Guide to

Young Students as Critical Science Detectives

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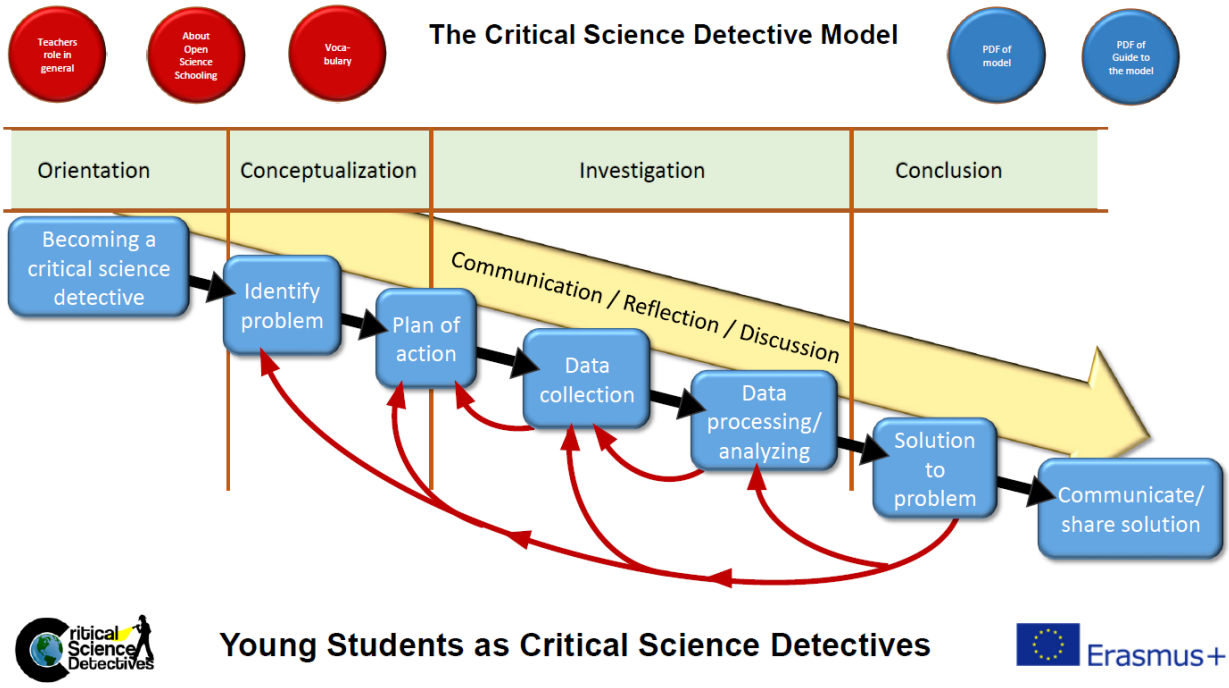
THE MODEL for
Young Students as Critical Science Detectives



Young Students as Critical Science Detectives (YSCSD) is a project under the Erasmus + concept. It was settled during the period of October 2019 to March 2022

The idea to create the Young Students as Critical Science Detectives emerged from a number of Erasmus+ experimentations with open schooling and open science schooling. The YSCSD concept, is at the same time able to integrate (due to the term "critical") important science learning policies from the European Union, such as "science with and for society" and "responsible science", but also to integrate sharing the science engagement with the students' families and with other citizens.
The open science schooling methodology is about student teams' long and immersive and full engagement in science activities and processes in the community – and this is quite demanding.

This extended guide provides an exhaustive introduction to the various steps in the model. By clicking on the individual buttons / steps in the model, you can get a shorter perhaps more manageable introduction to the sub-elements

Behind the button: 'pdf of model' button you will find the pdf version for printing for your class.

In this guide, there will also be recommendations and ideas for the students – to print or just to talk about.

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About Open Science Schooling

This text is partly inspired by previous projects related to Open Science Schooling (OSS). Articles and descriptions can be accessed via the button 'About Open Science Schooling, and the description of the project. The titles are listed below.

Open schooling is about collaboration, that strengthens both the school's teaching and the identity of the local community. In cooperation with other stakeholders schools will, become an agent of community well-being. On the one hand, it is quite obvious: The teaching of the school's subjects can become more rich in perspective for the students by being related to the outside world.

Open Science Schooling (OSS) is fundamentally different from modernization of science education: it is based on student teams' long-term engagement in real-life science challenges in the community, the science missions; the learning happens through such engagement and through the insertion of science knowledge on demand along the missions. The OSS methodology is the first systematic one to change science education for young students fundamentally.

The OSS is based on the top 10 recommendations for innovative science learning and engagement:

1. re-engagement strategies going far beyond instruction and classroom
2. re-engagement strategies that link strongly to the 21st century lifestyles and identities of young people in their teenage period
3. innovation of science learning not **for** but **with** the young people (the very important co-design and co-creation aspects)
4. innovation that links science learning to cross-sector collaboration with relevant private and public players in the near or general community
5. collaboration with those community players to bring real-life and real-time cases into the science learning process
6. science learning in integrated mixed realities (social and virtual ones)
7. science learning through international collaboration
8. science learning innovation will be strongly linked to what is important for society and the new young European generations in 21st century
9. science learning offering young people active explorative roles in the form of science detectives, science journalists, science adventurers, etc.
10. science learning that fosters interest in innovating changes taking entrepreneurial action

The idea behind implementing OSS is that young people conceive the science projects that they will be working on and running as a group. The successful implementation of a project developed through OSS is based active contribution of all the group members. As a starting point, young people are immersed in the project design with the aim of steering, carrying out tasks and taking initiative towards the fulfilment of their selected project. The expectation is that through this process the students' interdisciplinary competencies and skills may develop. OSS is a learner-centered approach that engages and allows them to try out new activities. Furthermore, OSS encourages students to find connections outside schools in order to understand science contextually in society, creating strategic partnerships between schools and relevant stakeholders, notably experts in different fields that could collaborate with the students. This may contribute to their knowledge bringing forth innovative ideas and solutions. In our work, the students chose participating in this type of non-traditional learning freely. (Montero, C.S., Baranowski, A. & Gejel, J (2019)

The OSS didactic

The OSS didactic approach is imbued in a science pedagogy implemented through the following processes:

• Problem identification and contextualization. Students are engaged in understanding what the real problems are that affect their local community, and how science can offer support to understand and meliorate the situation. In order to understand the problems students are prompted to involve the local community as collaborators in their investigations, including research and innovation centers, industries, NGOs, and other social stakeholders.

• Knowledge and competences acquisition. Once a problem has been selected to be tackled, students receive training and information on demand from school teachers and other stakeholders from the local community as well as from their own investigations. This invites the acquisition of digital literacy skills, cross-subject matter and cross-disciplinary knowledge as well as the development of self-regulation, collaboration and communication skills, cultural awareness, creativity and problem-solving efficacy. Here the students benefit from learning through a variety of practice-oriented work forms that support different learning styles.

• Documentation. The students are encouraged to keep a record of their process and involvement in their projects. This serves the students as a tool for self-reflection on the work accomplished, and provides them with a narrative of their experiences.

• Sharing. The students are also encouraged to share their experiences and solutions with peers in their schools and with their local community. The sharing can take place online.

