They use real solar data on the internet to make predictions about what the space weather will most likely be like, either for the com-ing days or for a date in the past. They then check data on the visibility of auroras for the relevant days to see if their predictions were correct.

Space weather forecasting is a very complex field of study, so the forecasting guide makes some simplifications. Students may find that their predictions do not come true and are encouraged to dive more deeply into the sci-ence to understand why.

This activity may be explored as science inquiry and uses the technological tool of current real-time images of the Sun and measurements of the near-earth space envi-ronment.

It complements the Northern Lights activity from the POLAR kit.
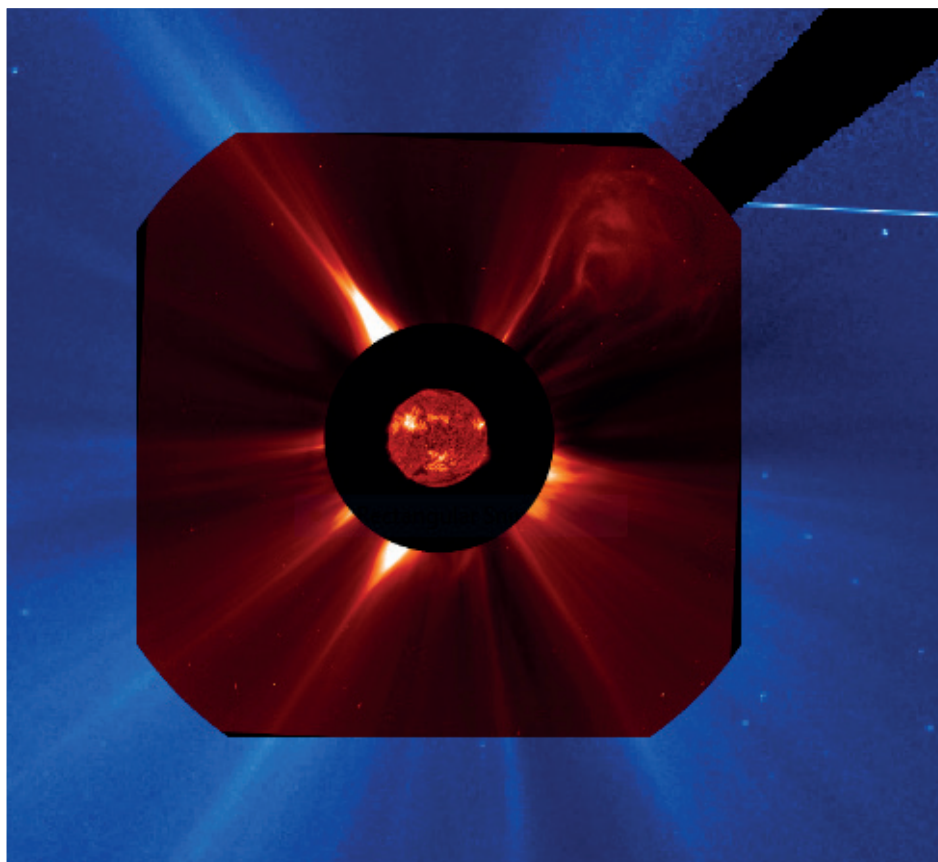
Solar image from Helioviewer.org, a free tool that shows near real time images of the Sun. Spot the CME!

Gravitational Waves

Detectable Gravitational Waves can be created by massive compact objects (like black holes or neutron stars) that orbit each other. Students learn about what gravitational waves are and how waves big enough for detection form. They also learn why they are formed this way. They can, optionally, create a model from normal household materials that can help with the understanding, although video files that work in Tracker software (an image and video analysis package and modelling tool) are included with the activity.

This activity focuses on science, making use of a physical model of orbiting spheres, with digital video analysis to study the circular motion. Physics concepts of circular motion, speed and period are central to this activity. Students collect data and use plots of their data to describe the motion of the spheres.

An additional optional focus on Engineering is given, if students want to create their own models and film them to analyse and collect data using Tracker software. Mathematical skills are applied extensively with data analysis and graphing.
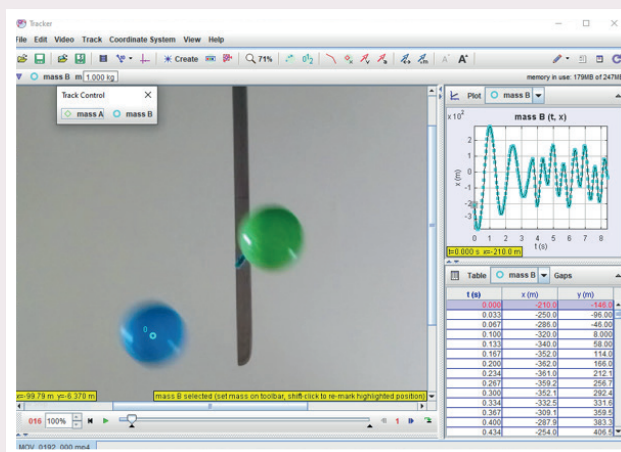
"

This opened the eyes and after the activity things became much more clear."
Finnish teacher

A model of orbiting black holes created at a teacher training event

Tracker software with pre-recorded video file

Observing the Skies

The James Webb Space Telescope was launched in late 2021, and has started to release amazing images, which makes it an ideal current space topic to engage the interest of students.

Students explore the construction of the James Webb Space Telescope and the design of its primary mirror. This activity outlines three engineering issues: What is the best way to make a large mirror that can go into space? How can we get the telescope to fit in the launch vehicle? Will the telescope survive launch?

In solving these problems students will have to find out what the simplest and best way is to make a huge mirror with a very specific shape out of smaller mirrors. They will also need to think of ways to fit something big into a very limited space, and build a prototype of a telescope, either one given in the materials or one of their own design, that has all the characteristics that they identified as being required in the previous steps. They will also test their prototype by mimicking the forces a telescope faces when it is launched. To do this, they have to determine what constitutes a successful test and prototype. At the end they make a list of improvements that could be done to their telescope for it to better meet the criteria they have set for a successful telescope.