- *" Our students are really engaged when they are able to do practical things especially outside the school e.g. workshops and laboratories at university or manual works. They also like visiting our local stakeholders and do interviews."*(teacher 1)

- *"In an open school environment, teachers are invited to work together with the community, such as parents, businesses and policy makers to transform their students into more responsible citizens. The commitment of the community to a school has many advantages for teachers. The community may support students and teachers inside, but also outside the school. These collaborations may help teachers to be more up-to-date with their own subject and to get more inspired by good examples from practice. Teachers will get more motivated and inspired students. This is because students find it much more interesting to be involved in the real world dealing with real issues."* (teacher 2)

"It's one of the most difficult things to encourage critical thinking in students. But through this method of OSS I think we have a new tool that we can use, a better tool, because the students can see from real person that working with science from a company or another job, they can talk to them and the science they learn in school matters and it can be useful for them in the future, so we can encourage them in this way to learn about science and to use their critical thinking to solve their problems. problems not solved by the teacher but they have to figure it out by using their critical thinking and by finding out the steps of the solution"

Supporting documents

To support the understanding of open schooling, the following documents have been prepared in previous 'Open Science Schooling' Erasmus + projects. They are based on the text above.

Grau, D., Torra, I., Mancho, F. & Mulero, L. (2020). *Open Science Schooling*

Suero Montero, C., Baranowski, A. & Gejel, J. (2019) *Open science schooling – rethinking science learning* In *EDULEARN19 Proceedings* (pp. 9159-9164). IATED.

WwEU (2021). *Guidance for Partners - Open Science Schooling*

WwEU (2019). *What is a mission*

And: https://openscienceschooling.eu/

Key concepts - Vocabulary

in Young Students as Critical Science Detectives

When working with Young Students as Critical Science Detectives, the critical science missions cover 5 main areas in the working process:

1. Detecting, mapping, and interacting: locally, virtually
2. Team dialogues and reflections: challenge and mission selection
3. Science learning on demand: investigations, research
4. Critical interactions with the science communities selected
5. Producing and sharing in wide networks the results of the science detective missions

See also the buttons: 'About open science schooling' and 'Teachers role in general'

1. Detecting, mapping, interacting: local, virtual

The science detectives will search the community for important and interesting activities linked to science; this will include dialogues with a wide range of community players; the local science activities might very well be linked to virtual science communities relevant to the identified topics. It is important that these science detectives' activities include serious dialogues with citizens and in particular with the students' families.

2. Team dialogues and reflections: challenge and mission selection

After the mapping of important science activities in the communities, the student team will evaluate the findings: which science activities are interesting and challenging, and perhaps even problematic in a responsible scientific perspective; the student's team may end up selecting one or two science activities to further investigations based on their own interests.

3. Science learning on demand: investigations, research

Now the student teams will need "learning on demand": to be able to interact competently with the selected science challenges that they will need to create basic learning about the science challenges .to engage in; Several learning on demand time-outs can be inserted along the interaction with the selected challenges, but always when the students need the learning; the student team will also engage with virtual communities to look behind the scene, and identify critical voices in a responsible scientific perspective.

4. Critical interactions selected with the science communities and with communities in general

The student team is now ready to continue its critical science detectives activity and engage in various forms of interactions with the selected science challenges, in the local community as well as virtually, and in their own social networks; the science detecting does not necessarily lead to fixed scientific standpoints or attitudes towards accessing whether the science activity is "responsible science"; the aim is for the students to be able to analyze science and science in the community critically, and to be able to communicate their findings to others. The student's critical interaction should include renewed dialogues with citizens and with the students' families.

5. Producing and sharing in wide networks the results of the science detective missions

To complete the critical science detectives mission the student teams will need to produce documentation of the long process they have worked through – from the first disoriented mapping to the final critical communications; the student teams can choose any form of documentation from website to video as long as the documentation really communicates what they learned on the way; the documentation, or the accomplishment of the critical science detectives mission, will then be shared at three levels: in the school to the other students, to a community workshop to which the parents of the team are invited, and in the students' social and gaming networks

Mission

When this project talks about 'missions', it refers to 'projects' carried out in real-life in collaboration with real-life science players. However, we use "mission" instead of "project" for several reasons:

- The term "project" was once very innovative, such as in project based learning; however, today the term can mean everything and nothing
- The term "mission" is much stronger: it refers to strong intentions, the will to accomplish and the ability of critical engagement
- The term "mission" is used in all sorts of video games, and most young people are familiar with the meaning of missions: working through levels and steps to be allowed to advance in the game and to finally accomplish

Science Detective

Like a detective, the science detectives will search the community for important and interesting activities and challenges linked to science.

Critical Science Detective

A critical science detective is critical of the issues from the local area that they have chosen to focus on. However, they are also critical of the scientific method they have chosen as well as of the data collected.

Learning on demand

In traditional education, the students are taught through the principle of “learning when scheduled”. That is, for example, learning mathematics Tuesday from 10-12. To the students this is definitely an abstract justification of the learning.

“Learning on demand” totally changes this perspective. The students will learn when they need to learn, when it is relevant, when they are motivated, and first of all: the students learn when they need to learn to accomplish their critical scientific missions. This form of learning is based on the students’ interest. In the project, this is called “time-outs for learning on demand”.

“Learning when scheduled” leads to short-term remembering, whereas “learning on demand” leads to deep sustainable learning and to the capacity to act. Obviously, schools need to learn how to organize such “learning on demand” – in collaboration with community resources. This is a part of the Open Science Schooling experimentation.

Teacher's role in general

The following is inspired by a "knowledge note" from Denmark regarding inquiry based learning in science

https://www.eva.dk/grundskole/vidensnotat-om-ubnu-grundskolen

Inquiry based learning in sciences is a form of active learning where the starting point is based on questions, problems or scenarios. In this project, this approach is combined with that on an open school.

Se the button 'About open Science Schooling'

The role of the teacher in Open Science Schooling (OSS) projects will be to support and guide the students rather than to be the communicator of academic material. It is therefore crucial that, with an eye on the students' various prerequisites, the teacher stimulates the students to be active and reflective. This can be done through open and constructive dialogue.

The work with OSS aims to give students more autonomy and influence. But that does not mean that the teacher gets a less important role in the teaching. As a starting point the teacher must always take as a the students' academic prerequisites and assess what can bring the students forward in their projects and their learning process, and assess how the teacher can scaffold the students' work from their current point of view continuously.

Communication is an essential focal point in this approach to learning. It can be constructive dialogues, where we see four important elements the dialogues between teacher and students:

1. To ask questions
    - Asking good questions can be the beginning of what is called exploratory conversations, where the teacher and students can wonder together and explore a topic through conversation
        - Opening questions, e.g. "what do you find out?"
        - Follow-up questions, e.g. "what do you think, it may be due to?"
        - In-depth questions, e.g. "why, how can you explain that?"
        - Silence to give students space to reflect
        - Interpretive questions e.g. "there may be other explanations: How can it be related?"

2. Having exploratory conversation

3. To train the use of professional concepts

4. To provide feedback

- Feedback can both be about guiding students to the next steps in their work process and noticing how the students have solved the task. It is called formative, respectively and summative feedback.

What should the teacher do in general

When the teacher facilitates the students' work, it is especially important that the teacher:

- Examines the students' academic and personal prerequisites and is based on this, when the teaching is adapted to the student group, so that all students can have an active, exploratory and reflective role in teaching
- Draws threads between different concepts and subject areas to provide students understanding of the field of science across topics and disciplines
- Stimulates students' reflection through a constructive dialogue based on open-ended questions, feedback, and a focus on training professional language and professional concepts

Short summary

- The teacher must accept that he/she does not know everything in the field in which the students carry out their investigation.
- The teacher should avoid correcting the student with answers, but make questions that will bring the students to think about/act towards a solution. The teacher must guide the student.
- The teacher should provide opportunities for learning on demand.

"Actually in this project we don't teach. We are managing the students in order to discover knowledge themselves. [...] The teacher should be transformed from the traditional role of the carrier of the knowledge to a knowledge manager." Greek teacher.

1. Becoming a critical science detective - Teacher

Introduction

Before starting the Science missions students must learn about the Open Science Schooling methodology about missions and the terms “critical”, “science” a ”detective”. Here science learning is organized as a mission, as a student-centered process, and as an opportunity for students to learn science in a relevant manner addressing local community issues.

Your role as a teacher

In general

- The teacher must accept that he/she does not know everything in the field in which students make their investigation.
- The teacher should avoid correcting the student with direct answers, but instead make questions that will make the students think about/act towards a solution. The teacher guides the students.
- The teacher provides opportunities for learning on demand.
  Read more here.

At the beginning - ‘Becoming a critical science detective’

First, students and teachers raise awareness about what each concept of “science”, “critical”, “detective” and “mission” means to them.

Therefore, first let the students discuss:

- *What is science?*
- *What is critical?*
- *What is detective?*
- *What is a mission?*
  Some inspiration in the ‘Definition box’ below.

Before next step

Students and teachers will have a common understanding of what the words “science”, “critical”, “detective” and “mission” means before they enter the phase of “identifying problem”.

Vocabulary

Mission: Is a specific real life and long term task conducted by a group of individuals in order to solve a specific challenge. Therefore, it is characteristic of a mission that the goal is already known from the beginning of it. It's also characteristic for a mission that a group of people are sent to another place to do a particular job.

Science: Any system of knowledge that is concerned with the physical world and its phenomena, and that entails are based observations and systematic experimentation.

Critical is to carry out an objective analysis and evaluation of an issue in order to form a judgement.

A **detective** is an investigator whose task it is to discover information in order to solve problems.

A **Science detective** is an investigator whose task it is to discover information using scientific methods in order to solve problems.

Here is some inspiration for questions that you or the students could ask at different phases of their mission:

Science is based on critical thinking

To be critical is very much to ask questions, either to oneself or to others. At the same time it is also important to be critical in a nuanced and well-argued way.

How should the students be critical during their science missions?

- To be critical when identifying the problem that their science missions should solve.
- To be critical about data/information collected during the mission and through Science learning on demand.
- To be critical in choosing appropriate methods for data collection and analysis.
- To be critical when presenting results.
- To be critical when looking back on your mission.

To be critical when identifying the problem that their science missions should solve

Initially students could ask questions in order to identify the problem that their missions should solve, e.g. :

- Which kind of local issues need a science-mission to be solved?
- Why is addressing this topic important to my community?
- Why is this topic important to me?

To be critical about data/information collected during the mission and through Science learning on demand

Regarding data from literature students could ask questions like:

- What is the author's point of view?
- What is the author's purpose?
- What is the intended audience?

- How reliable is the information?
- How do you know if something is right?

To be critical in choosing appropriate methods for data collection and analysis

Regarding methods for data collection different questions can arise:

- Which variables do you need to explore?
- What are the relevant variables to control?
- How can you control or measure these variables?
- How is your investigation/mission from start to end designed?
- Do you need to change how you are collecting data?
- Which logistical issues associated with the data collection should you be aware of?
- Do you need more data?
- Do you need to take data from other sources?
- Do you need to reduce your uncertainty?
- How strong is your data supporting the conclusion?

To be critical when presenting results

- In which way would you present your results?
- In which extent would you graph your data, create figures and other models?
- If an oral presentation, how would you present and argument for your results?

To be critical when looking back on your mission

- If you had to do the mission over again, what would you change? Why?
- Do you see any weak spots in your mission?
- In which ways can you improve your methods in order to, in a satisfactory way, complete your mission?

Recommendations and comments

- From the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *It is not easy for your students to become CSD. They haven't been teached how. It may take some time and effort from you to explain to them how they should become CSD. (GRE)*

- *I think it's important to clarify what "science detectives" mean. Students need to be well guided by teachers, there needs to be collaboration so that students understand what they need to do, what "science detectives" are and how they can become "science detectives." (ROM)*

- *Be open-minded and invite discussion, debate, creativity into your task activities. (LIT)*

- *Prepare visually interesting, intriguing, surprising information about the program (for distribution at school), posters and on the Internet. (POL)*

2. Becoming a critical science detective - Students

Brainstorm

You may have an initial brainstorm about local scientific issues that could be relevant to focus on, and where it is possible to implement initiatives

Recommendations and comments

- from the students in the project to students who would like to start working with Young Students as Critical Science Detectives

- *You should think and act how all great detectives do in the movies or in the mystery books. We will explain more in the next steps. (GRE)*

- *As a student, you must want to become "science detective", have curiosity and desire to conduct research and various other activities in the field of science. (ROM/Ed)*

- *Do not be afraid to explore new avenues and "out-there" ideas when working, and be sure to share them with your peers. (LIT)*

2. Identify problem – Teacher

Introduction

It is important for the students to identify the problem to be solved through the science mission. Therefore, with help from the teacher, the students must look at the local community in order to find the aim of the mission.

Your role as a teacher

In general

- The teacher must accept that he/she does not know all in the field in which students carry out their investigation.
- The teacher should avoid correcting the student with direct answers, but instead make questions that will make the students to think about/act towards a solution. The teacher guides the students.
- The teacher provides opportunities for learning on demand.

The part 'To identify problem' starts with a problem searching phase and ends with the exact problem that the mission should solve.

Therefore, with your students carry out an analysis of issues that must concern your students in the local area. The students may look at their local community for identifying problems in which they can play the science detective role. Therefore, they have to leave the "safety zone" of the classroom. Creating the groups students with the same interests can be placed together.

Points for the students to think about:

- Which kind of local issues needs to be solved by a science-mission?
- Why is addressing this topic important to my community?
- Why is this topic important to me?

As a teacher, you could give your students some clues on interesting topics to investigate if the brainstorming of the group seems to be halted:

- The biodiversity in the local area
- Agriculture in the local area
- Pollution in the local area
- Energy supply in the local community
- What happens to the waste?
- Which chemical substances are we frequently in contact with in our surroundings?

These subject oriented questions are only indicative to ask to scaffold the brainstorming process. The goal is that eventually the students would identify a problem that could be addressed by the student initiated science mission.

Before next step

Students and teachers must share a common understanding of the aim of the mission

Recommendations and comments

- from the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *Let your students do the research about some problems that they are interested in. If they are interested about the subject, they will be more motivated. (GRE)*

- *Students need to understand that everything around us is due to science, that unfortunately, certain things are not going well, and so we need our help, our skill to help the community and try to solve the problem. (ROM)*

- *Break it down into its simplest terms, use logical thinking and parameters to define the problem's focus. (LIT)*

- *Discussion with students, brainstorming: what field of science are we interested in? What can be done to increase knowledge? What problem do you see in the functioning of the city and its surroundings? What is the purpose of our activities? (POL)*

2. Identify problem – Students

Recommendations and comments

- from the students in the project to students who would like to start working with Young Students as Critical Science Detectives

- *Look for things that you are interested in. What are the problems that YOU think that need to be solved? (GRE)*

- *Make it understandable for yourself and easy to approach. (LIT)*

- *Your own perception of what is around us, are important to understand the problems of the community and in your own way, you can contribute to solving these problems. (ROM/Ed)*

3. Plan of action – Teacher

Once the problem/issue/challenge/wonder is identified and formulated, and the foundation of the student's missions are therefore clear, considerations regarding how to find out things must be identified. For that purpose, five general types of methods of investigation in science are presented and briefly explained. The descriptions are heavily inspired by the Danish site MetodeLab.