This Engineering activity can be related to larger science themes of the Universe and includes a strong mathematical connection to tessellations.
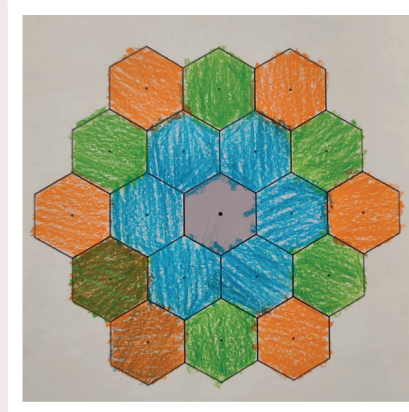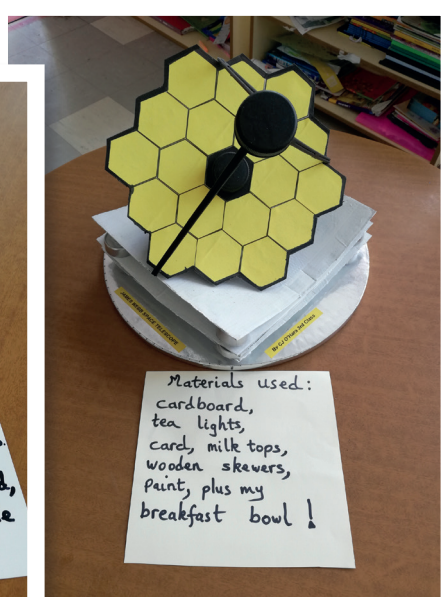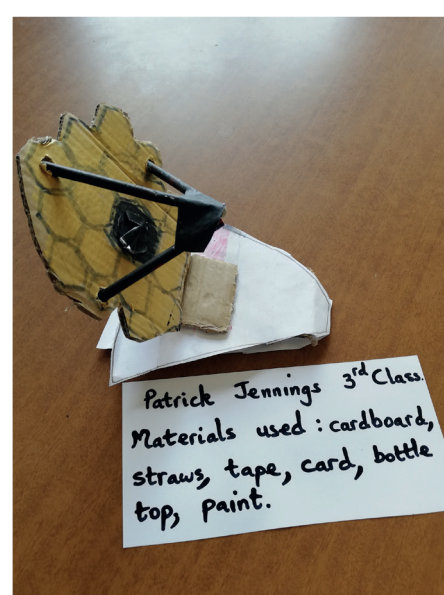
Webb telescope tile tessellations

Pictures from Robeen NS, an Irish primary school. Students have constructed their own versions of the Webb Telescope using different materials.
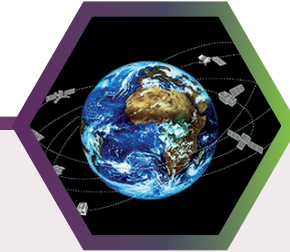
Earth Observation

How do we use space to look at ourselves? What do climate and weather measurements tell us about our Earth and environment? In this activity students explore Solar Radiation patterns on the Earth, using C3S Education demonstrator. The C3S demo tool is very powerful and lends itself to further use in open inquiry, although it is still under development. It was developed by the World Energy and Meteorology Council in early 2020 and uses Copernicus Earth observation data delivered by the Sentinel satellites.

Students can use this historical data to determine the effect of latitude within Europe on solar radiation patterns. Students use real scientific data and perform a scientific inquiry. Technology-wise, the focus is on satellites and how they are used to monitor Earth's climate. Through the activity students learn about the Copernicus mission.
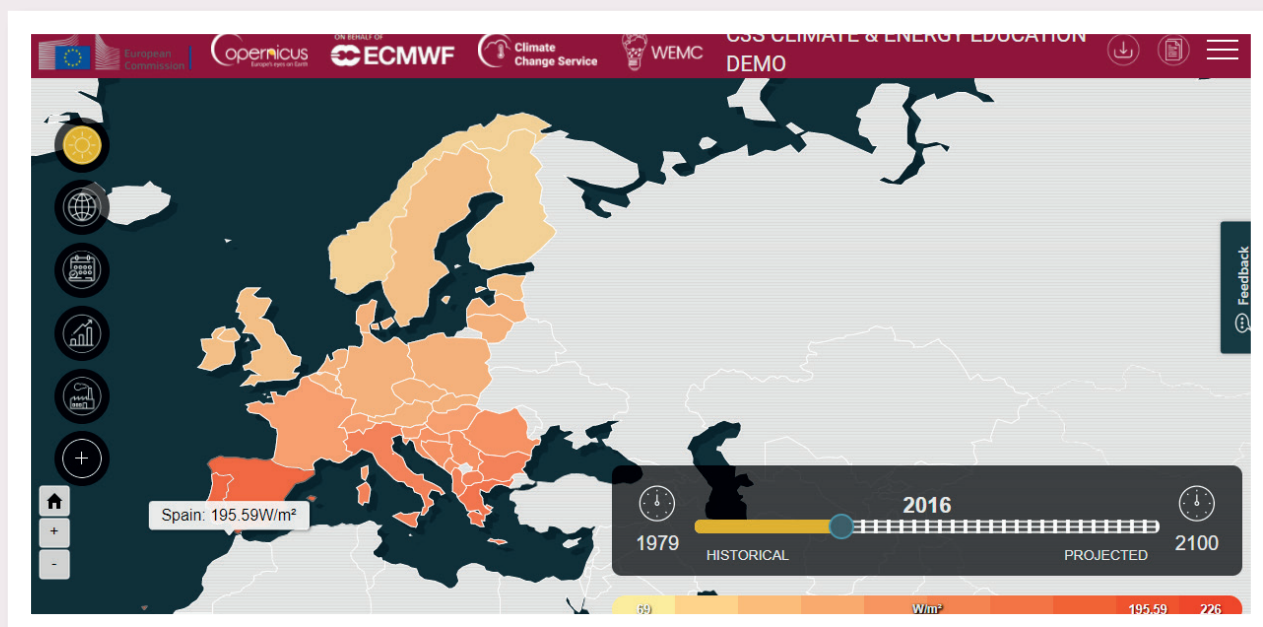
One Irish student extended her study of illumination and heating effects and entered the Irish national science and technology competition, the BT Young Scientist Competition.

Competition entry from an Irish student from Coláiste Muire, to determine how albedo affects heating within a building.

Bonus Activity: Mars Mission Escape Room

THE MARS MISSION

Following ideas from schools and their general interest in activities that involve contemporary missions and more specifically Mars mission, our team decided to design on more activity. This activity is quite different to the rest in our POLAR STAR kit as it is designed in the form of an escape room. This activity is a full STEAM activity that challenges students to solve different riddles and challenges to unlock the escape room. Riddles and challenges include elements from Science, Mathematics and Technology and Engineering. The Art element of the activity is the architecture of the escape room itself.

Teachers playing the escape room during a training event

The scenario

A group of science deniers has become increasingly dangerous. In an effort to prove their claim that all space missions are in fact a lie they are destroying tangible evidence and samples past missions have brought back to Earth. Your mission is to enter a secret NASA/ESA lab before them and retrieve a valuable sample of Martian soil that is believed to have proof of living organisms on Mars. To retrieve the valuable sample, you will need to follow the steps of a Martian mission. Your equipment allows you to carry back only one Martian sample so you will need to make sure that you pick the right one! The secret lab locks automatically once someone enters. To leave the lab you will need to enter a password. The password is the name of the mission that retrieved the valuable sample.