The five types of methods provide a framework from which you can get the students started and guide them in order to develop their investigational awareness and competences. The aims are that the students will be able to formulate questions that can be studied scientifically, and that the students will be able to design their own research and collect data in a scientific way, according to their levels.

1. **Read, Ask and Search for information.**
   Basically this is about seeking knowledge and information in books, online or asking questions to peers, or the teacher, and in a more formal way through interviews. This does not differ significantly from many other school subject research methods. Without knowledge, one cannot ask questions, and therefore this kind of method precedes and/or succeeds the other four methods described below. In addition, it is often necessary for the students to get back to this type of method throughout their entire work with their missions. The teacher's role is to provide and point out for the students relevant and adequate sources and materials.

   Where to Read, to Search and (in general) to ask other persons for information are common ways, the interview is a more specific method of its own. The teacher's role is here to guide the students to prepare the interview (interview guide) in order to ask relevant questions and to conduct the interview.

   Remember also the 5 W and 1 H questions: Who, What, When, Where, Why and How

2. **Trial and error.**
   In this type of method, the main emphasis is on finding a concrete solution to a practical problem or a satisfactory answer to a question, and it lends itself to learning processes where ideas can be tested and rejected intuitively and without major systematics. However, data can be made tangible in the form of logbooks with ongoing notes on hypotheses, successes and failures. It is just important to keep the focus on the students' trying out, pursuing ideas and gaining a lot of experience, rather than on focusing on a neat logbook.

   Missions can focus on finding out how things work and in that case, the trial and error method can be relevant. It can also be used when students are in the process of designing

or redesigning their investigations asking questions such as: How does this work? Or: What happens if? Teacher's role is to encourage students to ask questions and to try things out, not being afraid of making errors, but also to guide the students in the right directions so that they can stay on track and things don't get out of hand.

3. **Observation.**

   A common saying goes: "What is seen depends on the eyes that look", and transformed into science this means that when you look for specific things or reactions in specific ways in the quest to find differences, similarities, details, and patterns, you are observing. Observations are careful recordings of what one senses, and they can involve all the senses. Various equipment such as binoculars, microscope, sound recorder, scale, measuring tape, pH-sticks etc. can be used to amplify what one senses.

   Observation is an independent research method, but at the same time, it is an integral part of the other research methods. In contrast to the "Trial and Error Method", the observation method includes thorough and systematized data collections. Therefore, the teacher's role is to guide students in what to look for and how, as well as help them to structure their recordings. The aim is to produce systematized data, which must subsequently be organized and interpreted so that it is possible for others to discuss the interpretation of the observation.

4. **Models.**

   Scientists use models for representational-, learning- and predicting purposes, and in science teaching models are equally an essential part. They can be found in textbook illustrations, infographics and maps as well as on the shelves and in cupboards in the classrooms.

   Models are simplistic, manageable representations of selected parts of the real world and one of the forces of the models in the science is that they allow one to talk about parts of reality without the phenomenon being concretely present in the classroom. The big challenge with models is that it requires a high degree of abstraction to understand what they illustrate.

   The value of a model in a teaching context thus depends on students' ability to decode information within and, furthermore, to interpret this information to build up knowledge. The teacher's role is to guide the students in succeeding in those processes.

   Models can be the point of departure for the student's missions; the local area thus serves as the exemplification of the model, or part of it. In this way, the model becomes a predictive tool and may help generate ideas of what and how to investigate.

5. **Experiment.**

When you carry out do an experiment, it is to investigate relationships between a particular cause and effect. In an experiment, you only change one variable and keep all other variables constant. An experiment is also called a fair test.

When students perform an experiment much of their work and their learning are connected to the "variable control". In their hypothesizing and discussions about the relations between the variables they develop their understanding of both how to find things out in a scientific way, and about the matter they are dealing with.

Teacher's role is to encourage and guide their work and their reasoning as well as to ask questions about their understanding. Below is a 6-stage guide for structuring an experiment:

1. What is it that we want to find out? (conceptualization stage in YSCSD-model)

2. What are our hypotheses? (Conceptualization stage in YSCSD-model).
   Hypothesis should state something about the relationship between the variables, which leads to point 3:

3. What are the variables of the experiment?
   Three types of variables can be detected: The variable we change (the cause), the variable we want to observe/measure (the effect) and the variables we keep constant (because they can influence the effect).

4. How do we control the constant variables?
   In this stage the actual design of the experiment is formed. This involves the tools and equipment, the way the experiment will be conducted according to procedure, and how data are collected. As mentioned above the "Trial and Error Method" may be relevant here for the students to tune in on a reliable and valid design.

5. Doing the experiment (investigation stage in YSCSD-model)
   Once the setting of the experiment is clear, it is carried out, and data collection is initiated.

6. Data processing and analyzing (investigation stage in YSCSD-model)
   Can we detect relations between cause and effect? Can we then confirm or reject our hypothesis? In the latter case a new hypothesis is formulated, and the procedure is repeated. In case the hypothesis is confirmed, the students can be more sure that their thinking about the relationship between cause and effect in this particular case is right and thus this will be the knowledge they carry with them in their further work on their mission.

Traditionally when we think of the experiment as a concept it is something that belongs in a lab. However, experiments can very well be carried out as fieldwork. This is in particular important to keep in mind in connection with open science schooling and students' missions.

Investigations may also encounter both fieldwork and lab-work, e.g. data collection/sample collection in the field and then to further processing in the laboratory. In those cases samples must be secured when carried home as an integral part of the variable control.

Teacher's role in connection with creating the plan of action for the students' missions is to make them aware of the variety of activities that make up a scientific investigation. The teacher scaffolds and encourages students' thinking and discussion about which investigational methods to use and to engage in predictions, hypothesizing, and design and redesign processes as well as carrying out practical procedures in relation to their missions. This will strengthen the students' capabilities, increase their sense of what science is, and thus make them connect better to science as a provider of ways of thinking, of working methods, and of reliable information.

The teacher also facilitate the process with contacting stakeholders.

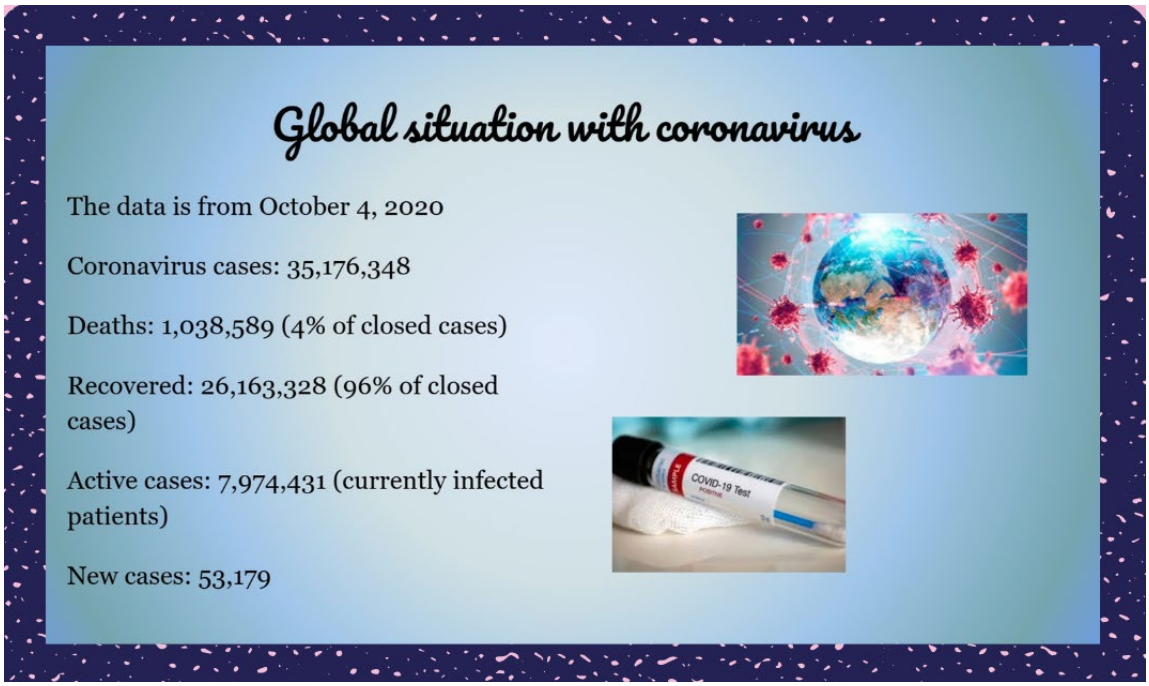
Recommendations and comments

- from the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *Teachers need constantly to communicate with the group of students, to talk to them and to establish together which activities they will carry out, which are the most useful activities for the community, the activities with the greatest impact. (ROM)*

- *Don't get tunnel vision on one aspect of the project. Try to think of innovative ways to support the students to put their plan into practice. (LIT/Ed))*

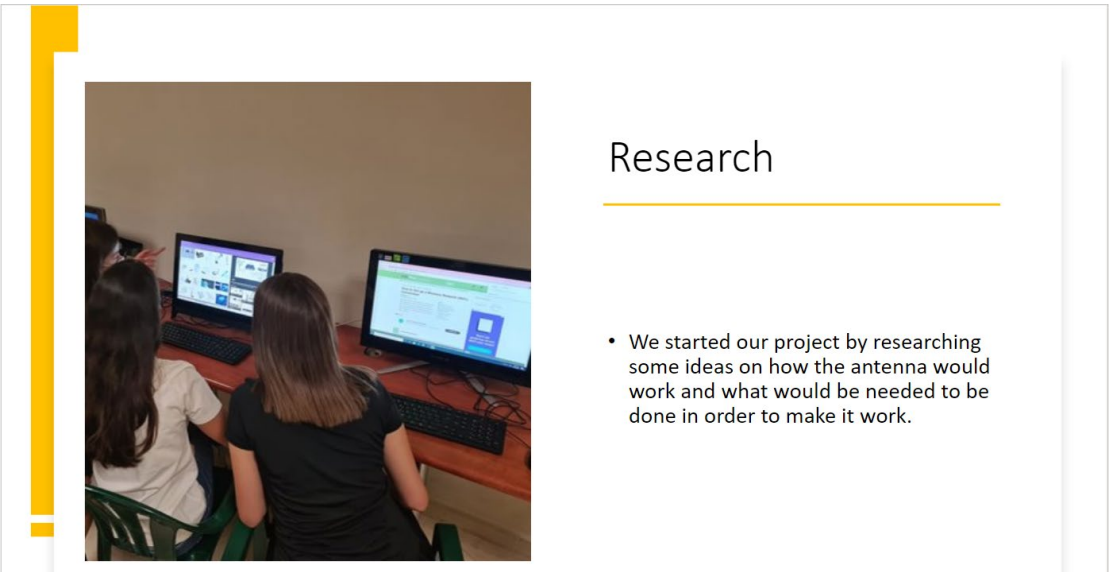
- *Allow students to choose tasks and assign a team on their own. Make it easy to read: who, when and what to do. Use different working methods. (POL)*



3. Plan of action - Students

In this section, examples of students' work within the five main types of investigation are shown. Examples derive from partner schools of the Young Students as Critical Science Detectives project.

1. **Read, ask and search for information**



Greece: Team 1, Internet is in the air

The copy of the slide above merely speaks for itself. Three students searching for information on the internet as an example of the importance of this kind of research.

Through thinking and discussion, the information can be processed and become knowledge which forms the basis for further work on their mission; new questions, hypothesis, action … etc.

An example of the interview as a genre of its own is shown below. Questions and answers have been transcribed into text in order to save information in another way for further processing. Selection of important parts may be useful in order to reduce workload when you transcribe - it is very time consuming.

The water way in our city - an interview with the director of the waterworks

Where is the water for the inhabitants of Łuków obtained from?
We draw water from deep wells. We have 9 wells. Water for water supply purposes is taken from aquifers from the Pleistocene and Miocene-Oligocene epochs.

How big are the water resources in our area? We analyzed the map of the voivodeship's water reservoirs, it seems we have a lot of rivers, lakes and ponds. Is this water as important as deep water?

It is true that the water is drawn from deep wells, but it is very important to keep the rainwater on the surface - it will seep deeper over time. That is why it is necessary to build storage reservoirs and plant trees and forests so that we have enough water for many years.

Which workplaces use the most water in Łuków? Vegetable and fruit cold store, bakeries. On the other hand, two very large facilities - meat plants and a dairy - consume so much water that it would be unprofitable to buy it from us. These plants have built their own water intakes

Do you need to improve the quality of this water, is it clean enough? And if it is not - what is the cleansing process? We have very good quality water. But water from deep water intakes must always go to the Water Treatment Plant. Aeration, removal of excess elements (e.g. iron) and disinfection are performed here.

How was it known where to dig deep wells?
Long ago, dowsers were used to locate watercourses with the help of a forked willow branch. Today geological surveys are simply being carried out.

At what depth is the water drawn?
- From a depth of 100m.

How much water do the inhabitants of the city consume?
- During the year, we use at least 25 m3 per person.

How extensive is the water supply network ?

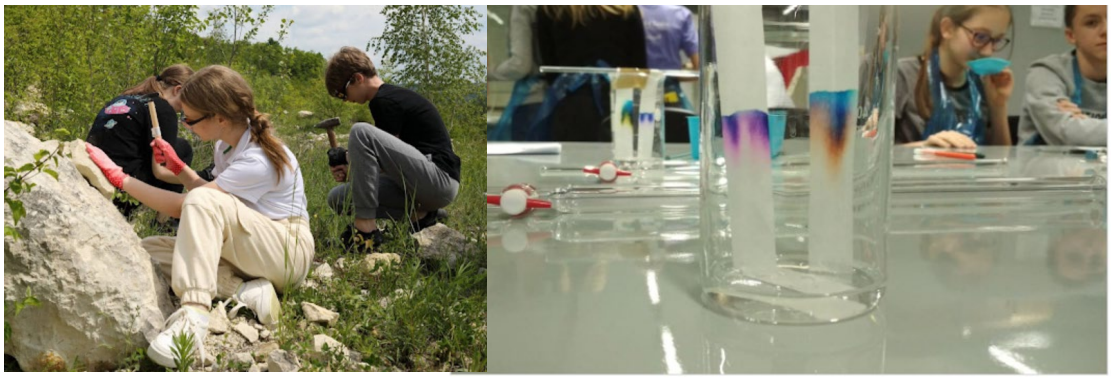
- The entire water supply network in Łuków is over 150 km long. We have about 5,000 water meters.