"

It took our team of technicians and me a week to fabricate the resources. However, it was well worth the investment of time because our students were engaged throughout. Our students have never before had an experience like this. Given the positive feedback from students, we plan to run more POLAR STAR activities for larger groups going forward."
British teacher

Escape room artifacts prepared by Bromsgrave school, UK.
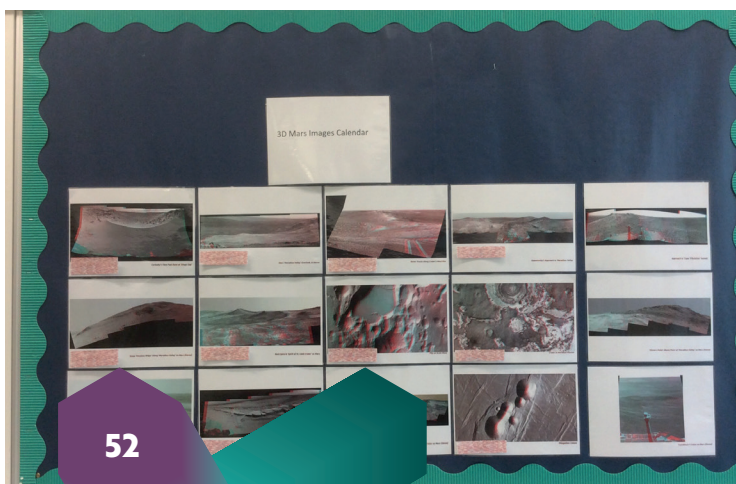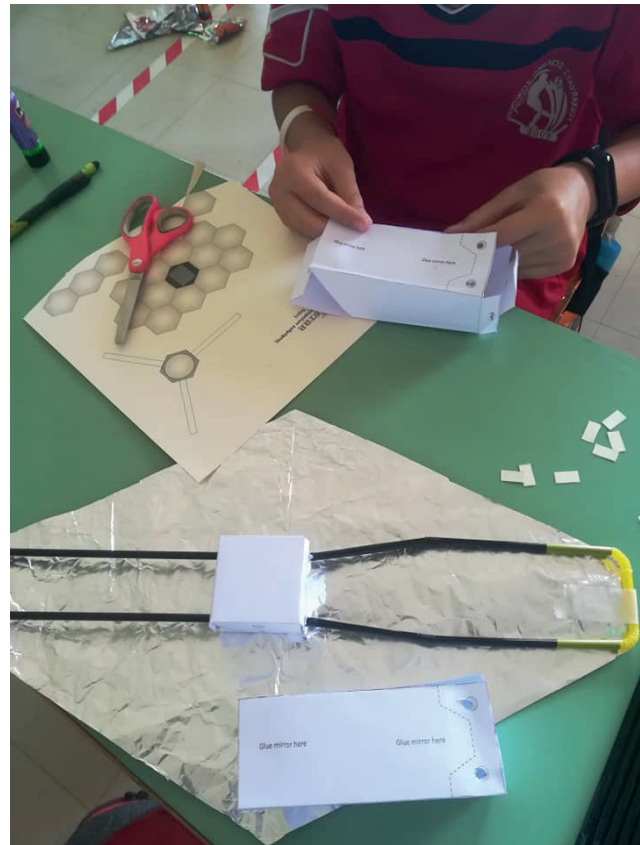
Students from the 26th primary school of Ioannina, Greece working on the Webb Telescope design from Observing the Skies.

STAR kit in schools

The STAR kit activities were used in 11 schools in 7 countries. The STAR activities were used with students that were on average older than those that implemented the POLAR activities. Gravitational Waves and Solar System Astronomy were the two most used activities. One of the 9th grade classes even took the Gravitational Waves activity further, making a video, where they explain in a simple way scientific terms related to gravitational waves. They did this in order to help others understand this complex and complicated phenomenon.

The Solar System Astronomy activity was liked by teachers and students, even though some had problems with using the software used to make the images.

Two school also played the Mars Mission escape room. According to the teacher, it took a while for the students to get an idea of what they were supposed to be doing in this completely new kind of situation, but after getting the hang of it they enjoyed the game a lot.

76 % of teachers consider that the STAR activities are interdisciplinary.

70 % of teachers think that the STAR activities are relevant to the curriculum in their country.

76 % of teachers consider the STAR activities help engage their students with current science discoveries.

82 % of teachers think they don´t need to make any changes in the STAR activities before implementing it.

5

Assessment tools

The POLAR STAR methodology is accompanied and supported by effective assessment and monitoring tools. These tools are focused on higher-order-thinking aspects of science activities. Their purpose is to provide evidence on students' improvement in conducting tasks creatively, building on past knowledge and understanding different aspects of scientific inquiry. Meaningful learning and deeper learning are more effectively achieved when building around an existing knowledge structure, which are created through the POLAR STAR methodologies (bigger picture, connection to other concepts, connection to everyday life). By attaching each piece of new knowledge to an existing organisation, which includes not only concepts and ideas but also personal stories and experiences, students are more likely to increase their knowledge retention, make connections, and recall existing knowledge in order to understand and explain phenomena.

In POLAR STAR the main objective of assessment is not so much to measure a certain level of development or learning, but rather to guide the students on how to improve their learning, to explain why they have the right assessment result and to provide them with the necessary indications to advance their learning. For that we propose four things: tasks that offer opportunities for success but also challenge students; stimulating and interesting assignments, activities and materials; tasks, materials and activities that are relevant and useful to students, allowing for personal identification with the task; and rewards and assessments that promote mastery, learning, effort, progress and self-improvement.

For this, POLAR STAR put together a set of tools for monitoring the learning process. These assessment tools are for more student-centred teaching models. There are tools for both online and offline use to help teachers in their work.

"The diversity of tasks and activities surprised me."
Portuguese student

Journal tool	Canvas tool	Rubric tool	Visual thinking

The POLAR STAR assessment tools

The journal tool

This is a self-assessment tool that has the format of a journal. It aims to help students systematically collect data on their learning, record the overall experience of a lesson and reflect on some key aspects. Students may write about their learning goals, reflections on their learning or their learning development. Reactions from teachers are necessary when using the journal tool, because they help the learners think further and to improve the depth of reflection. This tool can be used both online and offline.

POLAR STAR JOURNAL

My name:

Today´s date:

What and how much have you learned in this session?

What helped you learn successfully in this session?

How did you feel? Why?

What previous ideas or concepts have you remembered that relate to what you have learned?

What are your problems of learning in this session?

Write your reflections and conclusions here.

How does what you've learned relate to your life?

How will you solve the problem(s)? What will you do in the future?

POLAR STAR

Co-funded by the Erasmus+ Programme of the European Union

POLAR STAR JOURNAL

My name:

Today´s date:

What was the most important thing you learned in this session?

What helped you learn successfully in this session?

How did you feel during the session? Why?

What previous ideas or concepts have you remembered that relate to what you have learned?

Did you have any difficulties in this session?

Write your reflections and conclusions here.

Science as a whole
What is the bigger picture? Relation to the different STEAM areas?

How does what you've learned relate to your life?

How will you solve the problem(s)? What will you do in the future?

POLAR STAR

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The journal tool templates

The canvas tool

This tool is about the designing of the learning structure. Students relate all the ideas, experiences, previous concepts, the results of experimentation, and sensations, and create order to their learning structure. It is visualised in a global way in a canvas divided into the main aspects that involve the learning. This methodology encourages creative thinking, maintains a constant vision of the learning model from different perspectives and helps the learners think further and to improve the depth of reflection. This tool can be used both online and offline, and there's a version for both students and teachers to use.

POLAR STAR CANVAS – TEACHER CANVAS

INITIAL OBJECTIVES
What were the initial objectives?
Were the objectives always clear?
Has the whole group understood and accepted the objectives?

> Objectives in terms of content

21ST CENTURY SKILLS
What skills have been put into practice?

- Creativity
- Critical thinking
- Collaboration
- Communication

TEAMWORK
What role has each member of the group played?
How has the group work been?

> RIDE Assessment
> - Respectful collaboration
> - Intelligent collaboration
> - Deciding together
> - Encouraging

INQUIRY/ENGINEERING TASKS
What specific tasks have been carried out?