Poland: The waterway in our town

2. **Trial and error:**
When you want to search for something on the internet, you use search words on Google for example. Some words give more hits than others, and some words give relevant hits, others do not. This can very well be an important part of a fruitful learning process, but the balance between time consumption, effort and learning outcome must be considered. When you try to find out practical things, you may lose interest by trial and error if you are stuck, and your efforts are useless. However, making errors and learning from your mistakes are a natural part of the science class, and therefore of the students' work on their missions. To be prepared for this is important.

3. **Observation:**

It may take great effort and the use of a variety of tools and equipment to reveal the things you want to observe, as you can see in the pictures below. The point is, that observations are many things, and what they do have in common, is that you are looking for something specific one looks for. Observation can be a method of its own, but very often it is part of other

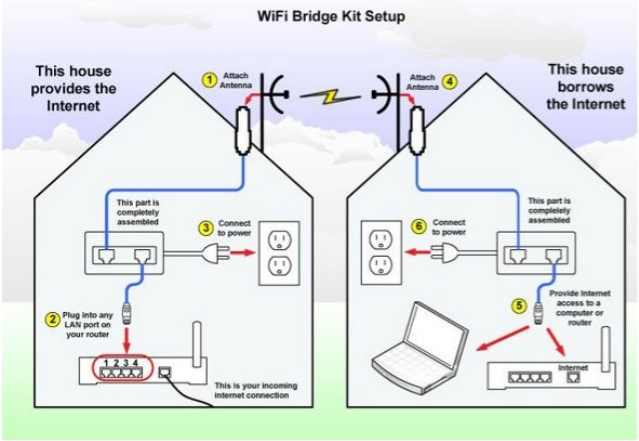


Poland: How the life has changed in form since 66M (left) and Night for biologists (right)

kinds of investigative methods such as read and search, inquiries on models, and doing experiments. Therefore, awareness of what to observe, how and when to observe, what tools and equipment to use, and also how to register data are important features to keep in mind as an integrated part of the plan of action.

4. **Models**

To understand how things work and relate to others the study of models is unavoidable. In this example students have found a model of how to distribute wi-fi signals from one building to another. Their mission was to improve wi-fi signals in their school building.



Greece: Team 1, Internet is in the air

Models often give an overview of what one's case, but may also contain important details. Therefore, students should be encouraged to do thorough research of models in order to decode and interpret information for their mission.

As a part of your plan of action maps may come in handy both as a practical tool to find your way when doing fieldwork (see example below), but also to be able to register data

Poland: How life has changed in form since 66M. Route to the limestone quarry.

with geographical reference, which may play an important role for further processing and, at the end, maybe also for your understanding of the results of your investigations. In the example below the concept of 'where' makes a difference.

5. Experiment

Experiments can be carried out in the lab, or in the field depending on their character and purpose. The common feature is that there is something specific you want to investigate, and you make a plan to keep control of the variables. In the example below, the students' mission is to find out whether the local sewage plant works as expected. Their experiment is to test the river water upstream and downstream of the outlet of the sewage plant (control of the variables), to find out if there is a difference in water quality. To carry out their experiment their plan of action then has two parts: a) taking water samples in the river (fieldwork) and b) testing the water quality (labwork). What the students are doing in the lab is learning and using a chemical test method, which can provide them with data of the water quality upstream and downstream of the sewage plant outlet. The chemical test method then becomes a part of the experiment, as they are taking samples in the river - not the experiment itself (one may consider the test method as a small experiment within the greater experiment). The results of the (greater) experiment may lead to further questions and investigations, such as: What does it mean if downstream water is more clean than upstream water? What could be the consequences if the sewage plant does not

work properly? - And in that case, what steps can be taken to change the situation? What impact can seasonal fluctuations have on our findings?

When you work on your plan of action, always keep in mind that once you have started, errors


Poland: Does our local sewage plant work properly?

may occur and revisions may be needed. Think of this as opportunities for learning and for improvement of your investigative work. The final results are not the most important thing - finding out how to produce them, that's where the learning is.

Recommendations and comments

- from the students in the project to students who would like to start working with Young Students as Critical Science Detectives

- *Explain to the others WHY do you think that it is a problem that needs to be solved? Explain what the benefits will be. (GRE)*

- *Depending on the problem identified in the community, students will need to come up with suggestions for activities to solve the problem in the community. (ROM)*

- *Take your time thinking about the steps you need to take for your task. Use simple means of approaching the problem, look for the quickest and most efficient solutions or modes of action for your task. (LIT/Ed)*

4. Data collection - Teacher

An important part of the Open Science Schooling (OSS) is to develop students' ability to carry out scientific investigations. In order to develop such skills, teachers must encourage students to ask questions and find out things scientifically. Students' missions point out areas of interest, and set directions for their inquiries, and teachers are to scaffold the students as they design their own research and collect data in a scientific way.

(See also 2. Identify a problem and 3. Plan of action)

Data collection can be …

- finding information and facts. The teacher helps students to find reliable sources and to verify information. The students use note techniques to take out relevant information and organize it. They can use written, audio- or video recordings for this purpose.
- to do an interview. The teacher scaffold the students in their preparation of the interview, e.g. by asking them questions about what they want to know,
- who want to interview and how to ask questions in order to get the wanted information. Questions are written down
- and answers may either be written down as well, or the whole session can be audio recorded.
- when the students search for information and facts, the study of models also requires registrations. The students can explain their understanding of models orally, and write it down so that the teacher can get an idea of their process. Likewise, the relevance of the models' for their mission must be clear and explained.
- observation/experiment. Here the teacher's role is to make sure that the students' design will provide them with the kind of information that they ask for, and that it will support their mission. It is of significant importance that the teacher conducts constructive dialogue with the students order to develop their understanding of how to collect data, and their purpose. Ways of making records of data are also to be determined. (Click the button "Teacher's role" in the main menu for more information)

> As for the covid barriers, there were online meetings throughout the weeks of the lockdown, via an "easy to use" - app used by every member of our project. We also made a research on the internet to inform ourselves about the right exercises to do in order to work out the muscles we want. Therefore, we communicated with our gymnastic teachers to give us a different point of view. Greece: Team 2, Easy gymnastic at home

In general, a key role of the teacher is to encourage students to take critical views on both methods of data collection and on the data themselves in order to be able to develop as critical science detectives. Ongoing reflections upon and revision of their designs support this development and must be seen as a natural part of the students' learning process.

Once the type (-s) of data collection is decided, considerations of how to register, secure and share data for further processing must be done. Teacher's role in this part of the process is to provide options for the students to consider, e.g. worksheets and practical things. such as cardboard and plastic bags, when the students do fieldwork and various kinds of digital and analog tools and equipment to produce and log data. Especially when the students use pictures/ videos and audio recordings the teacher must ensure that the students make the necessary agreements so that nobody is offended, and no legislation is violated (GDPR).

Under the heading "4. Data collection - Students" some examples from the work during the project are shown.

Recommendations and comments

- from the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *Internet is of course a great tool for research, but it is not the only one. Explain to your students that there are also other means like newspapers, magazines, discussions or interviews with people involved. Suggest some persons to your students. (GRE)*

- *Teachers need to collect students' suggestions, organize and discuss with them everything that has been identified as a problem. (ROM)*

- *Take your time to research various databases, ground your work in published data. (LIT)*

- *Take advantage of the offers of universities, museums and research institutions aimed at young people. (POL/Ed)*

4. Data collection - Students

In this section, some examples of how students have carried out their investigations as they have been working to fulfill their missions are shown. The ways the students have collected data are connected to the five basic types of investigations (see 3. Plan of action), however not all types are covered.