- Hypothesis making
- Designing an experiment
- Performing an experiment
- Processing data
- Drawing conclusions

DIFFICULTIES
What obstacles have you encountered in the development of the activity?

DECISIONS
What decisions have been made to overcome the obstacles and execute the tasks?

LESSONS LEARNED
What have your students learned from the activity?
What have your students learned as a group?
What would you improve with regard to the learning process?

DIGITAL TOOLS
What technologies have been used?

- Padlet
- Mentimeter
- Concept Maps
- Quiz

SCIENCE AS A WHOLE
How does the activity relate to the different STEAM areas?
Which area has been worked on in depth?

> Science WAND

FUTURE
What would we like to do and teach after this activity?

POLAR STAR — Co-funded by the Erasmus+ Programme of the European Union

POLAR STAR CANVAS – STUDENT CANVAS

INITIAL OBJECTIVES
What were the initial objectives?
Were the objectives always clear?
Haves the whole group understood and accepted the objectives?

21ST CENTURY SKILLS
What skills do you feel you have put into practice?
- Creativity
- Critical thinking
- Collaboration
- Communication

Any more comments?

TEAMWORK
What role has each member of the group played?
How has the group work been?
How would you rate your team in terms of:
- Respectful collaboration
- Intelligent collaboration
- Deciding together
- Encouragement

Any more comments?

INQUIRY TASKS
How do you feel about the tasks that you carried out?

- Making Hypothesis
- Design an experiment
- Perform an experiment

Any more comments?

DIFFICULTIES
What obstacles have you encountered during the activity?

DECISIONS
What decisions have been made as a group to overcome the obstacles and execute the tasks?

LESSONS LEARNED
What have you learned from the activity?
What have you learned as a group?
What would you improve?

DIGITAL TOOLS
How do you feel about the technologies have been used?
- Padlet
- Quiz
- Mentimeter
- ...

FUTURE
What would we like to do and learn after this activity?

POLAR STAR — Co-funded by the Erasmus+ Programme of the European Union

The rubric tool

The rubric is a scoring guide used in the assessment of student performance that describes the specific characteristics of behaviour, at various levels of performance, to clarify what is expected from the student work, to assess its execution and to facilitate feedback to the student. Rubrics are useful for formative assessment processes to improve student motivation to achieve better results. It fits perfectly with the approach that understands evaluation as a process of self-regulation. Using the rubric teachers can assess students on their inquiry skills and their performance on each step of the learning process.

Assessment of the Inquiry process

STEP 1: Gathering evidences

Performance in POLAR STAR

1st	2nd	
		Shows interest in knowing the problem to be addressed.
		Listens to the contributions of others.
		Participates by contributing ideas and opinions.
		Formulates hypotheses and/or questions based on the problem.
		Understands the relationship between variables.
		Collects data in an organized way.
		Is based on data when making conclusions.
		Expose your findings.
		Participates in discussions.
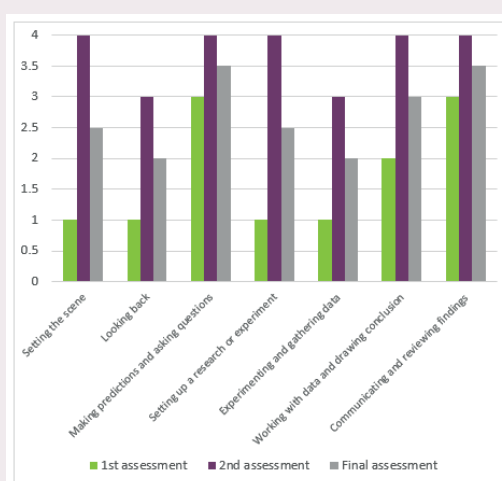
STEP 2: Assessment Rubric

	Level 1	Level 2	Level 3	Level 4	1st assessment	2nd assessment	Final assessment
Setting the scene	Does not pay attention to what others say and does not share personal views on the subject.	Gives attention to what others say but does not share personal views and ideas with others.	Gives attention to what others say and shares personal opinions.	Gives full attention to what others say taking time to understand, asking questions and sharing personal opinions and refers to previous knowledge.	1	4	2.5
Looking back	Does not pay attention to what others say and does not refer to previous knowledge.	Gives attention to what others say but does not refer to previous knowledge.	Gives attention to what others say and refers to previous knowledge.	Gives full attention to what others say, talks to others to convey information effectively and refers to previous knowledge.	1	3	2
Making predictions and asking questions	Has difficulty in making predictions, asking questions, referring to previous knowledge and identifying variables of the research problem.	Makes predictions and asks questions but has difficulty referring to previous knowledge and identifying variables of the research problem.	Makes predictions and questions, refers to previous knowledge but does not identify variables of the problem.	Uses logic and reasoning to make predictions and questions, refers to previous knowledge and identifies variables of the problem.	3	4	3.5

STEP 3: Global Assessment

N Student	Inquiry							21st Century Skills				final grade (out of 10)
	50%							50%				
	Setting the scene	Looking back	Making predictions and asking	Setting up a research or experiment	Experimenting and gathering	Working with data and	Communicating and reviewing	S1: Creativity	S2: Critical Thinking	S3: Communication	S4: Collaboration	
student 1	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 2	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 3	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 4	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 5	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 6	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 7	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 8	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 9	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
student 10	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30
Average	2.50	2.00	3.50	2.50	2.00	3.00	3.50	2.50	3.00	3.50	3.50	7.30

Screenshots from the rubric tool

Visual thinking tool

One way to increase creativity, engagement and consolidation of content is to synthesize the learning acquired using artistic expression. The visual thinking assessment tool is designed to achieve just that by encompassing three approaches: free expression, personal geography and storytelling, which are also elements deployed in our methodology. Giving students the freedom to express themselves freely can help teachers get insight as to what is the 'take home' message for their students. Their interests, possible misconceptions and/or talents may also emerge.

Students working on knowledge maps collaboratively and individually

To do assessment using visual thinking our team has deployed the tools designed for the "Science as a Whole" part of our methodology. The tools used to design these tools (personal geography and storytelling) allow the knowledge map and the knowledge hive to also act as assessment tools in the framework of visual thinking. In the framework of visual thinking we also advise teachers to encourage students to make their knowledge maps with tiles which they made on their own using free expression.

Having students use multiple tiles in personal geography to make knowledge maps will give teachers the opportunity to see how concepts connect according to students' understanding and which are the most prominent characteristics according to them. Stories can help teachers understand how students increase their willingness to communicate thoughts and feelings, increase verbal proficiency, use their imagination and creativity, and increase their knowledge retention by using concepts in different contexts. Visual thinking activates attention, facilitates understanding of concepts, trains the extraction of key ideas, contributes to improving motivation, develops the capacity for synthesis, cultivates artistic emotion, enhances creativity and helps structure content. Reactions from the teacher are necessary. This is an offline-only assessment method.

6

POLAR STAR in Action

Even though POLAR STAR had to be designed and implemented during the period of the pandemic, that did not stop us from reaching out to teachers and interested stakeholders all over Europe. Our team performed a long series of online and face-to-face training events for teachers, presentations of the project in conferences and other events and demonstrations of our methodology and toolkit. Aside from our advisors we had the opportunity and privilege to talk to countless teachers from different countries and retrieve valuable feedback for our project.

However, the highlight of POLAR STAR in action was the pilot implementation in schools. The methodology and school activities developed during the POLAR STAR were tested at schools during 2020-2021 and 2021-2022. Even though the pandemic brought many obstacles during the implementation period our team was able to work with several school to pilot test our materials. Our materials were tested in 11 different countries and at 80 different schools. Below we present some of the highlights and how pilot testing was done.

people reached	30853
students involved	2400
publications	38
schools reached	80

POLAR STAR in action

11	countries reached
26	project events
419	teachers trained
9	languages available
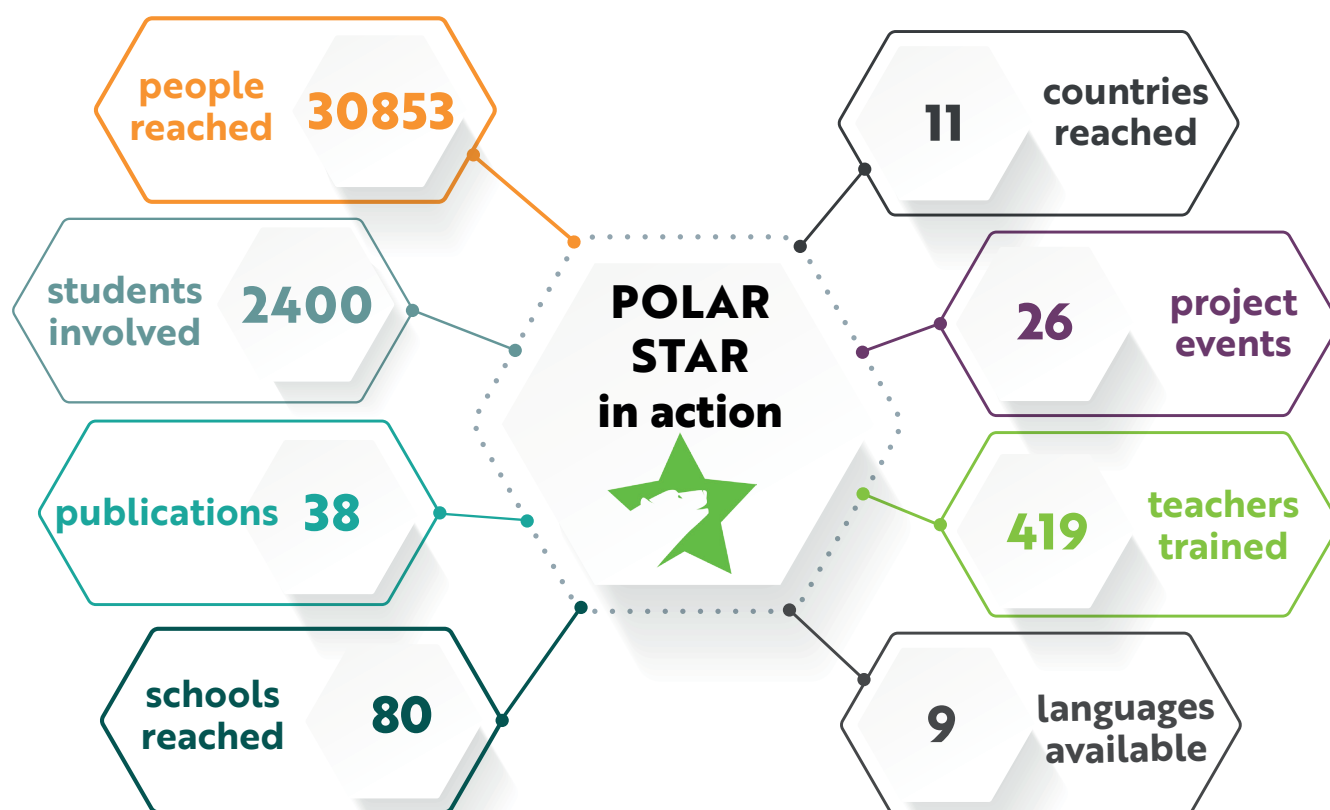
Polar Star in action.

Teacher training event in Poland

POLAR STAR final training event in July 2022

The schools that participated to the Polar Star during the implementation

Finland
4

UK
1

Poland
12

Ireland
3

Romania
2

Croatia
2

Bulgaria
5

Portugal
8

Spain
5

Greece
32

Cyprus
6

Northern lights

"My students made wonderful memories dramatizing the tribes' stories. They learned to work together, and they created their own artworks. What made me most proud is the fact that my students worked on their own and I only acted as a facilitator."

Maria Kalomoirou, Primary school of Panormo in Kalymnos, Greece

Plastic in the Arctic

Interestingly, at the beginning of the activity when formulating their hypotheses the children were only thinking locally about what the impact of their actions might be. Gradually, and this was an interesting observation, as the activities progressed, they started to think more globally.

Dimitris Lazarou,
Primary School of Agia Varvara,
Nicosia, Cyprus

Space weather forecasting

Even though the activity was for older children, I was able to get the sixth graders interested, especially when they found out that these things are done by high school students. We were proud that we were able to walk through the complicated tools, use the materials to interpret the results of the measurements and assess the cosmic weather