Pictures as data/documentation

Observation. In some cases, it makes sense to use pictures/videos for both documentation and as data collection. In this case several pictures of different parts of the site and of the city served as data collection, which gives us an impression of the extension of the problem with household waste in the environment.

Further inquiries into this issue could be separating the litter in different categories and either to measure volume or weight and then calculate percentage of each fraction (extending senses with instruments).

Romania; Pollution in our city.

Experiments. When doing experiments it can be a good idea to use pictures/video for documentation of procedures. In some cases, pictures serve as data showing the development of the experiment. Below is an example of pictures showing both procedure (part of) and the results of the experiment. Here the students have investigated the impact of polluted water the growth of beans.

Romania; Pollution in our city.

Further inquiries to support the pictorial data could be counting and measuring leaves, height and width of stem etc. (extending senses by use of tools and equipment).

Using tools and equipment

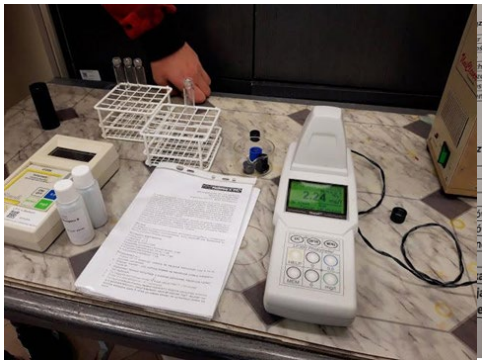
Observation. Doing observations in the local environment are carried out in many ways. One example is shown below where students have put a cup containing water and cotton by the roadside in order to catch particles coming from the traffic passing by. Obstacles experienced by the students were that some of their cups disappeared during the time of data collection (one week). In the first place, it affects the whole set-up in a negative way, but it also reminds us to be creative to find ways to carry out investigations like this. Plastic cups, cotton and water are of course affordable things to lose, but in order to maintain an ongoing data collection small

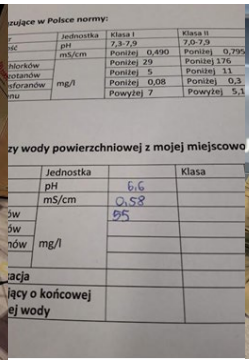
signs/labels stating that the school is carrying out scientific investigations here may prevent others from removing or destroying things.

Romania; Pollution in our city. After (left) and before (right) data collection started

Ideas for further to process the collected materials, in this case dust, sand and gravel, could be to investigate the materials with a microscope/stereoscope in order to be able to see differences, e.g. size (quantitative) or features of the particles (qualitative) as well as testing the water for pH and chemical reactions. In this way initial data from observations or even experiments can be further processed and produce new data to support the mission.

Doing lab-work always involves observations and data collection and is well known. Therefore no further comments will be said about this here. However, in the lab as well as in the field, data must be registered and for that purpose, a range of opportunities may be at hand. The pictures below show some examples:





Poland: Does our local sewage plant work properly? Lab-work

Romania; Pollution in our city. Registration of traffic on smartphones

Recommendations and comments

- from the students in the project to students who would like to start working with Young Students as Critical Science Detectives

- *Talk with people related to the problem that you are investigate. They will "guide" you to where you should search for more information. Keep in mind that there are always, at least, two sides of the problem. (GRE)*

- *You should communicate with both the teachers involved and the other students so that their proposals are as realistic and useful as possible for the community, in order to solve the identified problem. (ROM/Ed)*

- *Look up info online, ask your peers, but focus on individual information gathering for the most part. (LIT)*

- *Who can you meet? People and institutions of the city who will help us solve the problem. Use internet resources, search for interesting contacts. (POL)*

5. Data processing / analyzing - Teacher

The purpose of student's investigations is to produce information that can be processed to become knowledge in order for them to be able to understand both general and specific aspects of their mission. Thus an important part of their work is to organize and analyze the information they have found and the data they have produced.

- The processing of the information they have searched and asked for will in most cases be analyzed and reflected upon instantly. When keeping a record of what, where and how they came across this information as well as their reflections upon it makes it possible for them to go back and see their process. Likewise, the teacher can get opportunities to follow their development as they proceed. The teacher's role is to ask questions and challenge their reasoning, thus stimulating their critical thinking.

- When students do an interview the answers may be registered in written or in audio/video format. In the first case, answers may have the characteristics of conclusions or just the essence of what has been said. This way to register an interview requires that the students are able to instantly interpret and write down what has been said. In the latter case, the words that have been said are saved and can be overheard again. The challenge with this format is that it is time consuming to transform it to written format (the teacher should advise the students only to transcribe the most important parts of the interview). Another option is to take out the important parts as audio/video bits to make an edited version of the interview. In both cases, the students have worked with and processed the information that has most relevance for their mission.

- As for the student's work with models, the situation is the same as for reading and searching for information. The teacher's role is to make sure that the students are able to understand and explain what the model expresses and also how the model is relevant for their mission. One way of doing this is to make the students translate the model into another modality, e.g. from drawing/diagram to written text or oral explanation. Then they have to understand the elements and the processes, which the model consists of. This requires cognitive processing of what the model expresses and of considerations of which features the new modality have and therefore how it can be expressed in this new way. Such activities will challenge and stimulate their reasoning and raise awareness of the model's knowledge potential and relevance to their mission.

- Whether the students are producing data from an observation or an experiment, data must be organized and interpreted to become knowledge for the students. In the following section the work on two types of data is briefly described:

  Pictorial data can be organized according to either spatial or temporal principles. In the first case, emphasis is on location and extension of a phenomenon whereas in the latter case emphasis is on how things develop over time. In some cases, of course, both principles are relevant, that is when a phenomenon develops or spreads in an area. Other organizing principles could be relevant, e.g. when students are interpreting messages in pictures of people, other places or situations.

  Samples that are brought back to the school must be studied in microscopes, measured and weighed and/or their physical and chemical features tested. This will most commonly result in rows/tables of numbers and in many cases it will be relevant to do calculations (mean, min., max. % etc.) and to convert these into graphic representations (graphs/diagrams). This will ease interpretation as it requires transformation from one mode to another and therefore it will help students to understand the nature of their findings.

  In both cases when students bring back pictures or samples from fieldwork, the teacher's role is to encourage them to do thorough work in order for them to get the most out of it. In some cases, it may be relevant to ask the students to revise their plan of action and to reconsider their methods, e.g. the number of pictures/samples, spatial distribution of where pictures/samples are taken etc. so that their conclusion will stand on more solid grounds. This is especially important if they are to engage with the local community and in all cases, it will provide them with a better understanding of the nature of science.