Anna Krzyczkowska,
Primary school MTE in Milanówek, Poland

Northern lights
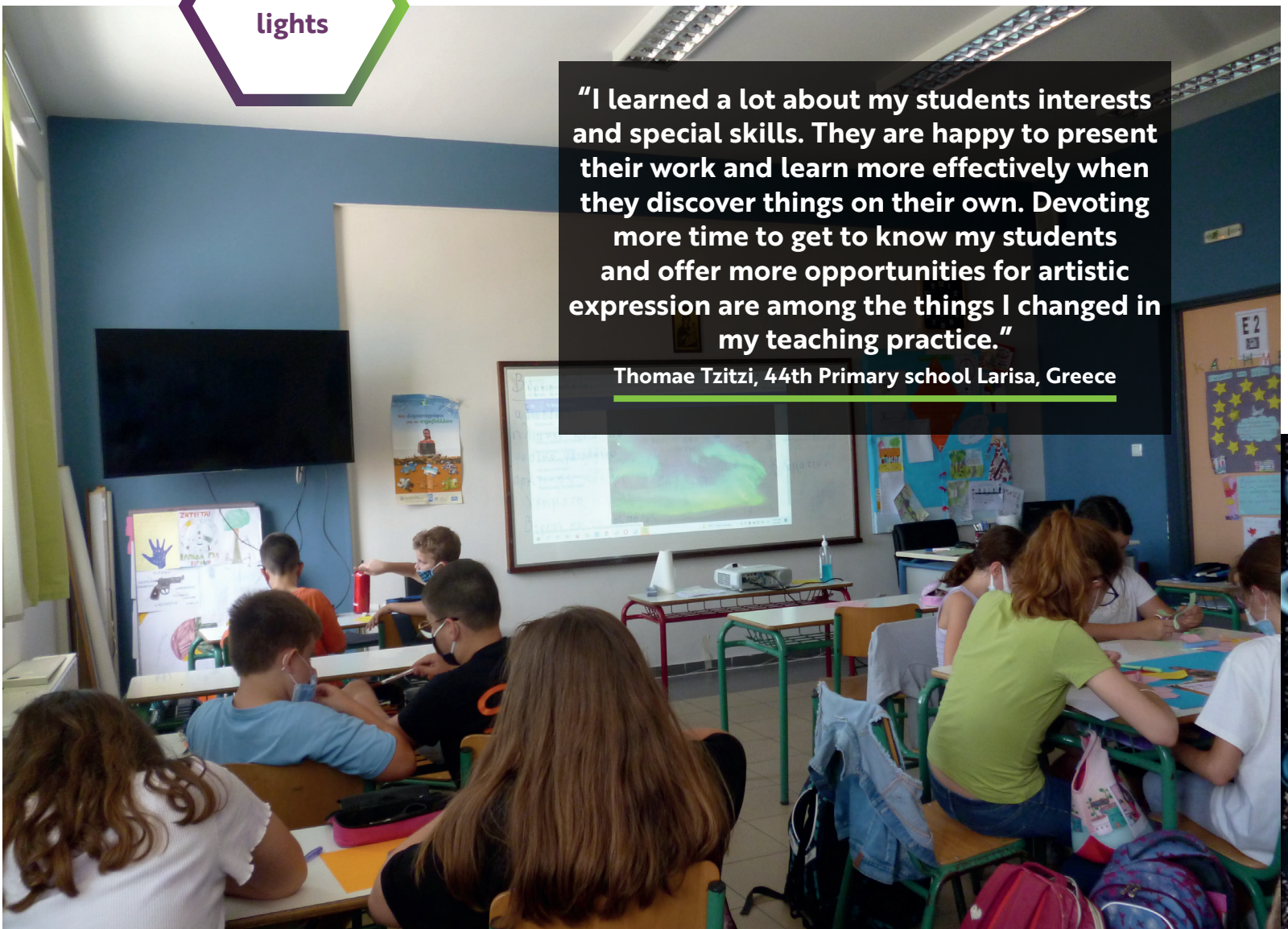
"I learned a lot about my students interests and special skills. They are happy to present their work and learn more effectively when they discover things on their own. Devoting more time to get to know my students and offer more opportunities for artistic expression are among the things I changed in my teaching practice."

Thomae Tzitzi, 44th Primary school Larisa, Greece
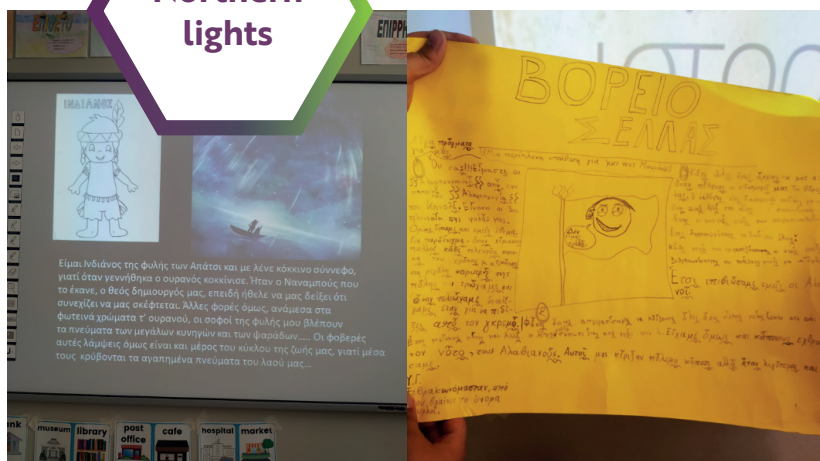
Plastic in the Arctic

Students working on Plastic in the Arctic
Psevdas Primary School, Cyprus

Solar system astronomy

Students working on Solar system astronomy, Colegio
Corazón de María Gijón, Spain

Northern lights

"My teaching became more fun. I want to introduce Arts more consistently. Making tribe stories was a lot of fun for all of us. I was very proud to see my students artworks."
Kiriaki Genitsaridou, Primary school of Heraklion, Crete, Greece

Northern lights

I was very proud of my students and one in particular, who hates getting up early in the morning. Despite our weekly Friday meetings being scheduled at 7:30AM, she did not miss any classes and took part actively. Her mother wrote me a letter in which she thanked me for encouraging students to participate in such projects.
Joanna Wilmańska, Szkoła Podstawowa nr 62 Poznań, Poland

"We learned interesting things about our students. The had impressive self-directed learning results and they enjoyed working together. They have good representation skills as well as research skills. They are interested in science-engineering topics."

Andreas Komitis and Eleni Odiseos, The GC School of Careers, Cyprus

"It turns out my students had many questions about the Arctic and the melting of ice. Through this activity they improved their digital skills, they looked at science through different eyes and were able to discover connections between natural phenomena. I was able to change my teaching and make it more inclusive and interesting for my students."