Recommendations and comments

- from the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *Remind your students to keep notes about everything. It doesn't matter if they are written notes, photographs, videos, audio recordings or another mean that they prefer. (GRE)*

- *The science teachers involved must constantly collaborate with the students, to stimulate their curiosity and desire to have activities in this wonderful field of science. (ROM)*

- *When processing data, avoid bias, especially when providing analyses for students to use. (LIT)*

- *Hear ideas and solutions from students. Allow creativity, don't impose. (POL)*

5. Data processing / analyzing – Students

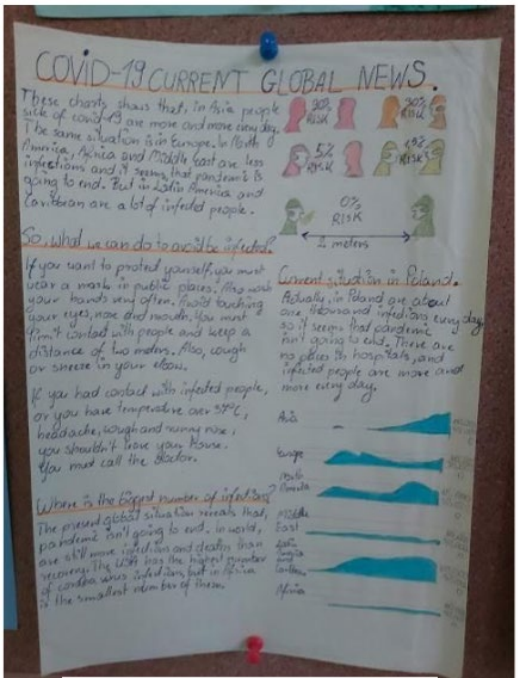
Recommendations and comments

- from the students in the project to students who would like to start working with Young Students as Critical Science Detectives

- *KEEP NOTES OF EVERYTHING THAT YOU DO. You cannot remember everything that you did one year ago. Gather all the information needed and discuss it with your team. (GRE)*

- *You need to understand how important collaboration is, how useful it is to accept suggestions from a colleague, and to be aware that what you have to accomplish can only be done as a team. (ROM/Ed)*

- *Look for raw information that is based on science, use anecdotal data when necessary, and don't get too emotionally invested into the scientific aspects of your work. (LIT)*



6. Solution to problem - Teacher

Introduction

Once the mission is accomplished, the students would hopefully have a conclusion or a solution to the problem. However, solving the identified problem is often a difficult process. Completing the critical science detectives missions the student teams must have produced documentation of the long process they worked through – from the first phase of identifying the problem all the way to 'mission accomplished'.

Your role as a teacher

First of all, some missions will in reality not be fully accomplished, this is not necessarily a failure. Teachers need to make students aware of that any step towards a successful mission is a victory, because the students will probably have learned a lot of science in the process.

Perhaps the students need some guidance in making a conclusion. Between "To identify problem" and "solution to problem" the students have done a lot of investigation. Help the students organize the collected and analyzed data, in a way so it is clear that they support the solution to the problem. If there are many possible solutions, help the students in going for a simple one, that requires least explanation and is the easiest to present to others in a clear way. Furthermore, help the students to be aware of how to argue for their conclusion, perhaps asking *"How strong is your data supporting the conclusion?"*

As a teacher, be aware that sometimes during their investigation students will get answers to questions that do not directly contribute to answering their main problem/mission. Students should therefore occasionally be helped to focus their conclusion so that they are actually concluding on what the mission was all about, and not on matters that may not be particularly important in that context.

Before next step

The next step, step 7, is closely connected to this step, because the next step is to share the solution/communicate the result of the mission to others. Therefore the students could prepare their data for sharing; what are the main findings? Which data supports the conclusion? etc.

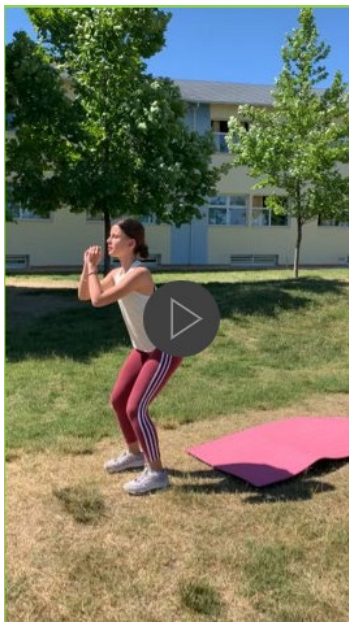
Recommendations and comments

- from the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *There are many problem-solving techniques. You should spent some time to present some of them to your students and let them decide which one they want to use. (GRE)*

- *Solving the identified problem is often an extremely difficult process. Teachers need to make students aware that any step forward for their purpose is a great victory. (ROM)*

- *Look for the simplest one, the one that requires least explanation and is the easiest to present to your students. (LIT)*



6. Solution to problem – Students

Recommendations and comments

- *from the students in the project to students who would like to start working with Young Students as Critical Science Detectives*

- *It is not easy to solve a multi factor problem. After the discussion with your team, you will have some ideas of solving the problem. Discuss the pros and cons of each solution and choose the ones that fit better for your team. (GRE)*

- *Students should be aware of their work, that they have learned a lot in science and that their experience is an example of good practice for other students. (ROM)*

- *Look for a solution that's adequately applicable and can be outsourced to other similar problems. Don't shy away from vague or inconclusive solutions, as the other students might build on your idea further. (LIT)*

- *Show the benefits of this solution. Introduce what others can gain. Show the path that the team took to the solution. (POL)*

7. Communicate / share solution – Teacher

Introduction

The students have now completed their mission, and if the mission is accomplished the students have a result to be communicated to others; the students critical interaction could include renewed dialogues with citizens, municipality administration services and with the students' families. The student teams can choose any form of relevant communication media; oral and/or visual (a model, poster, slide show, website, video. local press, Facebook etc.), in order to communicate how they accomplished the critical science detectives mission. Considerations on who are relevant parties for the information must be conducted; other students?, parents?, the students' social and gaming networks?, the school board?, the headmaster?, the mayor? Etc.

Your role as a teacher

Perhaps the mission was to establish better Wi-Fi at the School, or to have healthier food in the School canteen, or to have better waste sorting in the Municipality? Results from different missions will have different audiences. Of course, sharing experience in class will be relevant to many of the classmates; what did the different groups do, when, how and why? What was the result of the mission and what complications or recommendations will the outcome of the mission bring about? Who are actually the relevant parties to know about this? If the mission e.g. was that the canteen food become healthier, who should be told and in what way so that it happens? What arguments would be needed? What does it mean that the food is healthier? How can the healthier food be delivered without it being more expensive? Etc. As a teacher, you can help students organize the information so the target audience buys the message, and changes will appear.

Final evaluation

The mission is accomplished, but to what extent was the mission a success? Did the students use and learn science during the mission? As a perspective look at the students missions, you could ask the students; *"If you had to do the mission over again, what would you change, and why?", "Do you see any weak spots in your mission?", "In which ways can you improve your methods in order to complete your mission in a satisfactory way?"* etc.

Recommendations and comments

- from the teachers in the project to teachers who would like to start working with Young Students as Critical Science Detectives

- *Use all the means available to share the results of your students' work. School's page, FB page, Instagram, TikTok, local radio or tv, local newspapers, conferences, science fairs… (GRE)*

- *Teachers must make various efforts so that the experience gained by them is as well known as possible. Thus, they have as means of work various sites (of the school unit and others) Facebook, the local press, the media in general. (ROM)*

- *Always stay in touch with your students, provide feedback, help when necessary, and aid them in forming their own conclusions. (LIT)*

- *Organize a meeting, present a solution to the problem. Make an exhibition of posters, photos. Prepare and distribute leaflets and brochures. Disseminate through media, website. (POL)*

7. Communicate / share solution – Students

Recommendations and comments

- from the students in the project to students who would like to start working with Young Students as Critical Science Detectives

- *Use your social media to share what you have done. It is the best way to let everyone know about you have to suggest. (GRE)*

- *Students can contribute to this activity by sharing the experience gained with other students and friends.*

- *The data collected by them can be disseminated through various communication channels. (ROM)*

- *Work with your peers, not against them; share your ideas as much as possible and co-operate when finding ways of solving a problem and applying your solution on a larger scale. (LIT)*

- *Organize a meeting, present a solution to the problem. Make an exhibition of posters, photos. Prepare and distribute leaflets and brochures. Disseminate through media, website. (POL)*