Antonia Toutziari,
6th Experimental Intercultural Primary School of
Eleftherio-Kordelio, Greece
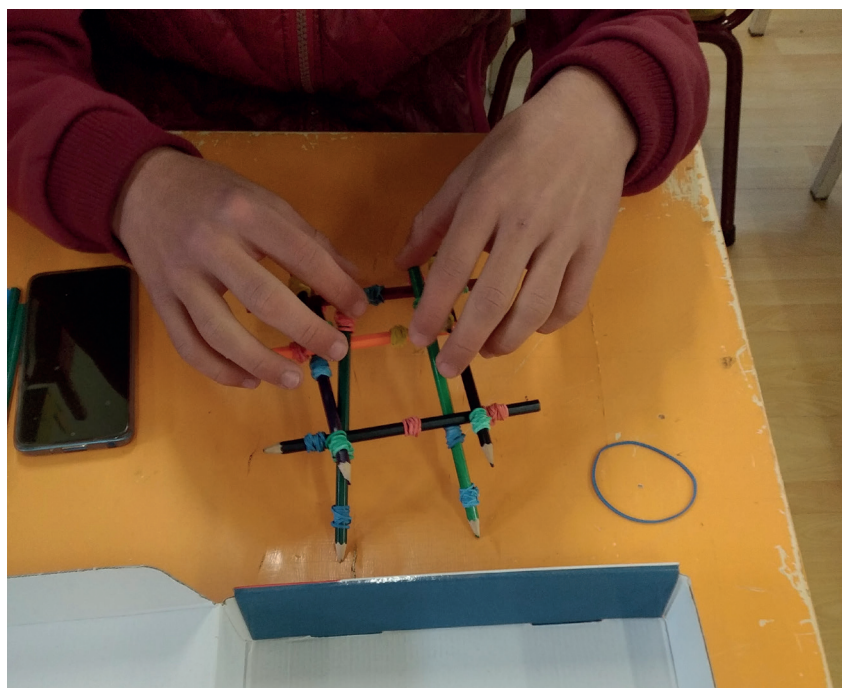
"I felt most proud when we built an electromagnetic engine as a result of the interest and autonomy of a group of students."
Luís Freitas, Agrupamento de Escolas Professor Agostinho da Silva, Sintra, **Portugal**
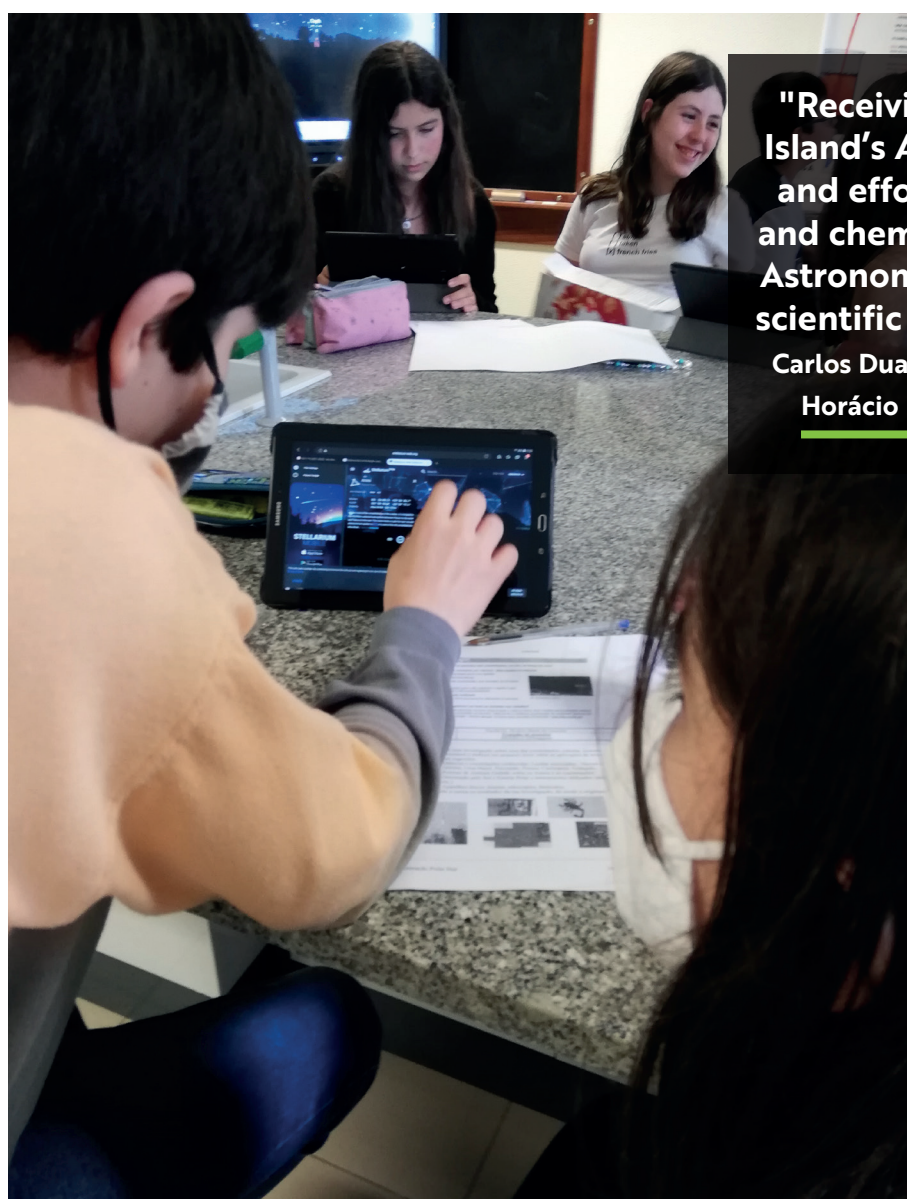
"Receiving compliments from the Madeira Island's Astronomy Association for the work and effort of the teachers (and the physics and chemistry group) in the dynamization of Astronomy to captivate students interest for scientific fields and relate them to daily life."
Carlos Duarte Gomes e José Arlindo Cruz, Escola Doutor Horácio Bento de Gouveia, Madeira Island, Portugal
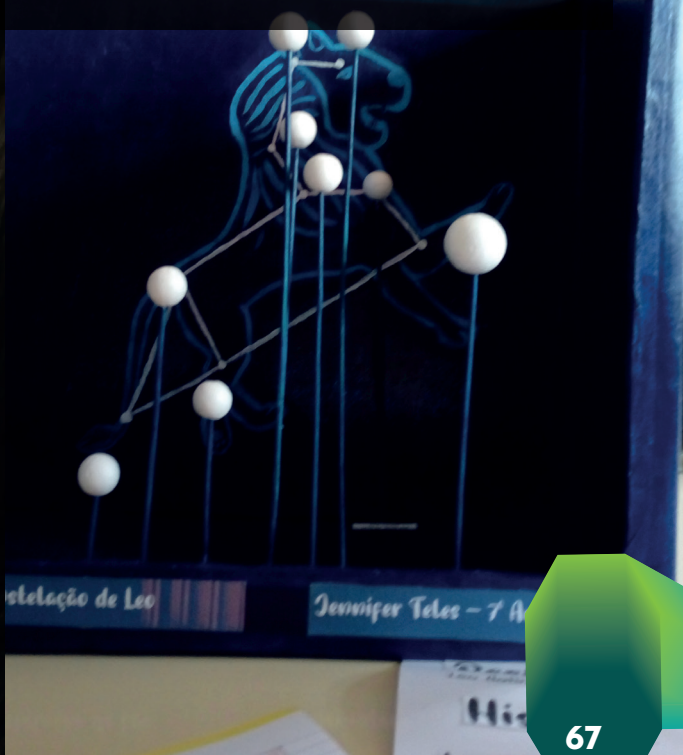
Students in Spain working on Solar system astronomy, IES Fortuny Madrid, Spain

Science as a whole

"My students realized that science is much more interesting than they thought. During my teaching, I now allow more degrees of freedom to my students encourage them more to think outside the box. It was difficult to introduce the methodology at first but the materials helped a lot.

Maria Barouta,
Primary school of Kanalia , Greece

Science as a whole

Energy
Πηγές ενέργειας

Energy
Η ενέργεια στην καθημερινή ζωή

Earth Ecosystems
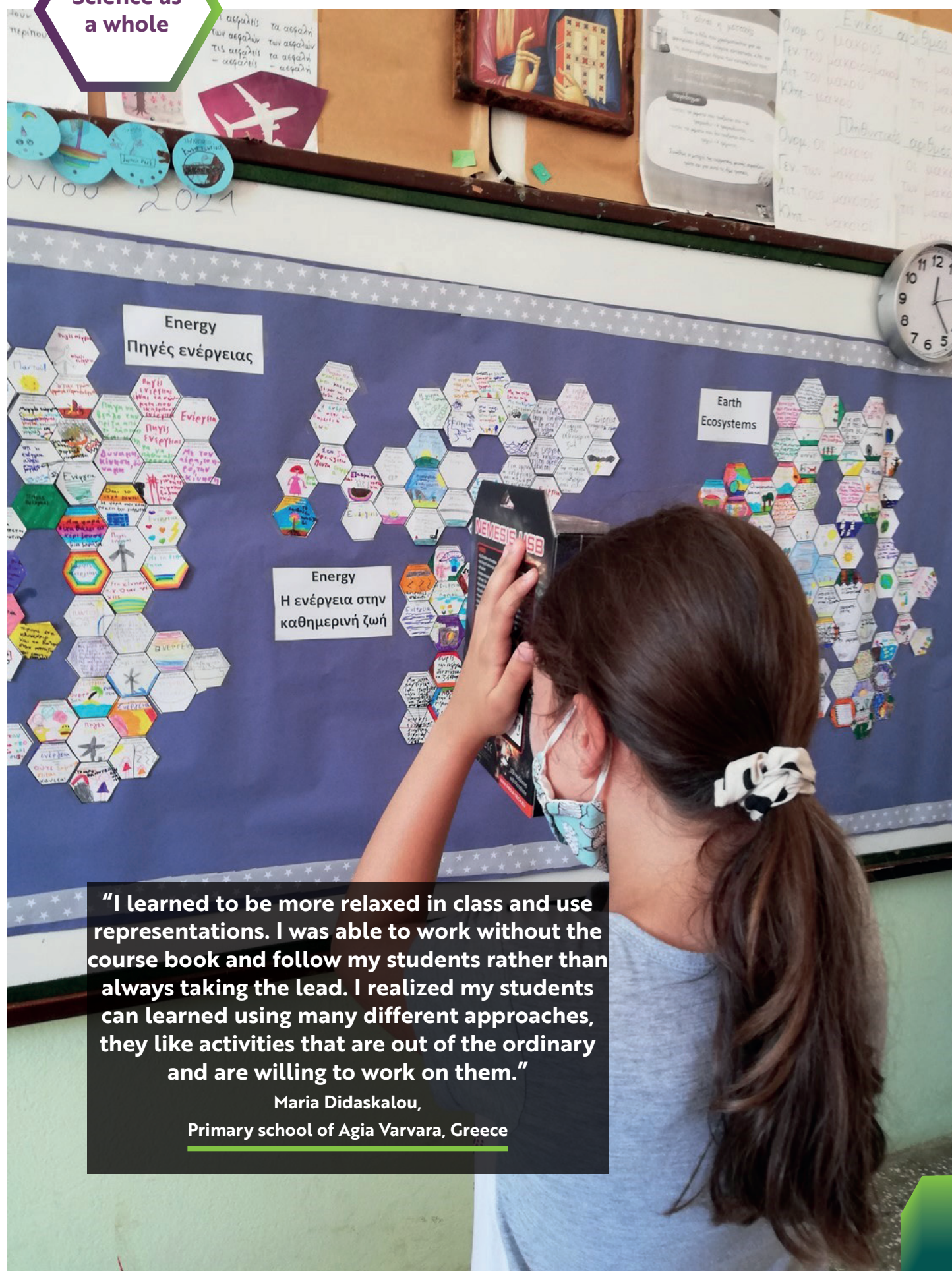
"I learned to be more relaxed in class and use representations. I was able to work without the course book and follow my students rather than always taking the lead. I realized my students can learned using many different approaches, they like activities that are out of the ordinary and are willing to work on them."

Maria Didaskalou,
Primary school of Agia Varvara, Greece

Lessons learned

Students

When it comes to students, our project aimed particularly on increasing students' appreciation about science and their confidence in doing STEAM activities. To that end, our team and used specifically designed questionnaires with students participating in the pilot implementation. Altogether, 1348 students from those who participated in the implementation of Polar Star in different countries answered the questionnaires. Based on the analysis we carried out, our team came to the following conclusions:

IMPACT ON STUDENTS

✓ POLAR STAR helped students to gain more confidence in science classes when searching for solutions to a problem, cooperating with others, and presenting their work to others.

✓ The subjects in which students perceive themselves to be most proficient are Technology and Mathematics.

✓ Thanks to POLAR STAR, students have improved their perception of their ability in the subject of Biology.

✓ After the implementation of POLAR STAR, students' perception of their ability to apply science concepts learned in class to problems in their daily lives has increased, as well as their perception of successfully performing science work at school.

✓ Students' self-confidence about their scientific capabilities has been improved.

✓ 92% of POLAR STAR students recognize that in science there are several ways to find the right solution.

✓ Thanks to POLAR STAR, students wish to have more involvement of families in supporting them in solving science problems.

✓ After the implementation, the POLAR STAR students are:
  o more confident in their ability to use inventions and technologies to take advantage of natural resources
  o in carrying out engineering projects
  o more confident in using art, design and creativity to solve problems
  o calmer when facing mathematical problems.

What has been the main achievement of POLAR STAR?

The data shows that students in general have increased their interest in studying something related to science.

Full Students Feedback Report ➤➤

Students in general have a very positive evaluation of the experience of implementing the POLAR STAR methodology and resources.

The evaluation of the students has been better for students who have used the activities of the POLAR STAR kit.

Student evaluation of the POLAR STAR experience as a whole:

3.97

on a scale of 1 to 5

Significant improvements among students:

✓ Perception of science and its multiple ways of finding the right solution.

✓ Perception of their ability to present science projects to others.

✓ Remain calm when facing difficult situations related to science because they have more trust in their mathematical skills.

✓ The perception of their capabilities in Technology and Geography.

✓ Perception of support received from families in solving science problems.

✓ Interest in studying something related to science.

✓ Perception of their ability to present their work to others.

✓ The use of art, design and creativity in solving science-related problems and projects.

Teachers

One of POLAR STAR's main objectives was to improve teachers' learning styles in terms of innovation and support educator. Therefore, it was very important to collect teachers' feedback to validate the impact that the project has had on their teaching styles. From participating schools 75 teachers from different countries responded to a questionnaire on the different resources that make up POLAR STAR. Based on the answers to these questionnaires, we have drawn the following conclusions.

Full Teachers Feedback Report

IMPACT ON TEACHERS

✓ Thanks to POLAR STAR teachers have improved their science teaching style.

✓ Teachers believe that the most useful elements of POLAR STAR for science didactics are: the POLAR STAR activities and the videos and explanations designed to teach the POLAR STAR methodology.

✓ Teachers recognize the impact of POLAR STAR in all the STEAM subjects, but especially in science.

✓ Teachers confirm that the POLAR STAR methodology has served to improve student engagement, motivation and learning efficacy and has helped students learn more effectively, compared to traditional methodologies.

✓ Teachers consider their teaching is more STEAM-focused after POLAR STAR.

✓ Teachers recognize that using the POLAR STAR resources students have been very participative, and they have been interested in relating learned concepts, new concepts, and phenomena of their daily life.

✓ Teachers consider the POLAR STAR activities help engage their students with current science discoveries.

What has been the main achievement of POLAR STAR among teachers?

88 %
of teachers say they have improved their science teaching style thanks to POLAR STAR.

Positive things that teachers have highlighted about the POLAR STAR methodology:

✓ It is a more child - centred approach.

✓ It is innovative, practical, and attractive to students

✓ Wide range of topics.

✓ Up-to-date scientific information.

✓ Ready-to-use material.

✓ The connection with everyday problems.

✓ The connection with art.

✓ Innovation linking different disciplines.

✓ Related to student experience.

✓ The step-by-step orientation of the activity.

✓ Freedom to students in their creativity.

✓ Developing the scientific method.

✓ Work by discovery.

✓ Encouraging work and cooperation between students.

✓ Activity-oriented teaching.

The teachers' evaluation of the POLAR STAR experience has been very positive.

Considering that the main challenge of POLAR STAR is to help teachers to improve their learning methods in STEAM areas and make them more innovative, this is a very significant achievement.

Teacher evaluation of the POLAR STAR experience as a whole:

4.69

on a scale of 1 to 5

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POLAR STAR

Showing the way to innovative learning

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